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Simulated design and analysis of a cognitive prosthetic for alzheimer's disease

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**SIMULATED DESIGN & ANALYSIS OF A COGNITIVE PROSTHETIC FOR
ALZHEIMER'S DISEASE**

A Thesis

Presented to

The Faculty of the Program in Human Factors/Ergonomics

San Jose State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

By

A. Rina Delnegro

May 2002

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ABSTRACT

SIMULATED DESIGN & ANALYSIS OF A COGNITIVE PROSTHETIC FOR ALZHEIMER'S DISEASE

By A. Rina Delnegro

This thesis addressed the need for the implementation of cognitive aiding devices in the homes of individuals with Alzheimer's disease as well as the means to design, test, and evaluate these prostheses. A human-centered analysis approach was employed to overcome the challenges faced with traditional research methods used for computer-based prosthetic design.

The processes of cognitive dysfunction in Alzheimer's disease were examined and simulated in a computational representation of human sensory, cognitive, and motor responses. The representation was then used to reveal requirements for cognitive prostheses in support of activities of daily living. Thereafter, the human performance model was used to predict the performance of the simulated computer-operators interacting with the simulated prosthetic system, using a Monte Carlo technique.

Based on the analysis, the quality of the prosthetic and of the use of computational representation in support of the aging population was demonstrated. Recommendations for future research are presented.

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The experimental tool used for this thesis study was the Integrated Performance Modelling Environment (IPME), version 2.0, by Micro Analysis & Design, Boulder, Co.

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CHAPTER 1

Introduction

Englebart (1962) had a vision that computer technology could enhance human abilities by potentially augmenting cognitive and intellectual activities. By the late 1980's, cognitive science researchers were actively exploring the possibility of assisting human performance through the developments in computational technology and artificial intelligence (Woods, 1988). It was at that time that Reason (1988) coined the term "cognitive prostheses", describing the potential cognitive tools as extensions of *normal* brainpower that could (theoretically) compensate for human cognitive limitations.

The development of technology-enhanced services has carried over into the health-care industry in response to long-term care moving into the home and community. Specifically, computer-based cognitive prosthetics are being developed to address the self-sufficiency needs of a broad range of activities for the older population suffering from cognitive deficits caused by age-related diseases such as dementia (Cole, 1999; Cole & Dehdashti, 1998; Newell, 1998a; Riederer & Pieper, 1998). The prevalence of older adults with dementia of the Alzheimer's type, which is characterized by severe memory deficits, is increasing rapidly as the baby boomer generation reaches 65 years of age (Taylor & Sloan, 2000). Thus, the implementation of computer technology in the homes of individuals with Alzheimer's disease (AD) could be very advantageous since the availability of long-term hospital and care services is already limited.

Individuals with AD were particularly neglected in the past as user groups who could benefit from computer technology, but a valuable study (Eslinger & Damasio,

1986) that challenged the common assumption that patients with AD could not acquire or retain any new information persuaded professionals to consider the integration of cognitive support for this user group.

Although research programs were successful in the past at providing computer-based cognitive prosthetics for individuals with AD, methodological problems exist (Cole, 1999). Traditionally, researchers have used single-subject case studies that proved very costly and time consuming (Cole & Dehdashti, 1998; Riederer & Pieper, 1998) and they were highly customized for each patient. There is a need for human-centered design approaches that are more economically advantageous. Methods are needed that can augment the planning process to better suit the design of interactive systems and to meet the growing population demand.

One of the most challenging aspects to finding a solution to the problem of bridging the gap between technology and cognitive impairments is identifying and appreciating the interdependency of the user requirements and system specifications in this context. The interface design should move from design *for* the operator to design *for use* by the operator, whereby the development process is guided by human activities to support rather than the features to include.

This study proposed that a computational model of human performance, which is highly user centered, can be used throughout the computer interface design process. It can be used before the use of prototypes and before the interface exists as an operational system. As well, it can be used for testing different phases of the interface design before and after prototypes are constructed. Moreover, a human performance model can be used

later in the design phase to assure compliance with guidelines. The task structure of the models, along with the cognitive and environmental representations, can provide recommendations for augmentative strategies for interface and system design.

The nature of Alzheimer's disease lends itself to a computational modeling tool for interface design and analysis since the modeling process can be faster, less costly, and does not require (initially) the use of actual participant testing. Empirical testing can be reserved for examining components of the interactive system not addressed by the computational models and after significant design specifications and guidelines are generated, thus saving considerable resources.

A human performance modeling and simulation tool was used to design, evaluate, and modify a computer interface design. The modeling and simulation tool was then used to test the effects of the new interface design on task performance. The iterative process of this study was divided into two parts. First, it consisted of building a model (AD INTERFACE I) that represented the first iteration of the cognitive prosthetic interface design. The human performance model was then run to evaluate the interface design and identify vulnerabilities in the system. Modifications were then made to create a new and improved model (AD INTERFACE II). The second part of the study consisted of statistical analyses comparing AD INTERFACE I and AD INTERFACE II. Figure 1 illustrates the steps involved to accomplish the thesis objectives.

Part 1 – Objectives

There were two main objectives, (1) to conceptually design a computer interface for use by individuals with mild-moderate Alzheimer's disease to assist in the activity of

taking medication and (2) to evaluate the proposed design, identify vulnerabilities in the interactive system, and make modifications accordingly to better meet the cognitive needs of individuals with mild-moderate Alzheimer's disease.

Part 2 – Objective

The purpose of the second part of the study was to test the modifications made to the initial interface design by determining: What effect did the modifications have on the task and cognitive performance measures of the (simulated) individuals with mild-moderate Alzheimer's disease, collected from the human performance modeling and simulation tool?

Research Hypothesis

The following research hypothesis was made for the purpose of the second part of the study: The modifications will improve user interaction so time on task decreases, forgetting decreases, repetition of tasks decrease, and completion of tasks increase as represented in the computational modeling simulation.

Research Questions

- 1) Will AD INTERFACE II affect the mean task time to take pills?
- 2) Will AD INTERFACE II affect the mean task time to make a confirmation?
- 3) Will AD INTERFACE II affect episodic memory failure?
- 4) Will AD INTERFACE II affect prospective memory failure?
- 5) Will AD INTERFACE II affect reading repetition?
- 6) Will AD INTERFACE II affect pill administration?

Figure 1. Two-part development process to meet thesis objectives, including the steps that were completed and the resultant information attained from each step.

Limitations

A limitation of the study was the lack of research and empirical data concerning computer use by individuals with Alzheimer's disease. Since there was no empirical research directly related to the present study, validation and verification of the human performance model was not possible. Another limitation was that the cause and effects of Alzheimer's disease are not completely understood.

Delimitations

The emotional symptoms that accompany AD were not incorporated into the study. Although non-cognitive motivation and personality factors were reported to influence the performance of individuals with AD, these symptoms were also reported unrelated to cognition or function (Harwood & Barker, 2000; Mohs, Schmeidler, & Mosen, 2000; Wilson, Gilley, & Bennett, 2000). Only mild-moderate stages of AD were included in the study; and therefore, generalizations were not made for every stage of the disease.

The models addressed the procedural quality of the interface design, leaving the visual and perceptual aspects of the design to future modeling efforts and/or empirical studies using prototypes of the system with 'real' participants. Individuals affected by the mild-moderate stages of AD begin to have difficulty with maintaining independence, but they have relatively preserved perceptual and motor abilities that are (to some extent) necessary for using a computer-based cognitive prosthetic proposed in this study (Foerstl & Kurz, 1999).

No human participants were tested using the proposed interface design. The human performance model computationally represented significant cognitive and behavioral components of an individual in the mild-moderate stages of Alzheimer's disease, within the context of the model scenario. Human participants are necessary for future design phases.

Definition of Terms

Cognition. Human cognition manages incoming information, which is used to either be stored in memory, used to reason, make decisions, and/or guide actions in accordance with task-relevant goals (Baddeley, 1998).

Executive Function. Executive function is defined as the cognitive component that coordinates the flow of information across all memory systems, providing the ability to sequence tasks, perform several tasks at once, or to switch back and forth between tasks (Hodges, 2000).

Memory. Memory is defined as the capacity to encode, store, and retrieve information (Baddeley, 1992). Of the many memory systems that are believed to exist, this study focuses on the memory systems that are affected by mild-moderate AD and considered necessary for carrying out the tasks represented in the computational model of human performance. These consisted of both long and short-term memory components; include episodic memory, prospective memory, and working memory.

Forgetting. Forgetting is the loss of memory, often explained by interference (replacement of old items by new) and/or by decay over time. Computationally defined in this study, forgetting resulted from the half-life of the exponential decay model of

working memory (based on capacity limitations and the passing of time) and on probabilistic chances based on empirical studies.

Cognitive Prosthetic. A cognitive prosthetic is defined as an environmental (external) cognitive support or replacement for specific task(s) functions. It is not necessarily just one piece of software or hardware; rather, it is an entire system that interacts to assist an individual. For the purposes of this study the modeled system was computer-based and made up of a desktop computer in conjunction with a medication dispenser device, designed to support tasks that an individual with mild-moderate AD otherwise be unable to reliably perform.

Interface. An interface is the medium for information exchange between two or more entities. The study of interface design is often focused on creating more effective and efficient (usable) information structures to support human-computer interaction i.e., how information about the human is delivered to the computer (e.g., touch-screen), how information about the computer is delivered to the human (e.g., computer displays), and how these inputs and outputs can be customized to an individual user or application. For the purposes of this study the distribution of cognitive and procedural tasks between human (an individual with AD) and computer were examined.

Alzheimer's disease (AD). AD is a progressive and debilitating form of dementia that impairs older individuals' cognitive, behavioral, and eventually physical abilities. There are two types of AD, known as early-onset (up to 65 years of age) and late-onset (after 65 years of age). Behavioral symptoms are often more pronounced and cognitive symptoms decline faster in early-onset AD, the less common of the two types. Late-onset

AD was the focus of the research. In medical practices, a seven-point scaling system is used to describe discrete stages of the late-onset disease progression, however the symptoms of each stage are described to overlap (Johnson & Johnson, 2000). Therefore, the focus of the study was on a combination of two stages, the third (mild cognitive decline) and fourth (moderate cognitive decline), referred hereafter as the mild-moderate stages of AD. Clear cognitive and functional deficits appear by the third stage of the disease progression marked by problems remembering recent events and/or retaining relatively little material after reading. Logical reasoning, planning, and organizing significantly deteriorates by the fourth stage of decline and individuals become distracted easily. As a result, individuals are often unable to put a series of steps together in the right order to carry out a task or activity. Motor performance and procedural memory is relatively still preserved into the mild-moderate stages of disease. During these stages, caregiver support for daily activities of living becomes necessary (see Appendix A for a more complete description of the deficits and limitations associated with the mild-moderate stages of AD).

Activities of Daily Living. Activities of daily living relate to the capacity of self-care and to the ability to perform routine tasks (sometimes referred to as instrumental activities of daily living). Improving or maintaining functional autonomy is essential to both patient and caregiver quality of life. The focus of this research was on supporting (via computer-based technology) a routine and necessary task of daily living namely, taking medication. However other tasks were also incorporated into the modeling

simulation scenario including, making telephone calls and receiving and responding to electronic mail (e-mail).

Primary Task. The main goal defined in the model scenario was for the computer user to complete the task of taking pills and then confirming that the pills were taken. The scenario began and ended with this medication adherence task and was considered the primary task. Dependent measures were collected only from components of the primary task.

Secondary Task. There were three secondary tasks defined in the model scenario. Two of these tasks, 1) making a telephone call and 2) writing electronic email, were incorporated to represent a portion of the operational environment and also acted as distracters when reinitiating the primary task after an interruption. The third secondary task was 3) answering the incoming telephone call, which was the scenario event that acted as the interruption to the primary task.

Significance of Study

Based on the review of literature, it appeared that the structure of commonly available software and conventional computer interfaces produces a complexity of Human Computer Interaction that is not yet suitable for the cognitive impairments associated with the special needs of the older population. Furthermore, it was believed that the current methodological approaches to computer-based cognitive prosthetic design are not adequate to support the tremendous demands being placed on society by Alzheimer's disease.

Alzheimer's disease (AD) is a progressive, degenerative form of dementia that causes severe intellectual deterioration (Taylor & Sloan, 2000). Early stages of AD may cause individuals to experience difficulties in memory (especially for recent events), disorientation in familiar environments, reduced spontaneity, apathy, and withdrawal (Cherry & Plauche, 1996). As well, they commonly forget to finish tasks or repeat tasks and have difficulty with abstract thinking, reasoning, and judgment (Riederer & Pieper, 1998; Seifert, 2000). Consequently, individuals who have AD eventually lose the ability to perform necessary activities of living and by the latest stages of this debilitating disease there is no chance for patients with AD to maintain independence (Kurlan, Richard, Papka, & Marshall, 2000). A major challenge for people with AD is their inability to keep themselves occupied while spending time alone, yet the majority of individuals with AD want to stay home (Riederer & Pieper, 1998). Quality of life inevitably suffers for the patient, family, and care provider, as supervision is necessary up to 24 hours a day.

The risk of a person developing AD strongly increases with age (Riederer & Pieper, 1998) and projections indicate that a quarter of the American, Canadian, and Western European population will be over 60 years of age by the year 2020 (Newell, 1998b) creating a substantial increase in the demographic proportion of older people. Thus, the prevalence of AD is rapidly growing, accounting for over 4 million Americans inflicted with the disease and rates seem to double almost every five years after the age of 65 years (D'Esposito & Weksler, 2000).

