HUMAN EXPERIENCE MODELER: CONTEXT DRIVEN COGNITIVE RETRAINING AND NARRATIVE THREADS

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Abstract (Needs re-write)
We describe a cognitive rehabilitation system developed at the University of Central Florida that allows therapists to explore cuing, contextualization, and theoretical aspects of cognitive retraining, including transfer of training. The Human Experience Modeler (HEM) mixed reality environment allows for a contextualized learning experience with the advantages of controlled stimuli and feedback that would not be feasible in a traditional rehabilitation setting. A pilot study for testing the integrated components of the HEM is also discussed where the participant within the study presents with working memory impairments due to a stroke.
Keywords: cognitive rehabilitation, mixed reality, stroke, story, assistive technology

INTRODUCTION

Context Driven Cognitive Rehabilitation Using VE

Functional loss from brain damage is described by the World Health Organization (WHO, 1998) in terms of impairment, activity (disability), and participation (handicap). Traditional rehabilitative efforts have their emphasis on reducing the underlying impairment through the development of compensatory procedures and the practice of functional activities with the intent of reducing the individual's social, vocational and/or educational handicaps. Ylvisaker et al. (2001) have proposed an inverse approach initially focusing on the participation of the individual by modifying everyday tasks and the environment in which they exist. Within this framework, rehabilitation seeks to increase activity by systematically evaluating present performance. This approach reduces the impairment by equipping the individual with strategies to succeed in varied settings. Such an integrative approach explores the complex interactions between cognitive functions with functional and social implications. The focus is on meaningful improvement and functional outcomes in their contextualized environment.

Rizzo et al (2004) included the capability of simulating naturalistic contexts, such as a door bell ringing during meal preparation, as an asset of utilizing virtual environments (VE) as a rehabilitation tool. The participant is faced with all the cognitive demands of the real to life task within a safe, risk-free environment where stimuli can both be systematically controlled and manipulated. In addition, performance parameters can be captured and the potential for objective, quantifiable feedback can be provided following the interaction.

Transfer of Training

The issues of general and specific transfer and generalization of learning to one's home environment are critical to cognitive rehabilitation research. In particular, developing the capability to train patients such that they transfer and apply their rehabilitated skills to the home environment has long been sought by the field. The contextualization and the level of experimental control afforded by utilizing a VE framework allows researchers a unique opportunity to further explore transfer of learning issues with brain injured populations.[1]

A growing number of studies are examining transfer of training using a variety of VEs. For example, with normal populations, Rose et al. [2] showed that persons receiving either VR or real-world training improved performance similarly on a real-world sensorimotor task. More importantly, both the VR and the real-world practice groups outperformed those persons who received no practice training suggesting that VR training may be as effective as real-world training when learning some tasks. The authors suggested that the sensory and motor elements (task elements) and the cognitive processing elements (organizational set) between the real world and the VE tasks are similar enough to facilitate training transfer (Rose et al, 1998). By placing transfer of training within the theoretical backdrop of Transfer Appropriate Processing (TAP), the authors have provided the foundational depth needed to explore these issues from a more explanatory basis.

Transfer Appropriate Processing and Ecological Validity

At its foundation, what TAP theory has identified is that synchrony between cognitive processes engaged during the time of learning or acquisition of a given material and the eventual use of that material is crucial for performance across a surprising number of tasks (Roediger et al. 2002). Contextual factors, therefore, are critical to learning and retention over and above the phenomena that are typically addressed in the memory literature. More specifically, TAP theorizing is most cogent with respect to rehabilitation research in that TAP theory has consistently identified that “recapitulating specific encoding and retrieval operations enhances performance” (Roediger, et al., 2002, p. 325). It is this latter notion that is critical to our research and we explore this construct considering how differing levels of ecological validity impact learning.

