

DESIGN PARAMETERS AND OUTCOMES FOR COGNITIVE PROSTHETIC SOFTWARE WITH BRAIN INJURY PATIENTS

Elliot Cole Ph.D.¹, Parto Dehdashti, Ph.D.¹, Linda Petti, Ph.D.¹, Marlene Angert, Ed.D.²

¹Institute for Cognitive Prosthetics, Bala Cynwyd PA
²Moss Rehabilitation Hospital, Philadelphia PA

Abstract

Three traumatic brain injury patients achieved a significant increase in level of function in a relatively short period of time using highly customized computer-based cognitive prosthetic software. Study objectives involved determining the kinds of interface and application design parameters and requirements for prosthetic software with brain injury patients. ^p Research subjects were between 1 and 5 years post injury. Increases in level of functioning were seen both in everyday activities targeted for the intervention as well as generalized increase neurobehavioral and psychological dimensions.

Introduction

Enduring cognitive deficits from traumatic brain injury interfere with people's ability to return to pre-morbid functioning, and have been remarkably resistant to remediation by manual systems. The rehabilitation of higher level cognitive functioning using computer-based technology has received considerable attention, and applied a variety of approaches (Kirsch, Simon, & Horstmann, 1992; Vanderheiden, 1992; Gunderson, 1991; Prevey et al., 1991; Henry & Friedman, 1989; Steele et al., 1989; and Kirsch & Levine et al, 1988). Our previous work (Cole and Dehdashti, 1992, 1991, 1990a, 1990b) has shown that brain injury survivors with residual cognitive disabilities have achieved a higher level of functioning with extensively customized computer software as an assistive device. Performance is enhanced when the patient can gain access to their abilities, and at the same time, have the computer be a bridge over the deficits; all this within the context of the patient's life situations.

Research Objectives

The principal goal of this study was to develop an understanding of interface and application features which are modified in the customization process and thus contribute to successful cognitive prosthetic software. The goal was approached through two major objectives. First is to identify the software features which need to be manipulated as part of an authoring system for therapists working with brain injury patients. The second is to track changes in level of functioning in cognitive areas of patients who are using prosthetic software. Both interface and application functionality -- which need previous research has shown that highly customized software lead to increases in patient functioning. This study explores the kinds of features which are customized in designing successful prostheses. The outcome of the study can be applied to design authoring systems which can be used to highly customize systems for brain injury patients. Specifically, the study explores the kinds of interface features and application features which are modified over a 2 month period in prosthetic software interventions.

Methods

The study design is a quasi-experiment single-subject study with three subjects, each as a replicate; each subject is able to act as its own control. The study population were outpatients with a diagnosis of traumatic brain injury and who were at least 1 year post injury. In addition, conventional techniques needed to have failed to remediate a functional problem which could be a candidate for this study.

The study design called for 1 *intervention to last* approximately 6 weeks, with the hope that measurable progress toward the intervention goal might be achieved *in* that time. When intervention goals were fully achieved earlier than anticipated, the design was expanded to add an *intervention* goal when one was achieved.

To make the study population more homogeneous, it was decided to specify that the intervention consist of "daily schedule" or "To Do List" software. However it was recognized that additional software modules may be needed, depending on the needs of the patient.

Subjects were recruited from the outpatient population of a research oriented rehabilitation hospital. Therapists evaluated their patients on six items, including failure of traditional compensatory strategies to achieve restoration of function for specific activities, and likelihood that an increase in level of functioning could be achieved using software with scheduling or "to do List" features (without doing detailed design of the therapeutic prosthetic intervention). The three patients with the highest scores were offered participation in the study, and accepted informed consent.

The general problems for a patient was analyzed in depth. This involved a review of rehabilitation efforts, and a visit to the patient's home to collect additional data on methods which were being used to attempt to deal with the rehabilitation problem. A review was then conducted to try to understand the nature of the failure and to define the intervention goal. An initial intervention design was developed jointly with computer scientists and cognitive remediation therapists. The design was then presented as a series of components to the subject in design and testing sessions. An error-free design approach was taken, and redesign continued until the subject was able to understand how to use the prosthetic software. All of the subjects played a significant role in the redesign of their software. Two of the subjects became the primary designer of their initial system. After each of the modules had been tested, redesigned where necessary, and accepted, the system was integrated and patients trained in the rehabilitation suite.