The combination of the number of older people living alone, decreased family care, older population aging, and increasing burdens on social protection and care systems is making the need for intervention great (Taylor & Sloan, 2000). The societal demand for care and assistance will continue to grow (Larson, 2000); therefore, new services, new ways of offering services, and new care structures are required.

It is no surprise that health costs are the most rapidly growing expenditure field in social policy since the early 1960's (Newell, 1998a) and 26 billion dollars is spent each year on institutionalization alone (Lederman, 2000). Long-term care costs of AD were reported to be almost 10 times greater than other age-related problems, accounting for over 13 billion dollars spent annually on institutionalization in the United States (Larson, 2000). Instead of resorting to costly, traditional long-term care that utilizes highly restrictive measures, there is a need to introduce new ways of helping people age with independence and dignity (Czaja, 1997). Self-help potential of older adults needs to be stimulated. There is no cure for AD; therefore, it is imperative to provide intervention early in the disease course to slow or augment the associated functional declines. A

period of relative well-being could be prolonged using various methods of intervention rather than the suffering that often accompanies the patient, family and caregivers (Foerstl & Kurz, 1999).

Interaction between persons with AD and computer technology is possible (Riederer & Pieper, 1998; Cole & Dehdashti, 1998). However, the specific system and interface features that would provide usable, error free or tolerant, and independent use are unknown. Researchers studying the use of computer aiding devices express the need for further investigations to clarify what concepts of human computer interaction are useful and how to offer a 'high quality of life' (Kato, Takeda, Toriumi, & Noguchi, 1998; Riederer & Pieper, 1998). "Cognitive disabilities . . . are underrepresented in computer science research . . . this is unfortunate because there is a richness of problems, and an opportunity for so many computer science fields to make a contribution" (Cole & Dehdashti, 1998, p. 17).

The development and implementation of information and communication technology offers unrealized potential for home care of individuals with AD. Computers have the potential to improve the quality of life of patients with AD while decreasing the workload of caregivers. A computer-aiding device can become a sequential timer and remind patients of medication schedule and how to accomplish that task, as well as provide access to friends and family. What is needed is the ability to develop and implement computer-aiding devices into homes of individuals with AD on a global scale, not just one patient at a time. A single case study with a one-on-one, patient-researcher ratio is too expensive and time consuming. A computer-aiding device could be designed

to complement and take advantage of a person with AD's preserved capabilities and act as a prosthetic to reduce the cognitive demands and replace some cognitive requirements of a conventional computer system. Human performance models have the potential to translate the needs, limitations, and capabilities of the AD target user group into system and computer-interface requirements.

CHAPTER 2

Background

Gerontechnology is a multidisciplinary area of research that focuses on technology directed towards aspirations and opportunities for older people for the improvement of daily functioning (Czaja, 1997). It encompasses research on how to optimize existing technology by compensating for declining capabilities in an attempt to improve the quality of life and enhance the independence of older adults. Technological advancements would be especially beneficial for those adults suffering from additional deficits other than those caused by normal aging, such as dementia of the Alzheimer's type. The present study focuses on the use of computer technology to provide a cognitive prosthetic; a technology intended to augment the functional skills of the user so that a highly structured set of activities of daily living can be performed (Cole, 1999).

Ideally, computer-based technology should support independence and choice and should fulfill the positive potential of the older adult with AD (Newell, 1998a). Unfortunately, the process of developing a useful computer-based cognitive prosthetic is complex and poses many challenges. The computer interface design is one such challenge as the decision of selecting the functional skills needed to be augmented are compounded by the decision of how to implement those requirements into the interactive system.

Computer Interface Design

There are a wide range of impairments that limit individuals' ability to use personal computers or any consumer electronic device. With respect to AD, cognitive

limitations are prominent. There are few specific guidelines or rules for computer application, specifically for cognitive disability. What *is* available is somewhat generalized. For example, according to a Resource Guide for Accessible Design of Consumer Electronics (TIA, 2001), individuals with cognitive impairments due to AD, coupled with age-related declines, generally benefit from; simple displays, low language loading, simple obvious sequences, and cued sequences. They tend to have difficulty with: understanding audio instructions, using automated systems, and using visual displays. Methods to improve design are suggested to be the use of; voice prompts, increased print size, simple fonts, high contrast, labels with icons or graphics, and progress displays.

These recommendations appear straightforward, but perhaps too naïve and even contradictory. For instance, what kinds of progress displays or voice prompts would be effective and how much or what kind of information should be provided to the user? Juergen (2000) defined usability as the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments. In human computer interaction development there is a set of formal principles that a system interface should obey, but then it may be up to a good designer to ensure a ‘usable’ design over and beyond those principles for an effective interactive system. In this study interface design requirements were investigated so that more definitive design recommendations can be available to system designers.

Traditionally, clinical research and development approaches to cognitive prosthetics have been single-participant case studies. As such, researchers focused on

creating a usable computer device based on the unique characteristics of the user. The following discussion provides a review of some of the previous research conducted in the field of assistive technology and cognitive prosthetic computing.

Cognitive Prosthetics Review

External memory aids are emerging into forms of microcomputers, and success has been reported in the use of computers designed to perform artificial thinking skills for patients (Cole, 1999; Kim, Burke, Dowds, Boone, & Parks, 2000; Van Den Broek, Downes, Johnson, Dayus, & Hilton, 2000). Internal mnemonic strategies, rehearsal techniques, and external memory aids were successful for helping people with acquired brain injuries and patients with early AD, which both have cognitive deficits that are medically difficult to correct (Camp, Foss, O'Hanlon, & Stevens, 1996). However, mnemonic strategies do not seem plausible for AD in moderate and later stages since they may be too difficult (Riederer & Pieper, 1998). Rather than focusing on restorative approaches (the use of cognitive exercises to enhance or re-establish memory functioning) researchers are now adopting compensatory approaches, teaching individuals with AD to use external aids such as electronic devices to help their forgetfulness. Compensatory approaches were also reported in a study using an application of entertainment software to reduce boredom and maintain AD patients' interest and engagement in a computer-based cognitive prosthetic that comprised of adaptable and extendible information systems (Riederer & Pieper, 1998).

There is a need to evaluate existing and proposed designs of aids for activities of daily living functioning but not in a one-on-one testing environment. For example, Cole

and Dehdashti (1998) reported that it took approximately 10 months to build the computer application software specific to an individual case study and then each component of the computer application was tested in multiple sessions, followed by additional testing on new applications. One case study alone “required creating or changing over 1000 interface and functional parameters” (p. 7).

User-Centered Design

In general, the goal of assistive programs is to improve a patient’s functional independence (Van Den Broek et al., 2000). Cognitive prosthetic computing systems must be ‘user friendly’ and therefore must be easy to learn, limit errors during use, and allow for easy recovery from an error (Cole & Dehdashti, 1998). Usability describes a relationship among user characteristics, task characteristics, and device characteristics. Therefore, computer-aiding devices can only be effective if these characteristics are understood and accommodated in the design process. When applying such technologies to older adults with AD, incorporating the cognitive requirements for system operation is essential (Kim et al., 2000). Thus, a user-centered design is necessary since it is intended to consider human capabilities in the design phase of procedures and equipment used in carrying out a task. In addition, because the study of AD is particularly challenging, researchers could benefit from shorter development times since an individual’s functioning can decline rapidly and fluctuate considerably.

The present study will use an analytical, engineering and cognitive psychological research method known as a human performance modeling, which consists of a computational modeling simulation that takes the elements of users into account during

the system design phase. There are no actual participants in human performance model; rather, the system is made up of simulated entities (computationally represented). Using the human performance model technique, system performance quality and success is determined from the interaction between the profile of the user, computer, and tasks within the environmental context. Not only does human performance model follow a user-centered design approach, but also it can be used to direct empirical evaluations towards likely problems in the system, which can be very useful since it is difficult to collect empirical data from a population affected by a disease that can progress at a fast and variable rate. The use of a human performance model tool is not intended to eliminate the necessity of testing real participants with prototypes and then fully developed systems.

Human Performance Modeling

Computational models of human performance can bring many important elements to a study, they force rigor and consistency in the analysis, serve as a framework for organizing and indicating what additional information is needed, allow prediction for systems during design phase of development before the product is completely built, and they can also allow a training regimen to be developed during the design phase (Corker & Smith, 1993; Graafmans, 2000). In combination with traditional methods of experimentation, the iterative process of model development and testing provides valuable information for system designers, whereby, performance considerations can be recognized early in the design phase, adjustments in the system can be made before unnecessary time and money is spent on implementation or further experimentation, and

can ensure that systems are designed for the users (Corker, 2000). Many different output measures can be captured from a HPM, including time on task, error rates, operator load, and system workload (Gore, 2000). They can predict the interaction of system performance and human behavior and have an analytical capability that defines the information that should be displayed to the user. This output is particularly important to designers and were, in part, derived from the cognitive characteristics germane to AD that manage task performance.

Human performance models assume that perceptual and cognitive processes, which are strongly influenced from events in the environment, control human behavior. Hence, the structural approach to modeling is constructed based on the models and theories that have been described to make up the human information processing system (Hollnagel, 1998). In order to develop an accurate model of the computer-user target group, these influences must be investigated as they pertain to the tasks and goals presented.

To provide a relatively complete and useful representation of the human operator for a task, the following components of behavior were incorporated: resource allocation (attention), scheduling, retrieval from long term and working memory, decision making, and motor performance.

Task Network Modeling

Task network modeling is a relatively mature technology that has been positively validated (Laughery & Corker, 1997). A task analysis is a formal human factors method of analyzing the performance demands made on the human element of a system. A

careful analysis of the human capabilities known to be affected by AD, coupled with a close examination of the system task demands facilitated the identification of potential weaknesses in the system.

GOMS (goals, operators, methods, and selection rules) is an established task analysis methodology proposed by Card, Moran, and Newell (1983) that can be used for human performance modeling to represent the procedural aspects of usability. The GOMS technique describes human task performance based on an information-processing framework and provides a formal method for procedure execution in the form of an action-selection framework. GOMS has been successfully used and verified to allow predictions of human behavior in real-world human computer interaction design (Gray, John, & Atwood, 1993). The GOMS technique is used to guide the construction of the task network diagrams and user actions, which are both external (e.g., motor) and internal (e.g., decision making, storing items in working memory) micro models.

In support of the task-network, a simulation engine was used called the Micro Saint Human Operator Simulator. The Micro Saint Human Operator Simulator is a simulation and modeling tool that is used to support simulation and task-network design. To simulate real-life processes and save a model developer time, Micro Saint Human Operator Simulator can access a library of micro models based on empirical research (MS HOS User's Guide, 1998). A variety of human performance timing measures can be calculated using the micro models' algorithms that are assigned to designated tasks. Performance times can also be set using the features integrated into the Micro Saint Human Operator Simulator task network software. No micro models were used from the

Micro Saint Human Operator Simulator library; all performance times were implemented within the structure of each task node.

This study used a model called the Integrated Performance Modelling Environment, which uses human-task sequences as its primary organizing structure, integrating theory-based models and algorithms. The Integrated Performance Modelling Environment consists of several component models that can be selected from to create a system (full scenario) model. The Integrated Performance Modelling Environment was developed to serve as a predictor of task performance and allows for the analysis of interface design (IPME User's Manuel, 1998). Figure 2 represents the modeling architecture used in the modeling tool.

Integrated Performance Modelling Environment

The Integrated Performance Modelling Environment combines psychological processes with physical task completion times with the use of micro models, task scheduling, sensation and perception, cognition, and motor outputs (Integrated Performance Modelling Environment User's Manuel, 1998). Task network simulation predicted operator performance and system workload, but does not measure the actual operator workload; therefore, a model of the human information processor was coupled with the Integrated Performance Modelling Environment from which operator load and performance could be inferred (Hendy & Farrell, 1997). An Information Processing/Perceptual Control Theory module was set to run with the Integrated Performance Modelling Environment to provide a timeline of modeled activity. The Information Processing/Perceptual Control Theory module contains an allocation of

attention model, memory, and task performance modifiers that can be used as a framework for investigating operator information processing limitations and their impact on perceptions of workload, error production, and performance (Hendy & Farrell, 1997). Information Processing/Perceptual Control Theory is a framework of applied psychology where task loading can occur due to a multiple of influences, such as physical, time, resource, or cognitive limitations (Card et al., 1983). The scheduler of the Information Processing/Perceptual Control Theory mode was used when a transition in task performance was invoked due to an interrupt event.

Alzheimer's Disease Overview

To guide appropriate model design, a further analysis of AD was required to relate the specific deficits associated with mild-moderate stage of decline with the requirements associated with computer use. Once the cognitive components that were thought responsible for the problems associated with carrying out activities of living were identified, the task networks and performance times were constructed accordingly.

Alzheimer's disease is often characterized by the progressive loss of memory and intellectual function (Hodges, 2000) but it involves changes in three domains, namely behavior (including emotions and personalities), cognition, and physical impairments that encompass psychomotor and functional capabilities (Carrasco, Guillem, & Redolat, 2000). The clinical presentation of AD varies widely and is dependent on the stage of the disease. In later stages of the disease, basic biologic functions are disturbed, including visual interpretation, all language abilities are lost, and abnormal reflexes and seizures

Figure 2. The Integrated Performance Modelling Environment (IPME) using the Micro Saint Human Operator Simulator engine (MS/HOS) was comprised of many components, which together were used to simulate the cognitive, system, and environmental components of the present research. The GOMS (goals, operators, methods, selection rules) task analysis technique was used to guide the task network diagram construction that defined the procedural flow of the system interaction. The Information Processing/Perceptual Control Theory mode of IPME was used to schedule task and resource selection. Cognitive models were created and embedded within the task network configurations, which represented Alzheimer's disease-related working memory and attentional deficits. Scenario events were added to represent environmental distractions.

also develop (Garand, Buckwalter, & Hall, 2000). There is no chance for patients with AD to maintain any independence by the latest stages of this debilitating disease.

