Brain Injury and Cognitive Retraining: The Role of Computer Assisted Learning and Virtual Reality

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Abstract

Accident, infection, surgery, or stroke resulting in brain trauma can leave individuals with significant and pervasive cognitive disabilities. The need to increase functional recovery for these individuals challenges the combined knowledge, skills, and vision across disciplines including neuropsychology, rehabilitation psychology, occupational therapy, speech pathology, and computer science. This paper reports such interdisciplinary research to develop an approach to computer-assisted retraining that can support and encourage patients' own efforts to take charge of their lives again and rebuild their cognitive skills and thereby enhance their vocational and social opportunities. The Adaptable Learning Environment for Rehabilitation Training (ALERT) will track user performance levels, interest, preferences, and progress within an environment that uses Virtual Reality for life-skill simulations and activities to functionally model cognitive task domains. A single standardized assessment method is being designed to collect information about cognitive variables in the context of mediating and support variables. The functional developmental model of recovery upon which ALERT is based will use the ongoing assessment as it updates the patient user model within the intelligent tutoring system to guide the suggestions for treatment at each successive stage.

Introduction

Significant and pervasive disabilities can result from injury to the brain. It has been estimated that 7 to 8 million people suffer traumatic brain injury (TBI) each year in the United States alone (Bennett, Dittmar, & Ho, 1997). These individuals are often left with long-term deficits that can severely impact their vocational and social opportunities for the rest of their lives. Resources are limited for the cognitive retraining that could increase their functional recovery; thus, a challenge emerges to develop more effective computer software to support cognitive retraining by applying the combined knowledge and skills of researchers from several areas. This paper reports progress of a collaboration among neuropsychologists, rehabilitation specialists, occupational therapists, speech pathologists, educators and computer scientists to attempt to meet this challenge in the interests of TBI individuals, their families, their employers, and society as a whole.

Cognitive rehabilitation employs the application of a constellation of procedures by a practitioner, usually a neuropsychologist, occupational therapist, or speech pathologist, to facilitate development of skills and strategies needed to overcome cognitive deficits in persons with TBI (Diller & Gordon, 1981). The use of cognitive rehabilitation techniques dates back to the time of the ancient Greeks; however, it was not until after World War II that the potential of cognitive rehabilitation as an intervention for persons with head injuries was first proposed (Zangwill, 1947). Early research in cognitive rehabilitation primarily focused on the application of these procedures to individuals who had sustained cerebral vascular accidents (CVA) (Gordon, Hibbard, & Kreutzer, 1989). It was not until Ben-Yishay was called upon by the Israeli government to develop an outpatient rehabilitation program for soldiers with head injuries that cognitive rehabilitation was applied to this population (Gordon, et al., 1989).

Within a relatively short time, cognitive rehabilitation has become one of the fastest growing rehabilitation interventions provided to persons with head injuries. Gordon, et al, (1989) cite numerous reasons for the recent expansion in this field including the following: (a) an increase in public awareness of cognitive rehabilitation coupled with the greater number of individuals who survive TBI due to advances in medical technology; (b) the establishment of the efficacy of cognitive remediation for individuals who have sustained CVAs, leading researchers to question whether this intervention may also be applicable to persons with TBI; (c) the potential of computers to serve as an ideal modality for administration of cognitive rehabilitation techniques; and (d) the results of studies in the area of brain injury have revealed that residual cognitive deficits contribute a major barrier to successful vocational rehabilitation of this population.

Computer-based Cognitive Rehabilitation

Data supporting the efficacy of cognitive rehabilitation are quite limited (Gordon et al., 1989; Pepin, Loranger, & Benoit, 1995; Rizzo, Buckwalter, & Neumann, 1997); unfortunately, computerized cognitive rehabilitation intervention has received even less research attention. Although some researchers have concluded that computerized cognitive rehabilitation efforts have been effective (Bracy, 1983), controlled research investigations of computerized interventions have not yet been conducted (Gordon et al., 1989).