At this point the system was delivered to the subject. Two of the subjects were given desktop computers which were installed along with dedicated phone lines in their home; the third subject was given a portable "notebook" computer. All computers were equipped with 386SX processors, 2 Mb RAM, a 40Mb hard disk, a VGA color monitor, and a 2400 baud modem. Printers were issued when appropriate; all three systems had printers by the end of the study. All computers used MS-DOS 5.01 and, when appropriate, the DESQview multi-tasking environment.

Extensive data was collected on interface and functional changes and the role of the individual who initiated the change. System logs provided extensive data on patient use. Clinical data included progress notes and the Saykin Neurobehavioral Inventory and ADL Scale.

Intervention Goals for Subjects

Prosthetic software was developed and customized to assist each subject in performing an everyday task which had been an unattained rehabilitation goal. Each subject had different deficits and different therapeutic goals that could be remediation

ted with portions of the same underlying application computer code and different interface designs. Each subject started with an initial rehabilitation goal, and then additional goals. The goals for each subject were:

Subject 1

Initial goal:

getting him to his activities on time; improve ability to work with concept of time; reducing impulsivity in attempting to perform a 2nd activity while performing the 1st; improve attention to detail (was determined through combining his notes in various places in the house, ...)

Goal 2:

enable communication between patient and therapist via computer

Subject 2

Initial goal:

to initiate an unsupervised activity in the home with cuing at a pre-set time daily; if possible, to initiate an unsupervised activity spontaneously during the day

Goal 2:

to follow a brief daily schedule of activities

Goal 3:

to provide a medium of scheduled, structured writing; to enhance reading activity and comprehension

Goal 4

to increase Subject's ability to make decisions; to follow increasingly complex sequence pattern.

Subject 3

Initial goal:

To set priorities in her daily activities, particularly errands; to provide memory support for activities and errands; to have a socially appropriate compensatory strategy; to have a compensatory strategy which she could use anytime, anywhere.

Goal 2

To support her ability to track and manage her work through providing organization and structure.

Development Effort / Functionality and User Interface

The research objective was to deliver a system to each subject that will satisfy critical needs and would require only minutes of training. The iterative nature of our approach required the delivery of multiple systems to ensure the success of the prosthesis. Over the course of 4 months 23 versions of the different systems were delivered to patients: to gradually increase functional enhancements, to improve interface, and to remove errors. The final applications delivered were: Daily Schedule, Daily To Do List, Priority List, Rolodex, Word Processor, Case Tracking, and External Activity Calls.

Functionality

The functionality of the systems delivered were defined by a collaborative effort. Day-to-day problems of the subjects were analyzed and translated into system functionality. In the original systems a set of 35 functions were delivered. As subjects used the systems, it was necessary to add or revise 50 other features. These features were partially shared among the subjects, with unique features of all the systems totalling 51.

Subjects one and two, who had more cognitive deficits

than subject three, were given minimum functionality for their initial systems. Later, subject two showed readiness for more functions; therefore a word processing application was provided with the capability to save and retrieve documents. Subject one, who has the same word processor was limited to using and saving one document at a time. Subject three, who was the highest functioning subject, initially required and was able to use the most number of features. In addition, a new application was added with a large pool of features.

One major change was made to subject one's system without first testing it with him. Although clinicians had requested a computerized weekly schedule for subject one, they decided against presenting it to him even though it matched his manual system. When clinicians saw the weekly schedule on the computer, they realized that the complexity of a weekly format, combined with manipulation on the computer, would be burdensome to the subject. Consequently, a daily schedule was designed.