The nature and progression of the declines associated with AD is often unpredictable (Johnson & Johnson, 2000), which presents a difficult challenge for researchers to perform valuable longitudinal studies. Until recently, the time between diagnosis of AD and institutional care was about three years (Stern, Hesdorffer, Sano, & Mayeux, 1990), leaving time for intervention rather limited. However, current knowledge of the clinical presentation and progression of AD has improved, allowing diagnosis to be made more reliably and much earlier (Cherry & Plauche, 1996).

The focus of this study was on the mild to moderate stages of AD, as it was revealed that these individuals could benefit from cognitive prosthetic interventions. The behavioral symptoms that accompany AD were beyond the scope of this paper due to their unpredictability and the complexities associated with the human performance modeling. Although non-cognitive motivation and personality factors were reported to influence the performance of individuals with AD, these behavioral symptoms were also reported unrelated to cognition or function (Harwood & Barker, 2000; Mohs et al., 2000; Wilson et al., 2000).

Task analyses revealed that carrying out the activities provided by the computer applications (medication, telephone, email) was presumed to involve several cognitive components that use either short term or long term memory, including:

- 1) Episodic memory = failure to remember if task was already completed
- 2) Procedural memory = failure to remember how to execute task

- 3) Working memory = failure to maintain the intention and knowledge to carry out task
- 4) Prospective memory = failure to remember the intended action(s) in the future

These cognitive processes, along with the component processes that influence their functionality, are examined in the following sections. As well, common problems that individuals with AD have for day-to-day functions are presented as they provide the bases for the tasks and activities modeled in the present study.

Cognitive Processes

Long-term memory, including anterograde (recent past memory), declarative (explicit), and semantic memory (facts, principles, and rules) were initially thought to be the main problematic areas of memory functioning in AD (Greene, Hodges, & Baddeley, 1995; Laurent, Thomas-Anterion, & Allegri, 1998). However, studies finding differences in memory performance suggested that the processes involved in recall, recognition, retrieval, and encoding may all be independent, causing patients to perform according to specific test or task requirements (Cherry & Plauche, 1996).

To investigate the concept that long-term memory deficits may stem from dysfunctional encoding Moulin, Perfect, and Jones (2000a) measured the response to repetitions of stimuli. Moulin and colleagues (2000b) proposed that metacognitive factors and/or poor strategies accounted for the deficits in long-term memory due to their effects on encoding. They defined metacognition as a regulatory system that mastered to-be-remembered items. They suggested that the deliberate efforts of encoding were

disrupted by AD rather than the availability or implicit and automatic response to stimuli. They concluded that the control processes were intact, but the explicit awareness to repetition was not. Budson, Daffner, Desikan, and Schacter (2000) also presented repeated information to patients with AD to examine false recognition of semantic associates. Their findings provided evidence that patients did not develop detailed item-specific recollection, regardless of the amount of repetition, but patients were able to learn the 'gist' of the information.

In their study testing memory for self-generated items, Barrett, Crucian, Schwartz, and Heilman (2000) reported that when participants with AD were not explicitly trying to remember they performed better on memory tests for incidental recall (i.e., without instructions to remember) compared to external memory. Because instructions to remember appeared to cause more deficits in memory, the researchers suggested that patients might have used a maladaptive strategy. They suggested that semantic networks might be more preserved for internally generated items if the externally supplied words did not make it past short-term memory processes. In summary, semantic information may still be intact but may not always be accessible, available, or able to be processed effectively (Barrett et al., 2000).

Episodic memory is memory for personally experienced and temporally specific events or episodes (Hodges, 2000). Although encoding information in episodic memory is strongly influenced by information in semantic memory, it is also possible for the episodic system to function relatively independently (Tulving, 1972). Delayed recall, the ability to retain new information after a period of time, is the most sensitive measure of

episodic memory (Hodges, 2000) and researchers that used this type of test suggested that AD was responsible for impairing a person's ability to learn and retain new information due to its detrimental effects on episodic memory (e.g., Cherry & Plauche, 1996; D'Esposito & Weksler, 2000). Within episodic memory, there are memories classified as short-term (having happened in the last hour) and those classed as long-term (greater than an hour). Only short-term episodic memory was represented in the models of human performance. Individuals with AD at the earlier stages of the illness did not commonly have any difficulty remembering distant events, but forgot having done something five minutes ago or even five seconds ago (Morris, 1994). In fact, Morris (1994) reported that patients with AD forgot a simple task 75% of the time after only a 20 second delay.

Procedural Memory

The severe memory deficits caused by AD do not appear to extend into the motor learning domain. In fact, patients with AD can acquire, retain, and even transfer new information into the moderate to severe stages of development (Seifert, 2000). However, even due to the aging process alone, motor behaviors change causing increased movement times, decline in the ability to maintain continuous movements, disrupted coordination, and more variability in movement (Vercruyssen, 1997).

Based on previous findings indicating that individuals with amnesia were able to learn and retain a variety of motor skills, Eslinger and Damasio (1986) studied patients with AD using a pursuit rotary task. Their results demonstrated that patients with AD and controls had a similar pattern of motor learning, however initially patients performed at a much lower level. Eslinger and Damasio proposed that neural structures that

integrate the visual, motor, and kinesthetic information used in the task were preserved in the subjects with AD, enabling the development and storage of a motor program to be supported. Overall, studies including moderately severe dementia have provided evidence that those individuals with AD could learn and retain new motor skills well into the disease course (e.g. Dick, Nielson, Beth, Shankle, & Cotman, 1995; Eslinger & Damasio, 1986; & Kluger et al., 1997). Furthermore, in their study of individuals with AD for retention and transfer of skills learned, Seifert and Baker (1998) reported that although the episodic memory of previous tasks was not present, the procedural knowledge or techniques for completing the *once learned* task were still available. Their findings were consistent with the view that procedural learning did not depend on recollection of the source of the information and was acquired implicitly (Baddeley, 1998; Tulving, 1972).

On neurological examinations, the majority of patients with mild-moderate AD exhibited no primary motor or sensory abnormalities (Ott, Ellias, & Lannon, 1993). Parasuraman and Greenwood (1998) also reported that although AD affected many cognitive functions, there appeared to be relative sparing of sensory functioning in the earlier stages of the disease and sparing of motor functioning up into the later stages of the disease. AD caused decreased performance only for complex psychomotor movements and activities (Franssen, Souren, Torossian, & Reisberg, 1999; Kluger et al., 1997).

Activities for Daily Functioning

In order to develop a modeling simulation, a scenario was chosen based on realistic applications for the computer-based cognitive prosthetic. Selected activities of daily living were represented based on the literature reviewed. The importance of daily functioning for individuals with AD and their consideration for assistive technology services is presented below.

By definition Mohs and colleagues (2000) suggested that problems with daily functioning accompany AD; also Foerstl and Kurz (1999) suggested that cognitive impairment had to be severe enough to compromise activities of daily living for a clinical diagnosis of AD. Activities of daily living, or the basic biologically necessary activities of living, are assessed using functional measures in AD studies. Examples of activities of daily living include such activities as toileting, dressing, and grooming. Functional assessments also include measures of the ability to perform more cognitively demanding activities such as using the telephone, writing letters, or managing money. Mohs and colleagues (2000) suggested they were referred to as instrumental activities of daily living because those types of activities involved using some type of instrument. Discussion to follow will use activities of daily living and instrumental activities of daily living interchangeably since functional assessments test for both and researchers often do not differentiate between them in their reports.

Computers have the potential to improve the lives of the aging population in a number of ways, including: (1) increasing access to services, (2) providing alternative communication options, and (3) facilitating social interaction (Czaja, 1997; Vercruyssen,

1997). Following those recommendations, making telephone calls, using electronic mail, and adhering to a medication regiment were the computer applications incorporated into the interface design of the cognitive prosthetic. These activities of daily living formed the basis for the scenario tasks developed for the human performance model.

Based on neuropsychological markers of early AD, Almkvist and Winblad (1999) as well as Doble, Fisk, and Rockwood (1999) reported that mild stages of AD was related to dysfunction of instrumental activities of daily living and multifactor cognitive deficits. They described patients with moderate stage AD as being dependent and there were greater marked cognitive deficits. During an unstructured period of the day in a nursing home, patients with mild-moderate AD were observed performing daily functions (Lucero, Pearson, Hutchinson, Leger-Krall, & Rinalducci, 2001). Whether out of boredom or a sense of need, patients attempted tasks but needed guidance or ongoing direction to continue or complete those tasks. An overview of the performance declines observed in mild and moderate stages of AD related to activities of daily living, cognition, and the common problems associated with both can be found in Appendix A. The computational structure of the human performance models were derived from clinical and observational research studies, which are presented below as they pertain to the specific deficits associated with mild-moderate AD.

The following section will explore the role of prospective memory, which is a key component of the cognitive system responsible for the actions that individuals engage in for necessary tasks of daily functioning and was represented in the models of human performance.

Prospective Memory

Virtually all instrumental activities of living are examples of tasks that require prospective memory. These tasks involve remembering to carry out an intended action or series of actions in the future, but they also encompass the complex process of remembering to remember (Troster, 1998). Overall, individuals with AD have difficulty executing any kind of prospective memory task and this type of memory may be particularly sensitive to AD even in the earliest stages of the disease (Huppert & Beardsall, 1993; Smith, Salsa, Logie, & Maylor, 2000).

Zacks, Hasher, and Li (2000) found that prospective memory was critical to the accomplishment of everyday social and personal goals. Thus, the mechanisms responsible for accomplishing goals associated with prospective memory received particular interest. Prospective memory was contrasted with retrospective memory, the system concerned with remembering information acquired in the past (Baddeley, 1998). There was evidence that individuals with AD in the early stages had greater challenges remembering to carry out intended actions and executing them at the appropriate time, than retrieving information from the past (Huppert & Beardsall, 1993). Moreover, when compared to retrospective memory failures, caregivers reported more frustration for prospective memory disruptions, which had a greater impact on their lives (Smith et al., 2000).

Based on his associative reminding model, Tulving (1983) proposed that cues in the environment lead to remembering a prior memory. Similarly, Craik (1986) highlighted the role of contextual support in memory processes to enhance performance,

suggesting that remembering depended on the interaction of environmental characteristics (retrieval cues) and internally driven, self-initiated retrieval processes. West and Craik (1999) reported that individuals with AD were relatively more dependent on the contextual or environmental support for remembering and were expected to have more difficulty when environmental support was weak. The processes thought to be necessary to initiate items internally are effortful, and therefore are potentially more problematic or susceptible to forgetting. When AD patients were provided with environmental support in the form of cues and reminders, they exhibited gains in performance of prospective memory tasks (Camp et al., 1996; Huppert & Beardsall, 1993).

Whereas healthy adults were observed to monitor time leading up to a prospective memory task, patients with AD were unable to perform those types of strategies for remembering (Herrmann, Brubaker, Yoder, Sheets, & Tio, 1999). In a study examining attentional processes during the performance of temporal tasks, the estimation of short temporal intervals was found to be a useful indicator of cognitive decline in AD (Carrasco et al., 2000). Therefore, prospective tasks that required temporal judgments were poor for patients with AD. The researchers provided an explanation that the lack of attentional resources was the probable cause. Episodic memory deficits might be another influencing factor if one considers Tulving (1972) suggestion that the role of episodic memory was to receive and store information about temporally dated events and temporal-spatial relations among those events. Episodic memory was incorporated into the human performance model structure through the use of probabilistic decision nodes.

Probabilities for the decision logic were derived from related studies of mild-moderate AD performing various tasks.

Many studies of AD are now focused on other components of cognition that influence memory and play a key role in the specific functional deficits found in individuals with AD. Hodges (2000) presented a synopsis of the stages of cognitive breakdown in typical Alzheimer's disease and an adapted view is presented in Table 1.

Most often, human performance models only represent a 'slice' or portion of the relevant system context under investigation since a fully comprehensive simulation would be very complex to achieve. Therefore, the following review was intended to identify the most relevant or useful properties of the system components.

Cognitive Deficits

In its earliest stages, memory loss is the most prominent feature of the deterioration of cognitive functions in AD and is the primary symptom of the disease (Becker, 1988). Loss of anterograde episodic memory in particular (Baddeley, 1998; Hodges, 2000) was termed the 'hallmark' of AD and current diagnosis criteria for AD (e.g., Mini Mental State Scale) emphasized its importance. However, disorders of executive ability and attention were also found to be among the earliest symptoms of the disease (Parasuraman et al., 2000; Perry & Hodges, 1999) and their role in poor functioning of instrumental activities of daily living may have been underestimated. Examining the impairments, preservation, and relevance of those components in the interrelationship between mild-moderate AD and a computer-aiding device was critical for design specifications to be realized.

The following discussion highlights the specific AD-related cognitive deficits that appear to play a significant role in functional declines. They include executive function, attention, and the central executive system of working memory. In the Information Processing/Perceptual Control Theory mode these components, to some extent, are represented through the allocation of attention module and its task scheduler, task priorities, short-term and prospective memory queues.