We broadly construe ecological validity as ranging from a form of task relevant “cognitive fidelity” for an activity to a particular content associated with the domain, or to synthetic task environments (Entin, Serfaty, Elliott, & Schiflett, 2001). The ecological validity issue is important from the rehabilitation perspective because the field is now wrestling with notions of *fidelity* in their research paradigms. Indeed, from the training sciences, a substantial body of research suggests that only certain components of the training need to be faithful to the operational setting (see Taylor et al., 1999). For example, low fidelity PC based simulations can effectively train complex individual and teamwork skills (Jentsch & Bowers, 2001). The level of simulation fidelity needed should be driven by the cognitive and behavioral requirements of the task and the level needed to support learning (Salas & Burke, 2002, p. 120).

Within the realm of rehabilitation, transfer of learning of activities of daily living (ADL) from the virtual rehabilitation setting to the home environment has not been explicitly demonstrated. Furthermore, the degree of similarity between the VE and the real task has not been explored nor have the perceptual or precise conditions that are most salient to generalization. Finally, the precise form of feedback of information and the manner through which it is conveyed remains an important area of inquiry. (Rizzo et al 2004)

Error-Free Learning

Within a clinical setting, Brooks et al.[4] demonstrated that an amnesic patient, who had been unsuccessful in navigating routes in a rehabilitation unit, learned the routes after VE training. These findings were attributed to the methodology used in the VE training. Specifically, during training, all errors were corrected so the patient received the benefit of errorless learning, not having the ability to learn from "trial and error." Further, post neuropsychological assessment showed "mild improvement on tests of general intellectual abilities, visual perceptual and naming skills but memory and executive functions remained severely impaired".[4, p.73] Two main findings of this study were: 1) cognitively impaired individuals are able to exhibit new learning following training in a VE and 2) feedback plays an important role in conveying critical learning content.

Feedback in the form of cuing (auditory or visual) was also an important component of Softhaven, a fully immersive VE designed by the University of Texas Medical Branch in Galveston, Texas (Christiansen et al, 1998) to teach and assess basic life skill performance (e.g., meal preparations) to persons with traumatic brain injury (TBI). The reliability of Softhaven to collect valid data was tested using a kitchen meal preparation scenario. TBI participants made soup within a simulated kitchen. Each participant received the same scripted task and the same cueing directives (e.g., the target location always changed color and flashed as the first cue).
Zhang et al.[25] further showed that Softhaven provided adequate construct validity for the assessment of cognitive functions in persons with traumatic brain injury. Furthermore, they found the VR environment to be a good predictor for the actual kitchen performance. However, the researchers did not assess the transfer of VE performance to the home environment.

In sum, the transfer of training literature clearly supports the efficacy of furthering research utilizing virtual rehabilitation paradigms; however, cost is one prohibitive aspect to creating and testing these types of training environments (Gourlay et al, 2003). In addition to the technology (display, tracker, haptics, etc), software, application development, and maintenance are additional expenses. Although some off-the-shelf products exist, most applications for cognitive retraining require customized applications.[5] Further, there is no standardized methodology for creating virtual rehabilitation environments[6] lending to redundancy and multiple system platforms that make replicability across research endeavors difficult. The use of open source applications is a possible solution; however, understanding which capabilities (e.g., 3D audio) a VE must possess to accomplish successful retraining and transfer is still an open question. This type of work may require a multimodal testbed, which can be easily modified to fit the needs of the rehabilitation environment. Such a testbed would have to model activities of daily living, yet be flexible to individualize training scenarios.