The initial design of the subjects' systems as well as the overall design was based on clinicians' input. Because of their long-term relationships with the subjects, therapists are most familiar with their needs and appropriate uses of the systems. The subjects felt comfortable discussing their needs and requesting feature changes which better suited their needs.

To support all the delivered functions, an average of 7063 lines of code were written per subject's system. However, 51% of the average lines were shared among the three systems. An additional 5% was shared between S1 and S2's systems, and 3% shared between S1 and S3's systems. About 10,000 unique lines of code are needed to support the functionalities identified during this study.

In addition to the systems delivered to the subjects, we developed a system for clinicians. During the study, it became evident that there were some unique requirement of the therapists in providing treatment. In addition, there were some subtasks which were assigned to the therapists which could be better performed through a separate executable manipulating a common database.

Interface

Interface components were originally designed by ICP's interface designer with clinical input. Interface characteristics of all three systems changed before system delivery. During design session with clinicians and during testing with subjects, changes were identified and implemented in the delivered system. This was an iterative process, until clinicians considered the system appropriate for subjects' private use.

When this research was completed, a total of 304 interface components were specified for all three subjects. The first version delivered to subjects included a total of 254 interface specifications (84%). To design the initial systems, many decisions had to be made as to what components should be included and how they should be specified. A total of 91 unique interface components were identified as details of 24 unique objects. For example, for a menu object we specified details of menu colors, number of options in menus, and menu styles. Examples of other higher level objects were menus, sound, cursor, and commands. Each change to an interface component affected various lines of code in the underlying programs.

Throughout the study, 66% of these original components had to be changed one or more times during the study to better accommodate subjects. For example, the color of the appointment highlighter for subject one's To Do List changed from the original design and changed when editing was added. This was to draw his attention to the function at hand. The rest of the interface components (33%) were not changed during the study. For example, borders around boxes were determined at the onset to be single or double lines depending on their content. Neither the clinicians nor the subjects

requested them to be changed.

Participatory Design

Almost two thirds of the interface object changes were requested by either the patients or clinician. Almost three-quarters of the functionality was requested by the patients or clinicians. It is clear that at least some of the interface and functional changes would not have been suggested by those with systems expertise because those changes were either counter-intuitive or violated accepted guidelines. Also, the impact on both patient and therapist of the opportunity to have their ideas implemented cannot be understated.

Conclusion

While the main focus of this study is prosthesis/software design, the most important result of this study is in patient improvement. This study contributes to a literature which shows the impact of prosthetic software which is highly customized to individuals with disabilities due to cognitive deficits. Patients who showed minimal or slow recovery demonstrated an almost immediate increase in rehabilitation progress. Each subject demonstrated a generalized improvement in neurocognitive functioning even in the relatively short time of this study. Extended increases in level of functioning for cognitive deficits are considered difficult to achieve in brain injury patients. This improvement is in addition to the rapid increase in level of function for a targeted activity. The study design anticipated working on only a single goal (activity) for each subject; however the pace of patient progress was sufficiently rapid -- in the case of task initiation, merely 1 week -- that we took the opportunity to add another therapeutically appropriate goal when the previous one was achieved.

Part of the success of this study needs to be attributed to the flexibility imposed on the software environment. As detailed intervention planning took place, it became evident that achieving the intervention goal place, adding application functionality which was not part of the initial software library when the study began. This means that prosthesis design was driven more by patient needs than by software module inventory. The increasing availability of rapid prototyping tools, function libraries, and add-on boards allows the software development process to be more responsive to relatively inflexible user requirements often found in rehabilitation patients.

Finally, part of the success of this study needs to be attributed to the treatment team, which included patient, cognitive remediation therapist, and computer scientist. The intervention design was conducted in a highly participatory manner. Patients exhibited considerable insight into the design of their prosthetic software. Rapid prototyping tools allowed alternative designs to be tested and changed during a therapy session. The clinicians and the patients both felt empowered and enabled by the combination of the software technology coupled with the design approach.

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Author's Address

Dr. Elliot Cole
Institute for Cognitive Prosthetics
Bala Cynwyd PA 19004
(215)664-3585