Executive Function

Executive functioning has been considered the central organizing function of cognition and appears to be mainly involved in operations that require systematic, goal-directed activity (Patterson, Mack, Geldmacher, & Whitehouse, 1996) by coordinating the flow of information across all memory systems (Baddeley, 1998). Richards and Kruater (1999) suggested that those goal-directed activities were a large determinant for patients with AD to depend on caregivers or institutionalization. By the time an individual reached the mild to moderate stages of AD, there was clear evidence in the literature that supported the notion that executive dysfunction played a significant and prominent role in functioning deficits (Binetti, Magni, Padovani, Cappa, Bianchetti et al., 1996; Baddeley, 1992; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; Lafleche & Albert, 1995).

Task planning pertains to executive function that executes, coordinates, and orders activities (Seifert, 2000) and was described as a mediator of some of the functional abilities of patients with AD (Patterson et al., 1996). To that extent, executive functions were required when sequences of responses were generated or scheduled, or when novel

plans of action were formulated and executed (Villa & Abeles, 2000). In their study of executive function deficits in AD, Laflech and Albert (1995) described these processes needed in “concurrent manipulation of information (e.g. cognitive flexibility), concept formation, and cue-directed behavior” (p. 313).

Thus, it was believed that an effective interface design would incorporate techniques for assisting executive components of task performance and execution. However, before proposing completing the models, it was important to examine cognitive components that provide essential inputs for executive functioning and that are affected by AD, namely, memory and attention (Duke & Kaszniak, 2000). Next, AD-related deficits of attention and short-term memory aspects of cognition are presented as they influenced executive functioning, task performance, and model development.

Attention

Within the information processing approach, that analyzes the mind in terms of different subsystems, attention was described by Pashler (1998) as the system to form, retain, and transmit representations of the world. Therefore, if attention were impaired it could potentially be a major source of disruption in cognition.

Following the information-processing tradition, attention was conceptualized as a system with limitations (Card et al., 1983; Pashler & Johnston, 1998) and the literature clearly indicated that those limitations were thought significantly increased due the effects of AD. Huppert and Beardsall (1993) proposed that integrative processes such as attention and executive functioning might fail at an earlier stage than storage components of cognition. Duke and Kaszniak (2000) reported that the planning and attentional

Table 1

Postulated components of cognitive breakdown in typical Alzheimer's disease and the severity of breakdown illustrated by the number of '+' signs for more severe and '-' signs for no signs of breakdown. Italicized terms represent the cognitive components associated to the present human performance modeling effort.

(Adapted from Hodges, 2000, p. 444).

		Minimal	Mild	Moderate	Severe
<i>Memory</i>	<i>Working</i>	-/+	+	++	+++
	<i>Episodic</i>	++	+++	+++	+++
	<i>Remote</i>	-/+	-/+	++	+++
	<i>Semantic</i>	-	-/+	+++	+++
	<i>Procedural</i>	-	-	+	++
	<i>Prospective</i>	+	++	+++	+++
Language (syntax and phonology)		-	-	+	++
Visuo-spatial and perceptual		-	+	++	+++
Praxis		-	-	++	++
<i>Attentional</i>		+/-	++	+++	+++
<i>Executive Function</i>		+/-	++	+++	+++

deficits observed in mild to moderate stages of AD correlated with the decline of activities of daily living.

Several models of attention were explored in the literature. Broadbent's (1958) filter theory proposed that prior to the identification of stimuli, a filtering process occurred early in the selection phase of attention. The filter theory was proposed to explain how some of the information processed by our senses was discarded before reaching the limited capacity channel. A selective filter ensured that only relevant content was subject to further attentive analysis. The filter model predicted that processing of unattended material should not proceed to the level at which semantic information is accessed, but that prediction was later disputed. Treisman (1964) proposed a modified version known as the filter-attenuation theory that helped explain how unattended information sometimes 'leaks' into cognitive stores. Conceivably, if an imperfect attentional filtering mechanism exists, then storage of information about an object in both short-term and long-term memory is greatly reduced and/or the potential for information overload is increased. Next, the relevance of selective attention deficits caused by AD and its model representation is discussed.

Selective attention is a component of many tasks and refers to the screening out of irrelevant information, whereby a person selectively allocates processing resources to some stimuli over others (Perry & Hodges, 1999; Wickens, 1999). Essentially, selective attention prevents us from being overloaded with information (Pashler, 1998). Examples of selective attention includes visual sampling, spatial and object selection in visual target search, and aspects of switching and response inhibition. Attention can be described as

an enhancement of processing of relevant information, however, if the mechanisms responsible for information processing are no longer functioning appropriately, then selectivity of relevant information might be compromised (Pashler, 1998). In this respect, a person with AD may not be able to 'cope' with irrelevant information or stimuli in their surroundings and performance decrements may develop as a result.

Inhibitory processes appear to play a major role in selective attention (West & Craik, 1999). For modeling purposes, an absence of a filtering process was presumed and as a result all information presented on the computer screen was attended. This lack of selectivity and inhibition simulated a challenge for the working memory storage and retrieval system. Perry, Watson, and Hodges (2000) reported that in their study of attentional dysfunction, patients with minimal AD had particular problems with response inhibition and speed of attentional switching. Langley, Overmier, Knopman, and Prod'Homme (1998) also found that selective attention was decreased due to impaired inhibition, reporting that patients had difficulty in suppressing responses to distracting stimuli.

In addition to selective impairments in attention, individuals with AD were reported to have difficulties with divided attention. Divided attention refers to the distribution of resources among two or more targets or processes simultaneously (Perry et al., 2000). Divided attention is thought to involve effortful processing, which is increased due to the effects of AD (Baddeley, 1998, Hodges, 2000). Therefore, based on the literature reviewed on the effects of AD on attention, the model scenario was

constructed to only allow one activity or task performed at one time. This decision was further supported by research concerning dual-task performance.

Studies of AD often involve testing patients on divided attention using a dual-task paradigm (Baddeley, 1992) that required participants to perform two tasks separately before performing the same two tasks together. Costs to performance tended to increase when individuals with AD were presented with more than one task. Morris (1994) also reported that performance decrements were observed when two simple tasks were performed simultaneously by patients with AD whom had performed well on those same two tasks when they were completed one at a time.

Attention was described as having several functions or manifestations that influenced a person's subsequent performance. The process of attending to and integrating more than one cue presents a significant challenge to human attention (Wickens, 1999) and clearly, AD increases this challenge. There is a close and notable connection between attention and short-term retention. Information-processing psychology generally suggests at least three ways in which attention is relevant to remembering (Zacks et al., 2000); 1) proper selection of what should be remembered, 2) concentration or maintenance of attention to what should be remembered (or the result of the ability to avoid distraction), and 3) the resources to accomplish more complex processing of information. Overall, these attentional mechanisms were implicitly represented in the human performance model by using clinical observational data to represent behavior. The modeling structures that represented these mechanisms consisted of a combination of attentional and working memory features. This consisted of a lack of

filtering for the attentional component of the model and limiting the capacity, as well as increasing the decay rate, of the working memory model.

As alluded to above, a critical role of the attention system is hypothesized to protect central mechanisms, such as working memory, from interference caused by irrelevant input. The central executive system of working memory (Baddeley, 1998) is discussed next as it related to the functional deficits that individuals with AD experience from day to day and a consideration in which a prosthetic should be sensitive.

Central Executive System

Baddeley (1992) made a conceptualization of normal short-term memory function and suggested that a particular set of cognitive processes, termed working memory, were actively involved in short-term retention. In the working memory model of Baddeley there are two subsidiary systems that are coordinated by a central executive system. In addition to temporarily holding information, the working memory system was described as a system for manipulating information as a part of a wide range of essential cognitive tasks such as learning, reasoning, and comprehending (Baddeley, 1998). Baddeley's concept of a working memory system for modeling short-term memory was particularly useful in examining the memory deficits in AD and many studies of AD adopted his model for experimental examination purposes (Becker, 1988; Cherry, Buckwalter, & Henderson, 1996; Morris, 1994; & Rochon, Walters, & Caplan, 2000).

Within the information processing framework, the central executive system was considered an external attentional mechanism that did not play a direct role in the actual execution of the task, rather, it was characterized in terms of attention shifting and

allocating processing resources (Cherry et al., 1996; Vecchi, Saveriano, & Paciaroni, 1999). Within the context of working memory, deficits were attributed to several causes including its capacity, ability to maintain, manipulate, or retrieve items (Deutsch, 2000).

At least a portion of cognitive decay caused by AD was explained by deterioration of working memory functions (Vecchi et al., 1999). Deficits of the central executive system were reported responsible for the poor performance on tests requiring non-routine behavioral responses (Becker, 1988), retrieval and organizing relevant information (Rochon et al., 2000), and encoding and maintaining information (Beuzeron-Mangina & Mangina, 2000). Representing the AD-related short-term memory deficits in the models was accomplished through creating an exponential decay model of working memory, which is discussed in the methods section.

Summary

Baddeley (1992) described humans as being equipped with memory buffers that hold information temporarily for inputs that have not yet been fully processed and for outputs that have been planned but not yet carried out. As well, various internal buffers were suggested (Pashler & Johnston, 1998). Those buffering and switching mechanisms were thought partially responsible for supporting (continuous) dual-task performance. Prospective memory typically takes place in a dual-task paradigm or during multitasking (Knight, 1998) and is a goal-oriented activity embedded in a hierarchy of activities (Troster, 1998). Tasks are resumed later or restarted; others are removed from the prospective memory if there are an excess of memory or if the memory trace decays.

Studies carried out using a dual task paradigm concluded that all tasks required resources from the central executive system, but it was when two tasks were introduced (of sufficient challenge) that the capacity of central executive system was exceeded (Morris, 1994; Vecchi, Saveriano, & Paciaroni, 1999). As AD progressed, the dual-task decrement observed increased, even though performance on the individual tasks did not change.

Assessing mental workload is closely related to an estimate of the attentional demands of person's tasks (Corker & Smith, 1993). More complex tasks usually involve greater demands on attentional selectivity as well as working memory (Baddeley, 1986). Incorrect decision making (in part) is attributed to vulnerabilities in the cognitive processing of an individual related to selective attention and working memory, and according to an information processing model of decision making, selective attention plays a critical role as effort and attentional resources must be used to process or filter cues in the environment based on past experiences (Wickens, 1999). Pashler (1998) suggested that attention may be used to concentrate on the ongoing processing demands of a primary task, generate expectation, or may be used to direct behavior selectively toward one of number of competing events.

If attention is thought of as the means by which scarce or limited processing resources are allocated to accomplish multitasking, then the decrements imposed by AD would most likely impede on an individual's normal ability to manage more than one task at the same time. Moreover, as task demands increased, so would time and error rates associated with this performance. Dual-task costs were suggested by Pashler (1998) to

arise as a consequence of two forms of competition: (1) competition for central processing capacity, which often appears to be discrete competition (resulting in queuing); and (2) competition for perceptual capacity that is probably modality specific. Individuals with AD performed normally on tests of auditory and spatial short-term memory but not on dual-task performance tests that required individuals to divide their attention, and subsequently, draw on the central executive system (Hodges, 2000).

Early signs of decrements in intellectual abilities, abstract reasoning, and judgment (Cherry & Plauche, 1996) appeared to be consistent with attention and executive functioning deficits. Active processing tasks (requiring information modification, integration, or transformation) were highly sensitive to the detection of working memory deficits in AD in contrast to passive tasks that were described as the maintenance (storage) of information in the same format as it was previously for encoded (Vecchi et al., 1999).

The environment in which an individual carries-out daily activities or interacts with a personal computer will conceivably contain stimuli that help reach goal attainment, stimuli that are irrelevant to goals, and stimuli that can encourage mental processes that are inconsistent with an individual's goals. When workload or task complexity increases, working memory efficiency and/or controlled attentional processing may contribute to declines or failures in prospective memory tasks. Einstein, Smith, McDaniel, and Shaw (1997) found that older adults showed a deficit in prospective memory tasks when the attentional demands of background activities increased. Presumably, the limited capacity of working memory explained the impaired

ability of older adults to concurrently hold the prospective memory activity in memory with several other ongoing tasks and was further hindered by the impairments associated with Alzheimer's disease.

CHAPTER 3

Methods

The first part of the study consisted of two objectives: (1) to design a computer interface for use by individuals with mild-moderate AD to carry out some tasks of daily living, and (2) to evaluate the proposed design using a computational modeling tool of human performance and then make modifications to better meet the cognitive needs of mild-moderate AD. The second objective was met by comparing performance measures between the initial interface design (AD INTERFACE I) and the modified interface design (AD INTERFACE II). Specifically, the study was designed to answer the question: Do the modifications implemented to create Model II exhibit characteristics of a computer-based cognitive prosthetic for use by individuals with mild-moderate AD?

Since common simulated participants and instrumentation were used throughout the study they are presented first. Thereafter, the chapter is divided according to part I and part II of the study. A description of how the initial interface was designed is presented along with the process of implementing the relevant cognitive aspects of AD and human computer interaction into a computational modeling tool of human performance. As well, measures of performance are discussed, including specific dependent variables and their role in the model structure. A brief description of the data output from the initial interface design (AD INTERFACE I) was revealed as it pertained to the verification of the models and to the interface design modifications intended to provide cognitive aiding in AD INTERFACE II. Examined in the second part of the chapter is the interface design and task network modifications made to AD INTERFACE

I to create AD INTERFACE II. Finally, the experimental design approach used to compare performance measures of AD INTERFACE I and II is outlined.