Investigations employing computers as a means of administering cognitive rehabilitation interventions have encountered problems and issues similar to those reported for the studies of non-computerized interventions. Moreover, additional criticisms have been concerned with the fact that few cognitive rehabilitation software programs were developed specifically for persons with TBI (Gordon et al., 1989). Most programs used in research in this area were designed for either young children or were specialized applications designed for special education students. For computerized rehabilitation efforts to attract participation and to be maximally effective with adults, the software applications must be appropriate for the person's age, gender, educational level, and professional and cultural background. In addition, the ability to use the treatment modality most appropriate at the time could greatly improve effectiveness. Relatively little research has focused on treatment modalities that improve cognition following brain injury (Parente & Herrmann, 1996).

The potential for application of Virtual Reality (VR) technology to the rehabilitation of persons with cognitive deficits has recently been recognized (Rizzo, et al., 1997). Such technology may indeed be highly valuable when applied to individuals with TBI. Through the use of VR employed within a rehabilitation context, brain-behavior relationships may be examined more closely and revolutionary treatment options may be developed (Rizzo, et al., 1997). Two general approaches have been proposed for applying VR technology to cognitive remediation: restorative approaches, which tend to focus on the systematic retraining of cognitive processes through repetition; and functional approaches, which focus on retraining of activities, behavior, and skills through discrete steps (Rizzo, et al., 1997) or task analysis.

Both restorative and functional approaches have been subject to criticism. Critics of restorative approaches argue that these methods have limited generalizability from the training environment to the individual's environment (O'Conner & Cermack, 1987). In contrast, critics of functional approaches assert that through placing a great emphasis on performing over-learned functional behaviors, underlying cognitive abilities are not developed. This in turn, may lead to the individual experiencing difficulty when performing tasks when cognitive flexibility is required (Kirsh, Levine, Lajiness-O'Neill, & Schnyder, 1992). There is thus a need to develop interventions that incorporate both the restorative and functional approaches and this need led to the ALERT concept and design.

An Adaptable Learning Environment

The purpose of the research reported in this paper has been to design an adaptable learning environment specifically for persons with TBI as a means of enhancing their cognitive abilities and vocational and social competence.

This computerized rehabilitation system will track user performance levels, interest, preferences, and progress. Its software architecture includes aspects of intelligent tutoring systems (Frasson, Mengelle, Aimeur, & Gouarderes, 1996; Brusilovsky, Schwarz, & Weber, 1996), helper/advisory systems (Winkels & Breuker, 1990), and interactive learning environments (Akhras & Self, 1996). It will eventually include aspects of a learning companion (Ragnemalm, 1996; Chan & Baskin, 1990) and of medical knowledge-based systems, especially those designed for protocol-directed therapy (for example, see Musen, Tu, Das, & Shahar, 1995). The "Adaptable Learning Environment for Rehabilitation Training" (ALERT) is being created to support multiple "system modes" which in turn share aspects of intelligent tutoring systems, helper systems, learning environments, learning companions, and protocol delivery systems. Its software architecture is described elsewhere (Ross & Chiang, 1998); the focus here is the cognitive task analysis and the vision of a patient-directed retraining environment for rehabilitation that informs the ALERT project.

The design of this learning environment addresses a variety of cognitive domains including arousal and orientation, attention and concentration, memory, visual and spatial perception, language and verbal skills, executive functioning (e.g., reasoning, planning, organization, problem solving), life skills (e.g., time telling, budgeting, following directions), and social skills. Cognitive tasks are activities specific to assessing the skills contained within a broader cognitive domain (e.g., attention, memory, executive functioning) and are designed to enhance the learner's skill level in that particular sub-domain. Enhanced cognitive performance will be developed through age-appropriate game-like activities and assessing performance on these tasks. After the participant achieves a pre-determined level of competency in a particular skill, he or she will then engage in a series of simulation tasks designed to enhance the functional use of the skill and increase the ecological validity of the intervention (Rizzo, et al., 1997). This is accomplished through the use of virtual environments created in the Virtual Reality Modeling Language (VRML) (Matuba & Roehl, 1996).

Cognitive Rehabilitation within ALERT

A multimodal approach to cognitive rehabilitation for persons with traumatic brain injuries includes examination of three types of variables: cognitive, mediating, and support.