Pilot Study Description (Connect HEM to Pilot, Yet do)

In this paper, we describe the implementation of two technologies developed at the University of Central Florida that have the potential to explore the theoretical implications of TAP as it pertains to rehabilitation, to determine optimal levels of contextualization for successful transfer of ADL retraining to a participants home environment, as well as explore individualized cuing options for personal training within the rehabilitation protocol. First is the Human Experience Modeler (HEM), a virtuality system based on the latest science and technologies of virtual, augmented and mixed reality.[7, 8] The HEM was developed by the Media Convergence Lab (MCL) at the Institute for Simulation and Training (IST), in collaboration with the School of Computer Science at the University of Central Florida. Second is the “Real-time Experience Capture and Analysis” (RECA) system, developed by UCF’s Institute for Simulation and Training. Originally developed to track “After Action Review” (AAR) sessions for the military, this technology is capable of providing a visual replay of the participant’s performance while training on a task. This system has been adapted and refined to provide support to more diverse applications such as education and rehabilitation.

The training paradigm for the pilot study extends the work of Zhang et al.[25] who explored the advantages of utilizing computer simulations of a VR kitchen as a training environment for persons with traumatic brain injury. We focus on the meaningful improvement and functional outcomes of a single patient performing a meal preparation task (i.e., making breakfast) in a VE modeled after his own kitchen. Our overarching goal is to explore how the ability to contextualize the learning environment with the familiar items of the patient’s own home alters transfer of training to daily tasks as well as shortens time spent in rehabilitation. We hope to accomplish three goals with this pilot study. First, we will explore costs involved in creating such personalized environments for patient use in the home or within rehabilitation centers. Second, we will assess the methodology for utilizing RECA within a rehabilitation scenario. Finally, we will conduct a transfer of training to home environment study.

MATERIALS AND METHODS

Participant

The participant for this study was a right-handed, 48 year old, Caucasian male who suffered an aneurysm in 2004. Spectroscopy scans revealed that the patient sustained left frontal lobe damage. At the time of this study, that participant was living at home with his wife and receiving speech therapy at the UCF Communicative Disorders Clinic. Prior to participating in the experiment, the participant was administered the Mini-Mental Status Exam (MMSE), Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), Wechsler Adult Intelligence Scale 3rd Edition (WAIS-III), and the Comprehensive Trail-Making Test (CTMT). The participant’s cognitive testing showed that the participant primarily presents with attention, memory, and executive functioning impairments consistent with frontal lobe damage. However, his ability to manipulate and process visuospatial stimuli remained intact.

Instrumentation (Addition- Dr. Hughes e-mail)

For this specific study, a depth camera (3DV Systems DMC100) and a 3d laser scanner (Riegl LMS420i) will be used to capture the participant’s home kitchen. These images will be processed by the Mixed Reality Software Suite. The resulting personalized story of making breakfast for this participant will provide the context for the HEM therapeutic environment. The participant will perform HEM therapy two times a week for four weeks.

Procedure (Redo)

During each training session, the participant will be given a task list for making his favorite breakfast. Following each training session, the participant will review his performance with a therapist using the RECA. Once all training sessions are completed, a brief in home observation will be conducted so as to videotape execution of the breakfast making task. Analysis of the videotape will provide evidence of transfer of training.

Data Analysis

HUMAN EXPERIENCE MODELER

Using the HEM, we can replicate the unique everyday domestic, workforce and consumer activities of the participant within a laboratory environment. This capability allows us to explore a variety of issues within health sciences, including simulation for cognitive rehabilitation and medical training. For example, in its mixed reality mode, the HEM can alter what a user sees and hears by combining real and virtual components (e.g., a burner can appear to be hot, even though it is perfectly safe) or (e.g., the live voice of a loved one can be altered to simulate the effects of a brain injury on auditory perception). These capabilities permit us to capture, simulate and measure each patient's physical and cognitive abilities for use in rehabilitation, scientific observation, and training. Further, HEM can play a role in educating healthy people on the potential debilitating effects of brain injury, in hopes that such education may encourage better lifestyle choices (e.g., motor cycle helmet use).