Participants

Performance measures recorded from human performance modeling simulations are likened to the performance measures that would be collected from participants in laboratory experiments, field studies, and case studies. Data collected from ‘real’ participants. For statistical analyses, the data sets collected from the model simulations were treated as if they came from ‘participants’ with mild-moderate AD that were interacting with a computer to perform specific tasks or ‘activities of daily living’ (i.e., medication, phone call, email). Each model’s run data was considered one participant’s set of performance measures.

Instrumentation

The tool used for the study was a commercially available software product known as the Integrated Performance Modelling Environment running in the Information Processing/Perceptual Control Theory mode. Version 2.0 for UNIX™ operating systems was used, which was distributed by Micro Analysis and Design. The software was run on the IRIX release 6.5, operating system on a SGI, P991, 19” monitor with 17.96” viewable image and was run on RIMM, 384MB, PC800, 400MHz, ECC, 2X64=2X128, Rambus memory. The capacity of the computer was more than capable of supporting the Integrated Performance Modelling Environment software product.

Information Processing/Perceptual Control Theory

Although the Information Processing and Perceptual Control Theory mode offers a good deal of control mechanisms to implement the theory discussed previously associated with mild-moderate AD-related cognitive deficits, the mode was not used extensively. The scheduler of the Information Processing and Perceptual Control Theory mode was used to manage the transfer process of cognitive resources necessary when task switching occurred as a result of the incoming telephone call. In addition, the task parameters available with this mode were used to define each task type (e.g. psychomotor, perceptual, cognitive), which ultimately influenced the scheduling process. The following discussion is an overview of the potentially valuable attributes of the Information Processing and Perceptual Control Theory mode for modeling cognitive impairments associated with AD. In future modeling efforts, more complex simulations could make greater use of the attentional and memory components of this mode.

Perceptual control theory represents the allocation of attention and memory together with a framework for tracking the load on the operator's information processing system (Hendy & Farrell, 1997). The purpose of the Information Processing/Perceptual Control Theory allocation of attention module is to schedule the tasks to be performed, either serially or concurrently depending on their levels of interference. Therefore, tasks that share common processing resources compete for processing time, but some tasks or processes can be under simultaneous control. A task may be performed on demand, interrupted, resumed, postponed, or shed. A representation of human task selection strategies is facilitated with a rule-based task scheduling mechanism, in which tasks are

given priority (time or state dependent) interruptability/resumability, and sheddability (discarding mechanism). Similar to Card and colleagues' (1983) Model Human Processor, the Integrated Performance Modelling Environment can simulate memory-retrieval failure using three different mechanisms, namely, spontaneous decay over time, interference, and displacement of old items by new ones.

The task time-line that the computer user follows to complete a goal is called the demand load (Integrated Performance Modelling Environment User's Manuel, 1998). The term operator load is given to the tasks that the user can execute simultaneously. To determine task sequence, a scheduler must be used when demand load exceeds operator load. The scheduler is also called upon whenever new tasks arrive or existing tasks finish. When the scenario event is activated, which represents the incoming phone call interruption, the scheduler is called upon. Because the interface was designed to allow only one task performed at a time, the need for the scheduler was limited.

The scheduler uses three queues to store different tasks called the active, working, and system queues that contain current, available, and externally initiated tasks, respectively (Integrated Performance Modelling Environment User's Manuel, 1998). Based on the construction of the task-network, when new tasks arrive or an ongoing task finishes, a list of all tasks currently running is retrieved from the short-term memory queue and/or the queue for externally cued tasks (i.e., information in the environment). Externally cued tasks can be integrated as scenario events to represent interruptions, which can significantly affect the flow of activities in the task network models. Scenario events were used as interruptions in the form of an incoming phone call.

There are several rules that accompany the scheduler of tasks. For example, the short-term memory queue is limited to a number chosen by the analyst and tasks will be shed (discarded) if this limit is met. The order of task shedding will be determined from the priority placed on tasks as well as the task scheduling rule-base discussed previously.

In the event that tasks all have equal priority value, then a hierarchy is used to determine the order of shedding. This 'shedding' ultimately occurs in response to excessive task loading and limited resources. This can represent forgotten, unfinished, or errors in carrying out tasks, which are associated with inconsistent goal behavior and unprocessed information due to deficient strategies of decision making or limited resources. An embedded flagging system is provided by Integrated Performance Modelling Environment to track and analyze those types of occurrences.

Control Manipulations

There are several model parameters associated with cognitive control, which is defined as the ability to manage thoughts, recollections, and actions in accordance with task-relevant goals (Craik, 1986). Parameters can be set to affect the system either at the task level (individualized for each task or sub-task) or at a global level (across all tasks) that requires pre-defined value sets. The available mechanisms will be discussed next.

When Integrated Performance Modelling Environment is running in the Information Processing/Perceptual Control Theory mode, task performance modifiers are used to address workload. Task performance modifiers can be set at the global level or by defining a new expression at the local level. The Information Processing/Perceptual Control Theory model can incorporate a number of modifiers, including; adaptation to

time stress (speed/accuracy and visual detection), forgetting, task history, task priority, aptitude, experience, and non-preferred limb.

The scheduler parameters are comprised of six items, which are part of a set of general Information Processing/Perceptual Control Theory parameters that can be set at the global level. These include critical interference, time pressure (serial processing), time pressure (overload), critical percent complete, task restart penalty, and prospective memory size.

It is possible to define various parameter capacity levels. The analysts can define the number of prospective memory items that can be stored in its queue. As a default, prospective memory can store three to four items before task shedding occurs. Similarly, the number of items in short-term (working) memory can be limited. In addition, the working memory decay time can be defined independent of the number of items present in the queue. A final capacity that can be altered is the amount of tasks that can be performed concurrently. As a default, the Information Processing/Perceptual Control Theory only allows a maximum of two high level tasks to be performed in parallel, and all other tasks are performed serially.

Various components within the allocation of attention module to schedule tasks can be manipulated. These include: priority levels, time to complete tasks, schedule inertia, time pressure and the period of refractory duration following periods of high pressure. Each task can also be assigned success probabilities, interruptibility, and sheddability.

Part 1 – Development of AD INTERFACE 1

The objective of the first part of the study was to build a human performance model of human computer interaction that could predict the cognitive effects of mild-moderate AD on the ability to execute instrumental tasks of daily living as defined in the modeling tool that was programmed. To begin the modeling process, a scenario was formulated based on research and literature reviewed in two areas of study: 1) computer-aiding devices for use by individuals with AD-related cognitive deficits and 2) prospective memory. Based on the scenario and tasks chosen to model, a task analyses was conducted that was later used to construct the task networks, forming the foundation of the Integrated Performance Modelling Environment modeling simulations.

Model Development

The model included representations of multiple cognitive processes and task structures relevant to computer interaction and complexity. A symbolic representation of the components modeled is illustrated in Figure 3a, along with a pictorial representation of the system configuration in Figure 3b. The interface designs were not physically generated; rather, applicable characteristics, traits, and attributes of the interface were computationally represented using the task network of the Integrated Performance Modelling Environment software and cognitive models. The amount and content of the information presented on each screen were critical to the modeling effort, whereas the color, picture quality, and screen layout were not within the scope of the study. The computer system was proposed to offer three task choices including the primary task of

Figure 3a. Symbolic Cognitive Model Representing Alzheimer's Disease.

Figure 3b. Pictorial Representation of System Configuration.

taking medication and the two secondary tasks of making a telephone call and using electronic mail. They were presented on the screen as touch-sensitive, labeled icons that were 1x1 inch squares. The information that was presented on the computer screen as a result of pressing one of the icons was task dependent.

Model Scenario

The interface was designed to allow only one task to be performed at any given time. This decision was based on research involving dual-task performance and task performance in naturalistic settings. The literature suggested that individuals with AD, even in the mild-moderate stages, had difficulty performing more than one task at a time. When individuals with AD divided their attention between two or more tasks, their performance suffered (Morris, 1994). Moreover, patients in the mild-moderate stages of AD were reported interested in initiating daily tasks of living, but were unable to maintain intentions and were easily distracted by competing stimulus in their environment (Lucero et al., 2001). Therefore, although patients were willing to attempt to perform tasks on their own, they required guidance or continued direction from caregivers in order to continue or complete those tasks.

Although the interface was designed to allow only one task be available at a time, this did not mean that it was designed to provide only one task choice. Three different task options were represented in the interface design, including taking medication, making a phone call, and accessing and replying to personal emails. As well, the represented interface facilitated the ability to answer phone calls via the computer. All options were selected by pressing icons that were labeled with their associated task

function. Therefore, the initial screen a patient saw was a set of labeled icons from which they could choose. This choice in interface design was supported by a study that reported that patients with AD taking part in Montessori-based activities exhibited greater amounts of constructive engagement and also elicited less passive engagement (Judge, Camp, & Orsulic-Jeras, 2000). Moreover, Riederer and Pieper (1998) suggested that the easiest form of human computer interaction for individuals with AD was through providing a choice of options. The touchscreen method of input for computer interaction was chosen due to the reduced number of procedural steps, as well as the demands on fine motor functions involved in interaction compared to using a mouse to point and click. Even the normal effects of aging had a negative impact on the basic pointing and selection requirements of simple mouse clicks in a study conducted by Worden, Walker, Bharat, and Hudson (1997) comparing healthy older and younger adults. Furthermore, a touch-screen approach was used and suggested to be effective in studies of computer-based prosthetics for AD (Cole & Dehdashti, 1998) and entertainment applications that facilitated interaction between individuals with AD and a computer using direct manipulation via touch screen (Riederer & Pieper, 1998). Only the medication task was examined in depth and used to collect performance measures.

Although software can potentially be designed to force a user to perform only one task at a time or only allow one task to be accessible at a time, it was not reasonable to assume that a computer user's external environment can be controlled and free from other stimuli. In fact, especially in the case of computer users with AD, it should be expected that other stimuli in the environment could potentially be disruptive or distracting, and

perhaps lead to disengagement from their primary task. Therefore, an interruption in the form of an incoming phone call was implemented in the Integrated Performance Modelling Environment model design to explore the resultant behavior and task sequences. The incoming phone call served two methodological goals, that of ecological validity and a measurable task of prospective memory.

The term ecological validity can have slightly different meanings in different research contexts. Here it is meant to suggest that an interruption was incorporated to make the study more applicable to the 'real world'. In other words, it is the extent to which the research is conducted under conditions that are in some way similar to the everyday life experiences of the participants and context under investigation. Therefore, some principles discovered can be generalizable and extended into practice.

Prospective memory was reported significantly impaired in individuals with AD as discussed in the review of literature. Again, prospective memory is the component of memory cognition that is responsible for remembering to carry out tasks in the future, following a delay. A typical paradigm used in prospective memory research is to provide the participants with a primary task and then instruct them to remember to perform another task in the future when the appropriate cue is presented. In Huppert and Beardsall's (1993) study of prospective memory and individuals with mild-moderate stages of AD, one of their prospective memory tasks was to remember to ask a specific question at the end of the experimental session. Participants in their study were given instructions at the commencement of the experimental session and then a delay followed that consisted of other memory and procedural tasks. The scenario for the modeling

effort is similar in the respect that the task of taking medication is initiated, but then is followed by a delay of answering a phone call followed by a conversation. Returning to the prospective memory task of taking medication depends on a number of factors defined in the model, which will be presented later. Next, a brief description of the medication task and the corresponding screen information is presented.

Medication Task

The model represented a targeted portion of the total process of the interaction with the computer to perform tasks: behavior after the user was engaged by the computer display up until the last sequence of the task was initiated to fulfill goal attainment. A cognitive and physical task analysis was completed for each of the four options provided by the computer device to guide the review of literature. From these analyses a pattern of cognitive components emerged that played the key role necessitating task completion. As most activities of daily living share many features, the activity of taking medication also has a specific goal, which is comprised of a set of discrete actions. Furthermore, the actions are normally performed in specific order and organized into sub-goals. Examination of individuals with AD performing activities of daily living using this task decomposition analysis method was successful in longitudinal work examining the use of non-verbal cues and the use of schemata by individuals with AD to aid in the recall of everyday routines (Rusted, Ratner, & Sheppard, 1995).

Goals, operators, methods, and selection rules comprised the GOMS task analytic technique, which was used to define the hierarchical and sequential relationships among tasks as well as timing predictions to actions performed (operators) in service of goals.

Figure 4 provides an example of task information for one task node, which is found at the lowest level of the task network hierarchical structure used in the human performance model. The task network structures and sequences defining the human performance model are presented in Appendix C and are discussed below.

The interface design was not physically operational; its procedural requirements were represented using the human performance model. The functionality and information conveyed through the interface design, along with the actions and behaviors of the computer user with mild-moderate AD, were conceptually and computationally driven. The following description of the task scenarios should be interpreted accordingly.

Using the GOMS task analysis method, the goal of taking medication was broken down into four main sub-goals: initiate medication task, acquire pills, administer pills, and confirm medication taken. To initiate the medication task, the medication icon was pressed. The result of pressing the icon was a screen with information regarding the medication and procedures, as well instructions to press the confirm icon, which was also included on the screen. When the reading was finished, the computer user followed the instructions to locate the pill dispenser. The dispenser was located beside the computer along with a bottle of water. The dispenser was pre-filled, had an automatic timer, and had an automatic lock so that extra pills could not be administered. It was also weight sensitive, which meant that a confirmation could not be made if pills were still in the dispenser.