Cognitive Variables involve operations, or skills, that can be learned. These are divided into two classes: (1) *Cognitive Activities* are cognitive operations that direct attention to enhance encoding or cueing of information (e.g., mnemonic techniques). These activities involve breaking down a particular cognitive domain (e.g. attention) into sub-domains, or components, and developing tasks to assess performance in each of the sub-domains individually. (2) *Functional Modeling* involves cognitive operations that utilize certain concept-learning, problem-solving, decision making, or reasoning techniques that are simulations of normal activities. Functional modeling tasks include computer simulations (i.e. virtual reality [VR]) of real-life activities that are designed to enhance generalizability of cognitive skills learned through the *Cognitive Activities*.

Mediating Variables, in contrast, are variables that the learner brings to the setting and could potentially affect the individual's overall performance (e.g. patient's inclination, disposition, or readiness to attempt a given task). Examples of mediating variables may include *Alertness* (e.g., level of arousal), *Mood* (e.g., emotional state, level of motivation, attitudes and preferences), and *Nutrition* (e.g. when last food was eaten, types of food, exercise, medication).

Similarly, Support Variables also do not directly influence cognitive functioning. Rather, these are variables contained within the physical or social environment that may influence performance on cognitive tasks. Support variables include factors, activities, or interventions that may compensate for cognitive limitations, prompt the implementation of compensation strategies, or facilitate memory retrieval. For example, prosthetic memory devices (e.g., calculators, computers, daytimers/personal calendars), environmental modifications (e.g. labeling contents of drawers), and modifications of the social environment (e.g. use of social reminders, social feedback) (Parente & Hermann, 1996).

ALERT brings into a single environment the assessment and analysis of cognitive, mediating, and support variables and will synthesize a user model and updated treatment plan. Currently there is no single standardized assessment method that collects information about cognitive, mediating, and support variables (Parente & Herrmann, 1996). Assessment of these variables is important for a successful development and implementation of a multimodal model of cognitive rehabilitation treatment. It is essential for its meaningful evaluation due to the interaction of mediating and support variables with active variables in cognitive rehabilitation. In ALERT, a matrix of cognitive, mediating and support variables will be used to track the user's performance and update ALERT's model of the user's progress. The section of this matrix involving the attention domain is displayed in Table 1.

Table 1: The attention section of the ALERT variable matrix.

	COGNITIVE VARIABLES		MEDIATING VARIABLES			SUPPORT VARIABLES
	Cognitive Activity	**Functional Modeling**	**Alertness**	**Mood**	**Nutrition**	**Use of Support Agents**
Attention						
sustained[1]	(time on task, performance)	(time limit, performance)	(7 point scale)	(7 point scale)	(multiple choice)	Agents activated
selective[2]	(time on task, performance)	(time limit, performance)	(7 point scale)	(7 point scale)	(multiple choice)	Agents activated
alternating[3]	(performance)	(performance)	(7 point scale)	(7 point scale)	(multiple choice)	Agents activated
divided[4]	(performance)	(performance)	(7 point scale)	(7 point scale)	(multiple choice)	Agents activated
vigilance[5]	(time on task, performance)	(time limit, performance)	(7 point scale)	(7 point scale)	(multiple choice)	Agents activated

[1] Sustained attention: Focusing on specific things for certain lengths of time. Remaining focused during a conversation or completing a task from beginning to end without interruption are examples of this type of attention.

[2] Selective attention: Focusing on specific things for certain lengths of time while ignoring distractions. For example, being able to compose a report while the TV is on or cooking dinner while a group is having a conversation in the next room.

[3] Alternating attention: Switching the focus of your attention from one project to another, without losing track of where you are in either task. For example, an office worker may be typing on the computer, then answer the phone, then handle questions from someone standing at his/her desk, then resume typing on the computer where he/she left off.

[4] Divided attention: Performing two or more tasks at the same time. For example, taking notes during class while still attending to the lecture.

[5] Vigilance: The ability to sustain attention and be prepared for any changes within the environment and having the ability to respond to the changes and return to a vigilance level. For example, driving a car while responding to a variety of changes (e.g., traffic lights changing, a deer running in front of the car).

Within this multi-system-mode framework, cognitive retraining will be dynamically designed following a developmental sequence and will employ a developmental model of recovery as proposed by Parente and Anderson-Parente (1991). This functional model of development was designed to provide suggestions for treatment at each succeeding stage. The model is premised on the notion that certain skills (e.g. arousal and orientation) must be acquired before other skills (e.g., attention, executive skills) may develop. Parente and Herrmann (1996) present a developmental model of cognitive recovery that includes the following stages of cognitive remediation:

- arousal and orientation
- attention and vigilance
- mental control
- rehearsal
- recovery of episodic memory
- higher order cognition
- recovery of social competence

Similarly, a developmental model is employed for transitioning between cognitive activities and functional modeling. Users must meet an established level of performance on the cognitive activities before advancing to the functional modeling component of the program. Table 2 provides examples of cognitive activities and functional modeling as applied to the domain of attention.