As shown in Figure 1, the HEM is designed to capture a patient's familiar environments and reproduce common experiences in this simulated setting. The HEM creates experiences within a three-dimensional visually and auditory enhanced landscape. The key word here is "enhanced" in that this implies that the real world images and sounds are part of the ambiance. This real environment is augmented with multi-sensory cues that potentially enhance training patients and educating caregivers and the public. Using sophisticated sensors and data collectors, the user's experience is captured for further evaluation by the RECA system, derived from a process commonly known as after action review (AAR). This captured experience can be used for patient evaluation and rehabilitation, professional training and public education.[9, 10]

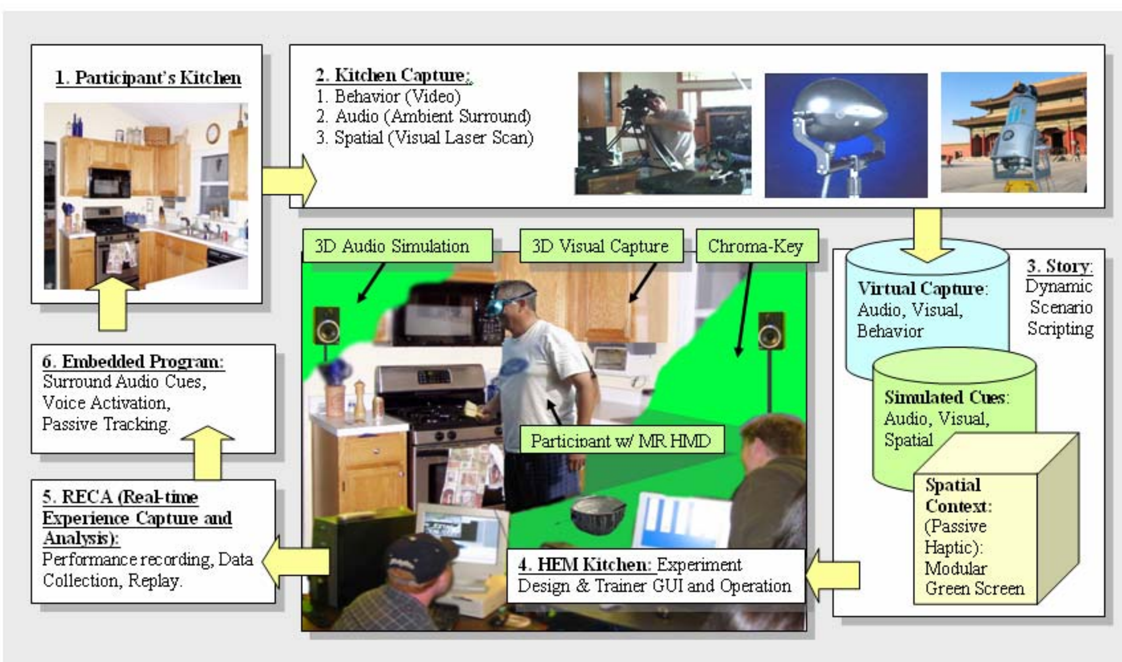

Figure 1: 1) Participant's Kitchen is 2) captured spatially, acoustically and behaviorally; 3) data base transform into a scenario with simulated cues within a chroma-keyed staging area; 4) that Kitchen HEM, with video see-thru Mixed Reality, becomes the virtual replica of the original (with real props and appliances) for rehabilitation; 5)

Real-time Experience Capture and Analysis (RECA) system is able to replay for participant and analyze performance for staff; 6) a minimized system and program is embedded within the participant's kitchen to re-enforce rehabilitation after training.