Since the information and instructions were held in working memory, there was a chance that forgetting could occur. The time it took to locate the dispenser was

Figure 4. Task information dialogue box for one task node in the human performance model that contained timing information, executing constraints, effects of the task, and routing information. (Used with permission, Micro Analysis & Design, 2002)

sometimes too long for the computer user model to maintain the intention of taking pills. In those cases, attention would be placed back onto the computer screen where the information and instructions were read again. Once read again, the confirm icon was pressed depending on the chance of remembering that the pills were taken. If the not remembered, then the dispenser was checked again for pills. When the incoming call rang after the pills were retrieved, but before the confirmation was made (intermediate interrupt type), there was also a chance (50% arbitrarily chosen) that the pills were located beside the dispenser and then administered. When the pills were not located beside the dispenser in the intermediate interrupt type scenario, a false confirmation was ultimately recorded.

Task Network Diagram

As is appropriate in network models, a considerable amount of the model functionality came from the configuration of the task networks, especially from the parameters, descriptions, and decision routing of the tasks and subnetworks. Within the task network diagrams of the Integrated Performance Modelling Environment software, there are several parameters that describe each task. All task types were discrete (versus repeating or continuous); all tasks had normal (versus gamma or exponential) time distributions measured in seconds with mean time values, coupled with a standard deviation, to generate execution times as was depicted in Figure 4; and no micro models or task performance modifiers were called to calculate performance times. Each task node contained timing information, execution constraints, effects of the task, and routing information (see Appendix B for a sample of the types of cognitive and motor execution

times and timing information derived from related empirical studies). Collectively, task network parameters, descriptions, and decision logic formed the foundation of the model.

Decision Routing

Task network modeling offers many different ways of defining task flow, one of which is through decision nodes. Decision nodes occur whenever a task has more than one possible path emerging from it and can be set as simple or complex as required. Decision types are probabilistic (only one task follows), tactical (rule-based routing), or multiple (more than one task follows). Probabilistic and tactical decisions played a critical role with respect to incorporating cognitive deficits associated with mild-moderate AD. In particular, three components of memory were represented from the use of decision routing logic, including prospective memory, episodic memory, and working memory. In addition, there was also a learning effect implemented into the modeling functionality with the use of decision routing, coupled with values derived from the exponential decay rate defining working memory.

Prospective Memory

A decision routing point that represented the success or failure of prospective memory was applicable only if an incoming phone call had interrupted the medication task. Therefore, when there was no interruption there was no data collected on prospective memory. When the incoming phone call was ended, the computer screen went back to its initial state of displaying the three icons. The decision at that point was to choose what task to pick next. Based on prospective memory availability, the

simulated user would either remember that the medication task was still pending, and once again press the medication task icon, or one of the other two icons was pressed.

Based on research reported by Huppert and Beardsall (1993), prospective memory was given a probability function distributed among all three task choices. No patients in Huppert and Beardsall's study remembered to perform the prospective memory task assigned, but when given a cue, the prospective memory task was remembered 20% of the time. The distributions of probabilities for the model were chosen based on the Huppert and Beardsall study. Consideration was also given to the additional task icons for making a phone call or accessing electronic mail. Therefore, in the AD INTERFACE I model the medication task was assigned a probability of 40% compared to 30% for the other two tasks.

Episodic Memory

There were three separate decision points that represented the success or failure of episodic memory, which was the chance of remembering that the pills were taken. After the task of administering medication was complete, the task of pressing an icon was required to confirm that the medication was taken. For the confirm icon to be pressed, the information concerning the medication and confirm instructions was read no times, a second time, or a third time depending on working memory decay rate. Regardless of the number of times the instructions to confirm were read a decision was made as to whether the memory of taking the pills was available. Episodic memory retrieval was estimated for the three decision nodes representing episodic memory within the models' task networks. Values were derived from studies reporting memory recall of information

presented after delays of up to 30 seconds and 10 minutes (Batchelder, Chosak-Reiter, Shankle, & Dick, 1997; Dick et al., 1995; Hart et al., 1988; Larrabee, Youngjohn, Sudilovsky, & Crook, 1993; & Morris, 1994). The probability of successful episodic memory retrieval was 25% after initial read and 50% thereafter.

The placement of decision logic that represented a third episodic memory node was placed at the beginning of the medication task, which was only applicable if the incoming phone call had interrupted the medication task after the pills were taken. That decision probability was given a value of 10% for episodic memory success. Successful episodic memory at that point shortened the time to confirm considerably since the process of reading the medication information and instructions to confirm was skipped, as well as the process of checking the dispenser for pills. A Type II error was not incorporated into the scope of the model; and therefore, a decision was never made that represented a false episodic memory.

Working Memory

As indicated above, along with episodic memory success or failure, working memory decay rate also influenced the amount of times the medication information was read. That relationship reflected the need to re-read the information and instructions if that information was forgotten due to the time taken to complete intermittent tasks or actions (i.e., retrieving pills from dispenser, administering medication). In order to confirm that the pills were taken, a memory for the instructions to press the confirm icon, as well as the memory of taking the pills was necessary to fulfill task requirements.

The central executive systems of individuals with AD were reported to function inferiorly to age matched controls and healthy adults in numerous studies that investigated working memory span and capacity (Batchelder et al., 1997; Becker, 1992; Kluger et al., 1997; Kopelman, 1985; Reid, Broe, Creasey, Grayson, McCusker et al., 1996; Walker, Philbin, & Fisk, 1997). An exponential decay rate of working memory was formulated based on the research above, accounting for both the limited span and decay rate of working memory for mild-moderate AD. Figure 5 illustrates the working memory model used in the model functionality.

After items (i.e., information to be remembered) on a computer screen are initially presented and attended, their availability for recall is assumed to decline gradually (Card et al, 1983). The residual trace of items that were attended at a given point in time was determined by an exponential decay function:

$$WM_{i+t} = WM_i - ^{[(\ln 2)/H]} t$$

Where WM_{i+t} is the item's availability for recall t seconds after the initial point in time i that the items were attended. WM_i is the initial number of items presented on the computer screen to remember and H is the half-life for working memory decay.

The half-life calculated for working memory decay of an individual with mild-moderate AD was 1.5, 3.0, and 45.0 seconds for 1, 3, and 9 items to be remembered respectively. If the half-life time was exceeded before a confirmation was made, then the memory trace was unavailable; and thereby, forcing a looping function that re-initiated the task of reading the medication screen information and instructions. When the half-life was exceeded after reading the medication screen and before confirmation, then the

Figure 5. Proposed exponential decay rate of working memory for mild-moderate Alzheimer's disease as a function of items/chunks to be remembered that was implemented into the human performance model.

task of locating the dispenser to check for pills was re-initiated. The interface was designed to assure that there was no chance of skipping tasks or moving ahead of task sequence. This was implemented into the model structure by creating a looping back function. Therefore, there was no chance for critical tasks to be omitted. This looping function, which simulates the repetition of sub-tasks or actions, follows the findings of Rusted and colleagues (1995) who (in their study of individuals with AD making a cup of tea) described the repetition of sub-tasks as one of the most frequent hindrances to whole-task completion. Moreover, based on their longitudinal study of individuals with AD, the researchers suggested that the deficits in working memory and task planning appeared to be the primary source contributing to the incompleteness of goals or whole task completion.

Learning Effect

Learning is a relatively permanent change in behavior or knowledge, often characterized by the improvement in performance of a task that usually occurs in healthy individuals as a result of experience or practice. As with healthy adults, individuals with AD can also benefit from experience and practice (i.e., repeated representations of information and procedural repetition) however, their learning rate is much slower and limited compared to young adults and older adults (Batchelder et al., 1997; Dick, Young, Wright, & Hsieh, 1996; Eslinger & Damasio, 1986; Kopelman, 1985; Seifert, 2000). Therefore, the time it took to read the medication information and check for pills was programmed in the model to decrease as a function of repetitions. As well, the exponential decay of working memory decreased at a slower rate, due to a decreased number of items to be remembered. When the medication task was re-initiated after an

incoming phone call, the learning effect was refreshed, setting the repetition count at zero.

Assumptions – AD INTERFACE I

1. Individuals with mild-moderate AD are motivated to adhere to their medication regimen.
2. Individuals with mild-moderate AD are motivated to use a computer to perform tasks.
3. A computer interface can be designed to meet the perceptual needs and limitations of individuals with mild-moderate AD.
4. An incoming telephone call will act as an interruption, whereby an individual with AD would disengage from the primary task and answer the phone call.
5. Implicit procedural memory will not fail an individual with mild-moderate AD, i.e., individuals will not forget ‘how to’ place a pill in his or her mouth and take a drink of water.

Structural and Content Validation

There were two forms of model validation employed including (1) extreme values tests and (2) embedded tests. In addition, two experts in the field of computational human performance modeling conducted a review of the models. An extreme test is a procedure that was used in the modeling verification procedure, whereby values in different components of the models were set to exaggerated levels, either lower or higher than the intended values. The majority of the critical model-flow configuration was embedded in the decision logic (nodes) of the task networks. Therefore, segments of the

models were run and analyzed for both the tactical and probabilistic decision nodes used in the models. That procedure was repeated for each iteration of the modeling effort as a means of double-checking the logical flow of events.

The second (embedded) test used for model verification consisted of gathering variable values, which were collected during model construction and again with the dependent measures for each model run. Those variables were collected during each of the 800 model test runs to check for consistency and correspondence with dependent measures.

Dependent Measures

The performance measures indicated by the research hypothesis (task time, forgetting, task repetition, and task completion) were collected using six dependent variables. Two durations were collected from the medication task; time to take pills and time to confirmation. Both task times had a starting time equivalent to the commencement of the model runs. A forgetting performance measure was also collected by two dependent measures, prospective memory and episodic memory. The number of times the medication information/confirm instructions were read determined the count of task repetitions. Finally, the number of true confirmations reached (successful pill administration) represented task completion.

Qualitative Analysis

Procedures for gathering qualitative data included observing and recording performance during and after the model runs with the use of a task network trace, which provided task flow information, and snapshots that consisted of all the variable data

collected. Thus, unlike many traditional observational studies, highly trained coders were not needed to be present. The software provided a record of the user and system performance and facilitated a more vigilant and careful analysis that was reviewed by expert analysts.

The interruption of an incoming phone call, which was discussed earlier, formed an independent variable that consisted of four levels: 1) no interrupt, 2) early interrupt, 3) intermediate interrupt, and 4) late interrupt. Interrupt types corresponded to the task of taking pills and making a confirmation. An early interruption came before pills were even retrieved from the dispenser, an intermediate interruption came after the pills were retrieved from the dispenser but before the pills were administered, and a late interruption came after the pills were swallowed but before a confirmation was made. One hundred model runs were collected for each of the four interrupt types. The resultant behaviors associated with each interrupt type were unique and contributed to the redesign of AD INTERFACE I. Results and modifications based on the qualitative analysis are discussed below.

Results

After the model was run one hundred times for each of the four interrupt types (none, early, intermediate, and late), descriptive statistics were examined for the total (400 runs) and also for each interrupt type. Working memory decay appeared to have the greatest influence on the task flow. Each time attention shifted from the computer screen to the pill dispenser, and vice versa, maintaining information in working memory was challenged. Vulnerabilities in the system also emerged with respect to the time between

critical task elements (i.e., take pills and confirmation). Those vulnerabilities were due to memory limitations and accentuated by the incoming phone call interruptions. Figure 6 represents the descriptive statistics of the mean task time of pills taken and confirm for each interrupt type.

Interface Modifications

Several critical problems in the system were identified through the process of constructing task networks and scenario building procedures. As well, careful examination of the data output from the 400 model runs revealed vulnerabilities in the interface design and task procedures contingent of those design features. A major and recurring problem manifested as a result of limitations in short-term (working) memory. As a result, there were many modifications made to the interface design, which ultimately influenced the nature of the proposed task procedures and (simulated) desktop computer and dispenser software/hardware configuration. Modifications were made in the form of automated cueing and reminding techniques, procedural task changes, and informational source modifications.

Automated Cueing and Reminding

1. A cueing mechanism representing a visual and auditory stimulus (flashing light with an auditory signal/alarm) was incorporated into the dispenser representation so that attention was drawn to the dispenser more quickly and with less effort. This was intended to increase the chances of locating the dispenser after reading the medication information screen by aiding working memory.

Figure 6. Mean task time to take pills for none (SE = 5.06), early (SE = 136.86), intermediate (SE = 255.50), and late (SE = 5.10) and mean task time to confirm for none (SE = 5.81), early (SE = 136.93), intermediate (SE = 165.42), and late (SE = 147.14) interrupt types in the AD INTERFACE I model runs.

2. A similar cueing mechanism was incorporated to help draw attention to the medication icon after the completion of the interrupt task (incoming phone call). That was intended to aid (or replace) prospective memory remembering by taking notice of the medication icon and re-initiating that task.

3. The automation was defined to track task initiation and progress and gave reminders and/or helpful hints accordingly after periods of inactivity, as was the case when a timely confirmation was not made after pills were retrieved from dispenser.

4. Automation tracked periods of delays and provided helpful reminders and hints of task history. For example, in the intermediate interrupt type scenario, pills were retrieved from the dispenser but a confirmation was not made, so there is a chance that the pills were set aside, rather than swallowed, and a suggestion to check around the dispenser for pills was implemented to decrease the chance of making a false confirmation.