Table 2: Cognitive variables: examples of cognitive activities and samples of functional modeling.

	COGNITIVE VARIABLES	
	Cognitive Activity	**Functional Modeling**
Attention		
sustained	Computer task: Individual is shown a screen with numbers on it and asked to cross out number that follow in order going forward, i.e. 3 8 4 2 0 **1 7 8** 6 4 9 2 4.	Visiting a virtual video store and making a list of all the program areas that videos can be selected from.
selective	Computer task: Individual is shown a screen with a variety of numbers on it, and asked to cross out numbers that are one less the number before it; i.e. 0 1 2 7 **6 4 3** 1 9 **8** 5 3 8. There is a distraction such as the radio playing while completing this task.	Preparation of a meal in the virtual kitchen with various distractions (phone ringing, cat running through kitchen, etc.)
alternating	Computer task: Add numbers on one part of the screen and switch to another part of the screen to cross out words from a list that begin with the letter H, then switch back to the other task.	Preparing a meal in a virtual kitchen with a variety of tasks, food on stove, making a salad, phone ringing, following recipe, pouring drinks.
divided	Computer task: Read a story and cross out words occurring before a coma, while also circling words beginning with the letter H. After reading the story, summarize pertinent aspects.	Listening to a virtual lecture, taking notes, and answering questions on a test afterward.
vigilance	Computer task: Complete a variety of tasks and games on the computer while watching out for "virus" that may pop up to try to stop the task.	Driving a virtual car while paying attention to a variety of dangers that would be found in normal driving.

Mediating and Support Variables

Assessment of mediating variables would include self ratings of how sleepy or alert patients are feeling, their general mood, and nutrition questions such as last meal eaten and if they are feeling hungry, when medications were taken. Since performance can be adversely affected by a variety of factors, monitoring these factors may help in the understanding of their role in performance (Sbordone & Long, 1996).

The role of the helper variable is two-fold. While examples are given of the role of support and help the individual can use in the community, it is felt that a support will also be needed with the computer. The support that is envisioned here is a key reminder that will be directed at the deficit areas seen with the tasks. For example, if the individual had left neglect (visual deficit in the left field of vision so the they miss things in this area of vision), a reminder bug would enter the screen and point to an area on the left side to remind them that they are missing things on this side. It is felt that this system will be gentle with the individual while at the same time allowing them the opportunity to make changes that directly relate to their deficits.

Advantages of the ALERT Approach

In ALERT, functional modeling is accomplished within Virtual Reality interactive settings for the cognitive task abilities being retrained. The user is able to navigate and interact with the virtual environment. Figure 1 provides an example of an ALERT virtual kitchen in which real-life situations are simulated, and a variety of attention tasks can be presented. Created in VRML with interactive objects, the user can move about the kitchen and turn on the faucet, wash the salad, make toast or coffee, answer the phone, etc. Once started, these processes (e.g., coffee brewing, sink filling with water, phone ringing) continue until the user takes action. Thus, the phone can be ringing, the sink filling, the pot boiling, and coffee brewing at the same time, thereby creating a need for prioritized attention. Meanwhile, the user's responses and response times are recorded and performance scores calculated to be used to update the user model and guide the course of treatment.

The ALERT approach makes an important contribution to improving computer-based cognitive rehabilitation by including both restorative and functional approaches. This facilitates an effective rehabilitation process by leading the individual through retraining of cognitive processes both as mental abilities and as (virtually) real-life situation coping skills. Eventually, the life-skill scenarios and virtual environments will be expanded to include many vocational settings and vocational and social problem-solving scenarios in order to support vocational rehabilitation (and alternate vocation exploration) within ALERT. The goal is to develop ALERT as a tool that its users can enjoyably use to help them take charge of rebuilding their cognitive skills and expanding their educational, social and vocational opportunities.