HUMAN EXPERIENCE MODELER FUNCTIONALITY

Experience Capture records both the spatial, audio and visual environment and performance of experience. The environment is captured in the field to accurately reproduce a space and its multi-sensory signature. This is done with 3D laser, image and acoustical recordings. Once captured, this real environment can be rendered within a mixed reality (a mixture of real and virtual objects and environmental conditions). Specifically, images are processed by the Mixed Reality Software Suite (MRSS), software tools developed for creating dynamic and interactive mixed reality experiences.[11] The MRSS system is made up of four subsystems called engines: three rendering engines simulate the multimodal simulation (Visual, Audio and Other) while a fourth engine drives the integration and creates an interactive, non-linear scenario of the chosen human experience Within this part synthetic, part real setting, an integrated system of sensors captures a user's performance in the form of time, space, movement, sensory perception, physiological response, emotion and expression. This quantitative and qualitative data is then recorded for replay.[12]

Experience Rendering consists of immersing a user within a multi-modal hybrid of real and virtual that is dynamically controlled and augmented with spatially registered visual and auditory cues. Peripheral and environmental perception is rendered with a combination of 3D sensory displays such as Mixed Reality (MR) Head Mounted Displays (HMD), audio earbuds (earphones for Mixed Reality), surround sound and spatially registered audio, haptic vests and olfactory stimulation.[13, 14]

Experience Replay and Review supports RECA by replaying the human experience with novel 3D Mixed Reality graphical displays that allow viewing events from multiple perspectives and with appropriate augmentation (e.g., data on the user's response times and measured stress levels). User interfaces also allow marking and annotating of sections during recording to simplify finding appropriate segments during review.

Environment for Multi-Modal Experience The rendering of human experience is conducted within a family room-size staging area that is integrated with hybrid multi-modal display, audio and sensory technology. First, visual effects rendering are produced from either a video or an optical see-thru HMD. The video see-through version is the Canon Coastar, a lightweight HMD with embedded cameras and displays.[15] The optical see-through display is produced locally in UCF's ODALab.[16] Visual effects can also be produced with embedded projection displays. Audio rendering is accomplished with a hybrid system that mixes real, modified real and virtual sounds.[17] This consists of a multi-tiered surround system with ambient, directional and point source audio. In addition, earbuds combine both a headset and microphone to produce MR Audio consisting of personalized ambient and directed real and virtual sound. Haptic rendering is provided by acoustical vest, motion base and force feedback interfaces that support a realistic and dynamic experience. Olfactory rendering is provided by a system that produces a limited range of smells.

REAL-TIME EXPERIENCE CAPTURE AND ANALYSIS (RECA)

IST's virtual After Action Review system was originally designed to aid training researchers investigate two overarching issues, one theoretical and one practical. The theoretical issue addressed was how should training feedback be best delivered so as to provide trainees with a common understanding of what happened during a simulation and why it happened, so that they can identify ways to improve their performance. The practical issue addressed how to facilitate data compilation and analysis in order to support training feedback. The AAR technology records the movements and interactions of users within a virtual or augmented environment and plays them back for the users to learn. Additionally, the AAR system lets a facilitator watch what is being done within the environment and lets him/her "tag" events in the timeline that can be used later during a review. Once the exercise is completed, the facilitator can sit down with the user of the environment and review his/her actions (both good and bad) within the environment. The AAR system can replay (capturing visual, audio and desired parameters) as many times as necessary, thereby promoting discussion between facilitator and user. The tagging system provides a fast access method to events in the scenario so that attention can be focused on them (rather than simply replaying an entire captured scenario from start to finish).

After action review has become an accepted approach in many areas (e.g., military), and there have been a number of studies on its efficacy and acceptance. For example, Lampton et al.[18] studied instructional strategies for an interactive training environment involving manipulation of demos, coaching and AAR groups. In the study, participants were given guidance before (demo), during (coaching), or after (AAR) a simulated military training mission. As well, some participants received no guidance at all (Control group). The results showed that AAR provided improved performance over the control group and works as well as coaching.

Studies on IST's virtual After Action Review system were conducted at Fort Benning, Georgia using simulated military training scenarios.[19] Soldiers completed six to eight 10-20 minute training scenarios. After each scenario, an AAR was performed to study positive and negative aspects of the soldiers' performance. At the end of each two-day session, questionnaires and interviews were conducted. Of particular note is that 83.3% of the soldiers agreed or strongly agreed that conducting an AAR was more effective than just receiving verbal feedback, and 94.4% agreed or strongly agreed that it helped them understand the simulation. Overall, the AAR system received high acceptance among this population of learners.