Procedural Task Changes

5. The confirmation task was moved from the computer screen interface to the dispenser interface. This change was implemented to decrease the time between taking the pills and confirming so that it was less likely that an interruption could interfere with that task process. In addition, it brought the visual cue of an empty dispenser in close proximity to the confirmation button when the memory of taking the pills was no longer available.

6. A change was made to the task procedure sequence for retrieving pills and administering pills in such a way that the pills were taken out of the dispenser after the bottle of water was grasped so that there would be fewer chances and/or less time for an interruption to cause the patient to set the pills aside after taking them out of the dispenser. An auditory instruction was also represented to remind the patient of the appropriate task sequence of picking up the water bottle before retrieving the pills from dispenser.

7. To increase the chances of taking the pills after the intermediate interrupt scenario, the dispenser tray was defined to be larger. This change afforded the patient with a surface to place the pills back onto if interrupted. In the case that the pills were set aside instead, the automation recognized the pills as not being replaced since the dispenser tray was weighted.

8. To decrease overall task times and to decrease the time between taking pills and making a confirmation in the intermediate and late interruption scenarios, the patient was instructed to bypass the task of reading the medication information again. Instead of repeating the reading task, instructions were given to check for the pills and then to make a confirmation accordingly.

Informational Source Modifications

9. Less information was presented on the medication screen that preceded the task of locating the pill dispenser to reduce the capacity requirements imposed on the working memory so that the exponential decay rate decreased.

10. The confirmation information/instructions were presented via the dispenser interface and removed from the medication screen to eliminate the need to hold that confirmation information in working memory and bring that information in closer proximity to the task of taking the pills and the confirmation task.

11. Confirmation instructions were added as auditory and visual information sources presented after retrieving pills from the dispenser to help remind the patient of the next task and help maintain attention and intention on that task.

12. To support procedural task sequences, auditory and visual instructions was added to keep attention on task and support procedural memory requirements.

Assumptions – AD INTERFACE II

1. Individuals with AD can listen to automated instructions, hints, and cues while at the same time performing procedural tasks.
2. A flashing and auditory cue will draw individuals with AD's attention faster than the absence of a cue.
3. Individuals with AD will not mind, or not lose motivation, if less information is provided on the medication information screen.
4. Individuals with AD will be able to learn and remember some task procedures.

Part 2 – Evaluation of AD INTERFACE II

To investigate the effects of the modified interface design on task and cognitive performance, several hypotheses were tested in response to the research hypothesis: the computer-based cognitive prosthetic will improve user interaction so time on tasks

decrease, forgetting decreases, repetition of tasks decrease, and completion of tasks increase as represented in the computational simulation of human performance.

Experimental Design

The independent variable tested was interface design, which had two levels (AD INTERFACE I & AD INTERFACE II). The models were run with and without scenario events (interrupt types). One hundred runs for each model had no interruption, an early interruption, an intermediate interruption, and a late interruption. Interrupt type was treated as a related independent variable and was analyzed descriptively. Five dependent variables, including (1) time to take pills, (2) episodic memory failure, (3) prospective memory failure, (4) frequency of reading task, and (5) true confirmation were examined using statistical tests. A sixth related variable that was statistically tested was time to confirm.

Overall, 400 model simulations were run for each interface design using a Monte Carlo technique. Every run represented a different 'simulated' participant for a between subjects design. For descriptive analyses, an equal number (200) of simulations were run for each interrupt type. Table 2 represents the test matrix used for the analysis of 800 model runs.

Analysis of Data

Since multiple hypotheses tests were conducted within the study, the Bonferroni (1986) adjustment was used to compute alpha level. This was done by dividing the overall alpha level of .10 (suggested for exploratory research) by the total number of statistical tests performed. As a result, an adjusted alpha level of .02 was assigned to

each of the 6 tests carried out. The Statistical Package for the Social Sciences® 10.0 for Windows® (SPSS) was used for all statistical analyses. A two-tailed t test was planned for each of the time-related performance measures and chi-squares were planned for the frequency data.

Table 2

Experimental design depicting number of model runs for each interface design and interrupt type used for descriptive and statistical analysis.

Interrupt Type	Interface Design	
	AD INTERFACE I	AD INTERFACE II
Model Runs		
None	100	100
Early	100	100
Intermediate	100	100
Late	100	100

CHAPTER 4

Results

The output from Integrated Performance Modelling Environment was used to evaluate the impact of the modified interface design on task performance and the underlying cognitive mechanisms modeled to influence performance. All model simulation runs were used in the statistical analyses; 400 were recorded from AD INTERFACED I and 400 from AD INTERFACE II. Each of the 800 simulation runs represented a different individual with mild-moderate AD (simulated participants) for the purposes of statistical testing. Parametric assumptions of the t test were not met. Specifically, the samples were not normally distributed (tested qualitatively using a histogram) and they did not have equal variances (tested by dividing lowest and highest standard deviations). Therefore, the planned t tests were substituted with the Mann-Whitney U, a non-parametric statistical test.

Research Hypothesis: The computer-aiding device will improve user interaction so time on tasks decrease, forgetting decreases, repetition of tasks decrease, and completion of tasks increase as represented in the computational simulation of human performance.

- 1) H_0 : There is no statistical significant difference in mean task time to take pills as a function of interface design.

A Mann-Whitney U was conducted comparing the mean ranks of time to take pills from each interface design simulation. A significant result was found ($U = 57082.00$, $p = .0001$) indicating that the time it took to take pills for each interface design was different.

The mean rank of 340.72 for the time to take pills with AD INTERFACE II was less than the mean rank of 395.29 for the time to take pills with AD INTERFACE I. This result indicates that time on task decreased with the use of AD INTERFACE II, which corresponded with the research hypothesis. Three percent of the variability of time to take pills could be explained by interface design and power for the test was .36.

2) Ho: Episodic memory is independent of interface design.

The proportion of episodic memory forgetting from AD INTERFACE I was .36 whereas the proportion of episodic memory forgetting recorded from AD INTERFACE II was .94. Figure 7 gives the proportion of episodic failure as a function of interface design. The pattern observed was significant, $\chi^2 (1, N = 200) = 73.93, p = .0001$. The strength of the relationship was moderate ($\Phi = .61$). The proportion of variability (37%) in episodic memory explained by interface design was poor. The null hypothesis was rejected but the direction of the relationship was contrary to the research hypothesis.

3) Ho: Prospective memory is independent of interface design.

The proportion of prospective memory forgetting from AD INTERFACE II was .19 whereas the proportion of prospective memory forgetting recorded from AD INTERFACE I was .61. Figure 8 depicts the proportion of prospective memory failure as a function of interface design. The pattern observed was significant, $\chi^2 (1, N = 600) = 113.78, p = .0001$. The strength of the relationship was moderate ($\Phi = .44$). Nineteen percent of the variability in prospective memory was explained by interface design.

4) Ho: Task repetition is independent of interface design.

Figure 7. Proportion of episodic failure as a function of interface design. Episodic memory failure represented the chance of the computer user with AD to forget that their pills had already been taken, which was only a possibility in the late interrupt type when a confirmation was not yet made after taking pills. In this case, the null hypothesis was rejected but the direction of the relationship was contrary to the research hypothesis.

Figure 8. Proportion of Prospective Memory Failure as a Function of Interface Design.

Prospective memory failure represented the chance of the computer user with AD to remember to reinitiate the medication task after the interruption of an incoming phone call. Therefore, prospective memory measures were not collected for the model runs that had no interruption from an incoming phone.

A chi-square test was conducted to test if task repetition was in fact independent of interface design. Table 3 represents the observed frequencies for AD INTERFACE I and II. The pattern observed was significant, $\chi^2 (1, N = 800) = 633.43$, $p = .0001$. With AD INTERFACE I, 84% of the time medication information was read 2-5 more times after an initial read. Whereas, 94% of the time the task was repeated one time at the most with AD INTERFACE II. The strength of the relationship was strong ($\Phi = .79$) and the coefficient of determination of 62% indicated that a good proportion of variability of task repetition was explained by interface design.

5) H_0 : Task completion is independent of interface design.

The proportion of task completion for AD INTERFACE II was .80 whereas the proportion of task completion recorded from AD INTERFACE I was only .53 as illustrated in Figure 9. The pattern observed was significant, $\chi^2 (1, N = 200) = 16.36$, $p = .0001$. The strength of the relationship was low ($\Phi = .29$) and 8% of the variability in task completion was explained by interface design.

6) H_0 : There is no statistical significant difference in mean task time to confirm as a function of interface design.

Since the data from both sets of model runs were not normally distributed, a Mann-Whitney U was conducted comparing the mean ranks of time to confirm from each interface design simulation. The mean rank of 309.60 for the time to confirm with the AD INTERFACE II was less than the mean rank of 491.40 for the time to confirm with AD INTERFACE I as can be seen in Figure 10. As hypothesized, the time it took to take pills for AD INTERFACE II tended to take significantly less time than AD INTERFACE

Table 3

Repetition Frequency for the Task of Reading Medication Information as a Function of Interface Design.

	Repetitions						Total
	0	1	2	3	4	5	
AD INTERFACE	Frequency						
I	0	30	120	134	83	33	400
II	294	84	18	4	0	0	400

Figure.9. Proportion of True Confirmations as a Function of Interface Design. The dependent measure, completion of tasks, was collected using the frequency of confirmations made after the pills had been swallowed. True confirmations were only collected for those model runs where the incoming phone call interrupted the computer user with AD after the pills were retrieved out of the medication dispenser but before they were swallowed (intermediate interrupt).

Figure 10. Median task time to take pills for AD INTERFACE I and AD INTERFACE II as a function of interrupt type.

$I, U = 43638.00, p = .0001$. Twelve percent of the variability in time to confirm was explained by interface design and power for the test was .78.

Descriptive statistics of measures of central tendency and measures of dispersion for the time to take pills for each interrupt type appeared to suggest that there was an improvement in task time from the original to the modified interface design. The most pronounced differences were observed in the early and intermediate interrupt types, which are illustrated in Figure 11. Further examination of measures of central tendency and dispersion of confirm times for each interrupt type appeared to suggest that there was also an improvement in task time from the original to modified interface design. However, the marked differences were observed in all interrupt types. The median times to take pills and to confirm for no interrupt, early, intermediate, and late with AD INTERFACE I AND II are presented in Table 4.

Overall, the null hypotheses were rejected for all six hypotheses tests. The following discussion will evaluate the outcomes of the hypotheses tests completed and discuss the implications of these findings with regard to changes made to AD INTERFACE I toward the goal of creating an effective computer-based cognitive prosthetic. According to the research hypothesis predictions, AD INTERFACE II would improve user interaction so that; time on tasks decrease, forgetting decreases, repetition of tasks decrease, and completion of tasks increase as represented in the human performance models. The first hypothesis test was performed to see if interface design affected the time to take pills. This test was the first of two that was conducted to explore the research confirm as a function of interface design.

Time to take pills was defined as the duration of time between the initiation of the

Figure 11. Median task time to confirm for AD INTERFACE I and AD INTERFACE II as a function of interrupt type.

Table 4

Median times to take pills and median times to confirm for none, early, intermediate, and late incoming phone call interruptions with AD INTERFACE I and AD INTERFACE II.

	<u>Take Pills</u>		<u>Confirm</u>	
	<u>Median (sec)</u>	<u>95% CI (sec)</u>	<u>Median (sec)</u>	<u>95% CI (sec)</u>
AD INTERFACE I				
<u>Interrupt Type</u>				
<u>None</u>	204.59	192.13 -- 217.06	322.21	307.90 -- 336.51
<u>Early</u>	1396.14	1059.15 -- 1733.12	1533.79	1196.62 -- 1870.96
<u>Intermediate</u>	1854.35	1222.38 -- 2486.32	1830.55	1423.23 -- 2237.87
<u>Late</u>	224.84	212.27 -- 237.40	1756.86	1394.55 -- 2119.16
AD INTERFACE II				
<u>Interrupt Type</u>				
<u>None</u>	171.51	162.23 -- 180.80	187.57	178.39 -- 196.76
<u>Early</u>	884.75	791.27 -- 978.24	900.76	807.33 -- 994.19
<u>Intermediate</u>	949.24	661.14 -- 1237.34	921.98	642.41 -- 1201.55
<u>Late</u>	172.04	161.33 -- 182.76	864.46	790.38 -- 938.54

task to take meds (Start_Meds_Task) and the point in time when the task of swallowing pills (Drink) was completed. The time to confirm had the same start time, but its time was calculated with an end point embedded in the task of pressing confirm on the computer screen (Press_confirm_icon). Accordingly, the task of taking pills would always precede the task to confirm. The only exception to this relationship was in the event that the pills were not successfully taken. If that were the case, then a confirmation was recorded as a false confirmation and marked as an uncompleted task (true confirm = 0); and therefore, time to take pills for that model run was left uncalculated.

There were several critical variables defining the interface design that affected the measure of time to take pills, namely prospective memory success, task repetition, the influence of automation and task flow, and the timing of an incoming call (interrupt). The influence of prospective memory was relatively straight forward, since its success rate was based on a probability decision type. For AD INTERFACE I, the probability of returning to the task of taking medication after an interruption was only 40% compared to an 80% for AD INTERFACE II. The change in probability values from AD INTERFACE I to II represented an automated reminder in the form of a flashing medication icon. There were still other pieces of information on the computer screen (i.e., icons) that were still available as an option to press. As such, the remaining probability was divided into the other available tasks of making a telephone call or using electronic mail. Since there was a better chance of avoiding the other tasks in AD INTERFACE II, there was a better chance of going back to the medication task

immediately following the interrupt task of answering a phone call. The sooner the medication task was initiated again, the quicker the task of taking pills was completed.