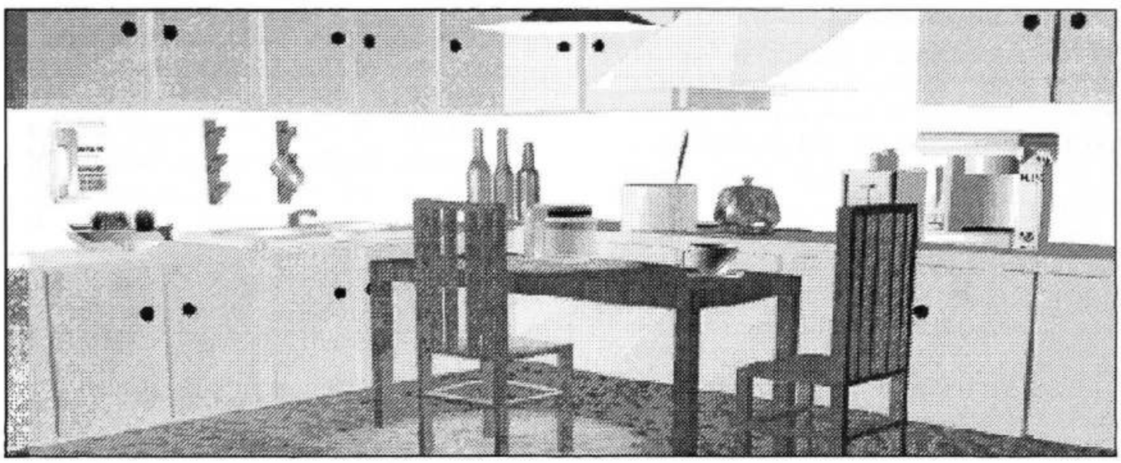

Figure 1: VRML kitchen which can be utilized for a variety of attention tasks in ALERT.

Case Study of ALERT in Use

In the following description, ALERT is used by a therapist to support cognitive retraining. Patient A is a 23-year-old male who sustained a traumatic brain injury in a car accident. He had damage to the left frontal and temporal lobe, and was in a coma for three days. He spent three weeks in acute care and two months in inpatient hospital rehabilitation. Following discharge, he entered cognitive training with a speech and language pathologist. The therapist obtained baseline measures on cognitive activities using ALERT. Restorative training focused on cognitive activities in a variety of areas. For simplicity, an example of just training tasks in the area of sustained attention is provided below (Table 3). The patient worked on training of cognitive activities until a target level of performance was achieved. Once the target was met the patient was advanced to work in the area of functional modeling.

Table 3: A snapshot of variables tracked in ALERT for Patient A after three sessions

	COGNITIVE VARIABLES	
	Cognitive Activity	**Functional Modeling**
Attention		
1. sustained	Baseline on task time 2:15 minutes Baseline performance 17/30 items correct Transition perform. of 25/30 across 3 sessions	Patient A located 5/6 items in virtual store within a 5 minute period. Then A was able to follow 4/5 steps in preparing a salad in virtual kitchen.

Interdisciplinary Collaboration

Breaking new ground in computer-based retraining for cognitive disability required combined knowledge and experience to develop a shared understanding of problems and solutions as well as participants' willingness to join forces to create ALERT. The authors represent rehabilitation psychology, neuropsychology, speech pathology, linguistics, education, and computer science. The potential for this collaboration was discovered only months before this paper was written; yet a shared sense of the urgency of patients' need for help in rebuilding their cognitive skills and their lives has led to a plan for providing this help. It is hoped that publishing these preliminary results may attract other researchers into this quest to create a new class of cognitive rehabilitation interventions and to assess their potential to support effective retraining. Interested parties are invited to contact the authors.

Conclusion

The ALERT system is designed to address the individual's specific deficit areas. Starting from computer-based activities for restoring cognitive abilities, exploring games and tasks to reinforce this learning, and progressing to more complex problem-solving scenarios in the virtual environments, individuals can work on their deficit areas. Thus ALERT provides a "safe" way to support learning and failure prior to reentering the real world where failures can be much more costly (Rizzo et al., 1997).

ALERT will be made available over the Internet and on CD-ROMs that patients can use at home as well as in a clinical setting. The first release is scheduled for Spring 1998; information and demos will be available at the ALERT web site: "http://www.earthlab.com/alert/

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