The AAR capabilities of IST's virtual After Action Review system is supported within RECA with additional Mixed Reality and evaluation capability for single or aggregate analysis. Thus, the capability to review an accurate representation of training performance is encapsulated with the HEM trainer. Further, the RECA system allows for multiple viewing perspectives (e.g., top down 2D or fly modes) so that feedback can be specifically addressed within a particular aspect of the training scenario. By providing viewing modes for use by a facilitator during both the exercise and the review, the training is better monitored such that normal metacognitive functions typically engaged during learning can be scaffolded.

In particular, during the course of a replay the trainees will be able to see a simulation from a number of perspectives. The top down 2D view and fly modes may promote the user to see the big picture and learn to see the whole environment. The entity view, seeing through the eyes of others, supports a number of training functions. For example, it will help the trainee determine whether he/she saw an action or problem but failed to respond, or was not looking in the right direction at all. The RRCA replay provides unequivocal answers to those questions and provides a means with which to examine how feedback can best be tailored with such a system to facilitate learning. Preset views can be selected at any time prior to or during the exercise for immediate use and these can be used for perspectives or positions that the RECA facilitator deems useful. From a theoretical standpoint this will allow us to ascertain the degree to which the broader perspectives afforded by the RECA system will scaffold what may be deficient learning on the part of cognitive rehabilitation patients or augment normal monitoring on the part of learners in general.

EMEDDING NARRATIVE AND CONTEXT INTO COGNITIVE REHABILITATION

The implementation of scripts in the rehabilitation of persons with cognitive impairment is foundational to Ylvisaker's framework for "positive, everyday, routine-based intervention".[21] The re-establishment of scripts, the organized internal representation of the event including the people, places, objects, language, is central to functional rehabilitation.

Research in the cognitive sciences also supports that humans are predisposed to follow script-like or schematic structures.[22, 23] Indeed, a number of complex cognitive processes are engaged when one comprehends a story. Specifically, when a story is presented coherently, “the enabling events and causes form a web of connections among other events and conditions. A statement’s number of connections determines how centrally important readers consider it to be”.[23, p. 45]

It is this notion of the inherent connectivity of story that we argue is important from the learning standpoint, tapping into people’s emotions in order to create lasting memories.[14] This entails integrating the latest developments in the creative conventions of interactive story structure with grounded instructional strategies within training. Learning augmentation tools (e.g., simulations) that enable learners to build an appropriate understanding of the relations between concepts have been shown to encourage the acquisition of knowledge similar to an expert. For example, members of this team have shown that the inclusion of schematic diagrams in technology-enabled learning facilitates the development of integrated knowledge consistent with an expert mental model.[24] We suggest that story increases the memorability of learning content by utilizing a more meta-level comprehension skill associated with stories and that rehabilitation should leverage this possibility to determine if the inherent causal structure facilitates training efficacy in brain-damaged patients.

DISCUSSIONS AND CONCLUSIONS

In short, we suggest that the simultaneous exploration of HEM, RECA, and narrative presents a powerful research and development context through which to extend the efficacy of cognitive rehabilitation. Such an integrative approach explores the complex interactions between cognitive functions with functional and social implications. The focus is on meaningful improvement and functional outcomes in their contextualized environment. However, this is not currently possible in the sub-acute stages of rehabilitation. The HEM would lend itself to the philosophy of a contextualized learning experience with the advantages of controlled stimuli and feedback that would be plausible in a rehabilitation setting. Thus, mixed reality with the principled inclusion of training tools such as RECA and cognitive concepts such as narrative offers a promising new method with which to develop both theoretical and practical knowledge associated with cognitive rehabilitation.

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