The frequency of repeated tasks also played a role in the time to take pills when those repeated tasks occurred prior to administering the pills. AD INTERFACE II influenced that change in frequency in a couple ways. First, the amount of medication information was reduced in AD INTERFACE II so as to slow down the working memory decay rate of the model. The reduction in pieces of information (to be remembered) was intended to reflect a filtering of essential information that a patient would need to take his or her medication. The filtering of information included the extraction of the information to confirm after taking pills, since the confirmation icon was removed from the computer interface design and added to the dispenser interface/functionality.

Second, when the interrupt type was intermediate or late, that created a situation in which the administration of pills was initiated (pills taken out of the dispenser) but a confirmation was not made. As a result, it was assumed that the patient either put the pills back into the dispenser to take later or arbitrarily put them down. The modified interface design skipped the task of reading medication information and initiated a check for pills that may have been placed near the dispenser, after the interrupt of the incoming call. The change in task flow was due to an auditory message informing the patient that the administration task had been initiated and instructing the patient to check that the pills had already been taken by looking around the dispenser.

In the scenario when the interrupt type was late, the pills were already taken but a confirmation was not made. Therefore, there was a small chance (5%) in AD

INTERFACE II for the patient to remember (episodic memory) that he or she had already taken the pills and skip directly to pressing the confirm button. As a result, no repetition of reading medication information or checking for pills was made. A brief discussion will follow to offer an explanation as to why the episodic memory component of forgetting was greater for the initial interface design model, a result that was opposite to the prediction made in the research hypothesis.

There were more opportunities in AD INTERFACE I for episodic memory to be checked, since two of the three decision points that represented episodic memory came after the task of checking the dispenser for pills. As well, the probability in the first episodic memory decision point was slightly greater in AD INTERFACE I (10%) compared to AD INTERFACE II as indicated earlier. That change was incorporated to capture the new automation in AD INTERFACE II that was implemented to remind and inform the patient of prior actions and consequently, influenced the decision so as to not rely on a limited cognitive function. Therefore, forgetting as defined from the episodic memory failure was greater in AD INTERFACE II, but only because AD INTERFACE II intended to force a patient to rely less on limited episodic storage and retrieval capacity.

The percent of time a true confirmation was made was found dependent on interface design. While running the intermediate interrupt type, it was assumed in AD INTERFACE I that the patient would put the pills down somewhere other than back inside the dispenser tray before answering the incoming phone call. After the medication task was re-started and the task of locating the dispenser was released, there was a 50 % chance that the pills were identified on the table. If not, the task of checking the

dispenser for pills was triggered, which eventually ended with a false confirmation since no pills were found in the dispenser. The chance that the pills were identified on the table remained the same in AD INTERFACE II; however, the chance that the pills were put back on the table was only 50 % compared to 100% in AD INTERFACE I. False confirmations were only made when the pills were not placed back in the dispenser, and since there was a 50% chance in AD INTERFACE II that the pills were placed back in the dispenser, the number of true confirmations increased in AD INTERFACE II as well.

CHAPTER 5

Discussion

The iterative process of computational modeling forced a comprehensive examination of the phenomenon of human (with AD) and system behavior. Based on the literature, there were many general recommendations suggesting ways to structure the environment (e.g., interface design) to better meet the needs of an individual with AD. Those recommendations are presented as they related to the research findings, as well as more specific guidelines discovered from the methods used to design and analyze the computer-based cognitive prosthetic proposed from this research. Other implications such as training and economical considerations are discussed as they were revealed from the modeling process.

Guidelines

Based on the literature, several considerations were recommended including (1) avoid divided attention or attentional switching tasks; (2) avoid tasks that require the maintenance of information in short-term memory, including tasks that force users to keep track of intermediate results (mental multiplication/active processing); (3) avoid tasks that require pacing, temporal judgment, or accuracy demands. When these types of design attributes are unavoidable, then assistive techniques for compensating for cognitive deficits must be implemented. Techniques might include adding critical information (cues/reminders) or removing unnecessary (distracting) information. As well, a decision-making component might be needed for tasks that involve several sub-tasks or lengthy sequences. A decision making component might also be useful to

provide flexibility in task execution, such as when a task is interrupted or when the system requires more than one task to be performed concurrently.

The extent to which performance on procedural tasks require some explicit recall of the procedure may determine an individual's overall capacity to carry the task to completion. Interruptions and repetitions may represent an inability to explicitly recall how much of the task was already completed. Prospective memory situations are multidimensional and involve several qualitative memory components. By using strategic cueing techniques, time-based tasks could essentially be turned into event-based tasks and a study that demonstrated this transformation reported that there was less forgetting as a result (Sellen, Louie, Harris, & Wilkins, 1996). Therefore, environments that encourage greater reliance on recognition strategies should be implemented. These strategies would replace more cognitively demanding tasks where patients needed to remember in the future through implicit means.

The demands of the explicit aspects of the medication task are considerable since individuals with mild-moderate AD may have extreme difficulty in explicit recall of facts and short-term memory for facts just recalled may be very brief. When examining the medication task, it is apparent that these types of demands will be placed on recent episodic memory recall and working memory when the individual must read the instructions for taking the pills and then shifting attention away from the computer screen while administering the medication. As well, the step of confirming that the pills have, in fact, been successfully administered places a considerable demand on the individual's recall as well as working memory. In fact, confirmation entails two demanding aspects.

The first, as already discussed above, is the need to remember that the pills were been taken and this is often after the individual shifts their attention back to the computer screen and reads the instructions to press the confirm button. The other lends itself to an error commonly known as a post-completion error. This type of error seems to occur when people have an extra step to perform in a procedure after the main goal has been accomplished. Byrne and Bovair (1997) reported that these types of errors in the execution of an otherwise routine procedure might be best explained by considering the working memory load at the time the step was to be performed. Since an AD patient has a limited working memory capacity and an accelerated decay rate (central executive system related deficit) it seems plausible that they would have higher error rates for these types of errors i.e., confirming that medication was taken.

Because of the reported findings of preserved motor skill and learning (procedural/implicit memory), interventions which emphasize practice and use of specific movement patterns -in conjunction with directions and cueing- may be most successful in reducing functional deficits. Steps should be taken to support proper task sequencing. An individual might keep repeating sub-tasks within the larger task, because of inability to explicitly recall that the sub-task had been completed. Therefore, automation must provide the explicit remembering and planning components of an activity.

Until a particular scenario and activity is studied in depth, it is difficult to apply guidelines offered by the literature to an interface design. For instance, one of the modifications made to the initial model involved changing some task sequences that preceded medication administration so that critical task actions were moved as close

together as possible so as to avoid disruptions from interruptions. In a human factors study of flight-deck checklists, a similar consideration was proposed by Degani and Wiener (1990), whereby they suggested that the most critical items on the task-checklist should be listed as close as possible in order to increase the likelihood of completing the task before interruptions could occur.

The changes were made after recognizing vulnerability in the system, specifically the time duration between when the pills were retrieved from the dispenser to the time that the water bottle was picked up and a drink was taken to swallow the pills. The significance of this was appreciated after considering the consequences of interruptions (incoming phone call) during this time duration. Specifically, if an incoming phone call interrupted an individual after retrieving the pills out of the dispenser, but before the pills were swallowed, then the pills could potentially be set aside and not found after the medication task was re-initiated. Therefore, the task sequence was changed so that the pills were not retrieved from the dispenser until the bottle of water was picked up, leaving a very small time frame for an interruption to disrupt the task of taking the pills.

Training Considerations

One group of modifications made to the initial model involved changing task procedures with the assumption being that individuals with mild-moderate AD can learn motor and procedural skills. Therefore, training would be necessary to acquire the necessary skills involved to use the proposed cognitive prosthetic. Training was presumed to affect two aspects of performance (1) to decrease time on task so that there was a better chance for information to be available in working memory and for attention

to be maintained on the appropriate task and (2) to carryout tasks in a particular sequence that was better suited to avoid vulnerabilities in the system and account for potential interruptions. Although, based on the literature reviewed, the assumption was made that AD does not completely interfere with implicit motor and procedural learning, it was not assumed that learning would be free from errors. Therefore, new automation consisting of helpful guidance or hints was incorporated into the design to support the procedural sequence of task performance.

Economic Considerations

As a result of the modifications implemented to create AD INTERFACE II, the design of the medication dispenser had to change accordingly. By adding to, or changing the device's functionality and interface requirements, there would presumably be associated monetary costs. Since the changes were conceptual model-based changes, the costs associated are minimal compared to the physical reconfiguration and rewiring that would be necessary for an actual interface design. The financial implication of the changes made could be assessed from the data collected from each interface design. For instance, one of the results of moving the confirmation button to the dispenser was that the time between taking pills and making a confirmation appeared to considerably decrease, creating less of a chance of forgetting to confirm. The repercussions associated with failing to confirm would be that family members, caregivers, or doctors would be automatically contacted to notify them that a patient's pills might not be taken. Responding to this type of alarm, which could possibly be a false alarm, represents a

failure in the system that would result in considerable time and money lost. In addition, trust in the system might be diminished after a few 'false' alarms.

Conclusions

Computer-based cognitive prosthetics have been used successfully to compensate for the cognitive deficits associated with AD so that individuals affected by the disease could carry out some instrumental activities of daily living. The challenge is finding an efficient method of designing computer interfaces and systems to meet the needs of a population affected by this disease. At present, the time and costs associated with globally implementing computer aiding devices in homes are overwhelming, not to mention the difficulty with gathering a group of individuals with AD and conducting tests over any length of time. However, if the implementation of computer support were possible, then it could decrease the need for 24 hour caregiving in homes and/or the need for institutionalization, which is already extremely limited. Moreover, assistive technology could increase the self-sufficiency of this population while improving their quality of life, as well as the lives of their family members and caregivers.

The use of a human performance modeling tool is one method that overcomes many of the challenges associated with the implementation of assistive technology. A computational model avoids the initial need to build an operational computer system, as well as the need to use human participants. In addition to these benefits, evaluations, modifications, and testing of computer aids can be made without substantial losses in time and resources.

Recommendations for Future Research

The next desirable step in the developmental process would be to work towards the validation and verification of the human performance model and interface design considerations. This would foreseeable involve the active participation of a subject matter expert(s) in the field of occupational therapy, specializing in the care and treatment of individuals with Alzheimer's disease. Further recommendations for future research would be to add more internal and external complexity to the system model. The external complexity could be derived from additional variability or disruption in the environment in which a computer-aiding device is used. Internal complexity of the model can be improved with additional cognitive models, including a more elaborate attentional model. In addition, secondary tasks could be defined and measured more comprehensively.

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Appendix A

An overview of the performance declines observed in mild and moderate stages of AD related to activities of daily living (ADL's) and instrumental activities of daily living (IADL's), cognition, and the common problems associated with both.

Mild ADL/IADL Changes

- communication suffers due to deficits in vocabulary and word fluency
- impairment in object naming
- spatial disorientation
- some difficulty with time relationships and geographical orientation
- more difficult chores, hobbies, and interests abandoned

Mild Cognitive Changes

- recent events are forgotten
- reduced ability to plan, judge, and organize complex tasks
- attention is poor, concentrating is difficult

Mild Stage Common Problems

- may be some dysfunction in IADL
- may forget how to get home
- work and reading start to suffer
- driving becomes dangerous
- often aware but in denial

Moderate ADL/IADL Changes

- hesitant to initiate actions
- language difficulties are more prominent
- reading and comprehension start to decline
- more mistakes and omissions in writing
- face recognition declines
- household chores and finances can not be managed

Moderate Cognitive Changes

- severe impairment in recent memory
- inattentive, disorganized, and less effective problem-solving

Moderate Stage Common Problems

- travel becomes extremely difficult
- unable to handle finances

- need help dressing & choosing clothes
- recall of phone number, address, and family member's names difficult
- often want to stay close to home
- strain on family/caregivers increases

Appendix B

Sample of the types of cognitive and motor execution times and timing information derived from related empirical studies used in the Micro Saint Human Operator Simulator, Integrated Performance Modelling Environment software to generate execution times for modeled tasks.

	HUMAN FUNCTIONS	EMPIRICAL RESEARCH
Motor	Execution Times	Walker, Philbin, & Fisk, 1997 Dick, Young, Wright, & Hsieh, 1996
	Movement Times	Ott, Elias, & Lannon, 1993 Dick, Young, Wright, & Hsieh, 1996 Elble & Leffler, 2000 Worden, Walker, Bharat, & Hudson, 1997
Cognitive	Reaction Times	Walker, Philbin, & Fisk, 1997 Becker, 1988 Reid et al., 1996 Elble & Leffler, 2000
	Initiation Times	Walker, Philbin, & Fisk, 1997 Dick, Young, Wright, & Hsieh, 1996
	Verification Times	Walker, Philbin, & Fisk, 1997

Appendix C

Task network diagrams used in the human performance model.

Starting Point:
AD Interface I & II

Medication Task:
AD Interface I & II

Initiate Medication Task:
AD Interface I

Initiate Medication Task:
AD Interface II

Acquire Medication: AD Interface I

Acquire Medication:
AD Interface II

Administer Medication:
AD Interface I

Administer Medication: AD Interface II

Confirmation:
AD Interface I

Confirmation:
AD Interface II

Incoming Phone Call: AD Interface I & II