HUMAN EXPERIENCE MODELER: CONTEXT DRIVEN COGNITIVE RETRAINING TO FACILITATE TRANSFER OF LEARNING

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Abstract

We describe a cognitive rehabilitation mixed reality system that allows therapists to explore natural 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, experience capture and feedback that would not be feasible in a traditional rehabilitation setting. A pilot study for testing the integrated components of the HEM is discussed where the participant presents with working memory impairments due to an aneurysm.

Keywords: cognitive rehabilitation, mixed reality, stroke, story, assistive technology

INTRODUCTION

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 virtual environment (VE) framework allows researchers a unique opportunity to further explore transfer of learning issues with brain injured populations.[1]

A growing number of studies examined transfer of training using a variety of VEs. One theory for why VE based retaining should allow for successful training transfer was put forth by Rose et al.[2] 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. By placing transfer of training within the theoretical backdrop of Transfer Appropriate Processing (TAP), Rose et al. provide the foundational depth needed to explore these issues from a more explanatory basis.

With respect to rehabilitation research, TAP theory has consistently identified that "recapitulating specific encoding and retrieval operations enhances performance."(3, p. 325) Thus, contextual factors are critical to learning and retention over and above the phenomena that are typically addressed in the memory literature. This notion of contextualization or natural cuing is critical to our research and we explore this construct considering how differing levels of ecological validity impact learning.

Cost is one prohibitive aspect to creating and testing contextualized training environments.[4] Further, no standardized methodology for creating VE rehabilitation scenarios[5] exists, lending to redundancy and multiple system platforms that make replicability across research endeavors difficult. The Human Experience Modeler (HEM) developed at the University of Central Florida is a multimodal VE testbed that can potentially alleviate these hindrances and increase our understanding of which capabilities (e.g., 3D audio) a VE must possess to accomplish successful retraining and transfer.

The training paradigm for the present pilot study extends the work of Zhang et al.[6] 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 mixed reality 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.

MATERIALS AND METHODS

Participant

The participant for this study was a right-handed, 48 year old, Caucasian male who suffered an aneurysm in 2004 and presented with left frontal lobe damage. Prior to participating in the experiment, the participant was administered a comprehensive test battery from a speech/language pathologist and a psychologist. The participant's testing showed attention, memory, and executive functioning impairments consistent with frontal lobe damage. However, his ability to manipulate and process visuospatial stimuli remained intact. The participant was independent in his personal activities of daily living (ADLs) in his home but was not engaged in his meal preparation.

Instrumentation

The HEM is a virtuality system based on mixed reality (MR),[7,8] which allows modeling idiosyncratically ecologically-valid training environments (e.g., a patient's home). Initially, the spatial, audio, and visual environment is captured in the field utilizing 3D laser, image, and acoustical recordings to accurately reproduce a space and its multi-sensory signature. 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 and delivering dynamic and interactive mixed reality experiences.[8]

The MRSS system is made up of four subsystems: three rendering engines simulate the multimodal simulation (Visual, Audio and Special Effects) while a fourth engine drives the integration, delivering an interactive, non-linear scenario (story) of the chosen human experience. The output of the MRSS is a mixed synthetic and real setting where an integrated system of sensors in the environment captures the user's performance for replay.[10]

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, special effects (e.g., lighting changes, breezes and opening/closing doors), haptic vests and olfactory stimulation.[8, 9] The visual effects rendering are by a Canon COASTAR™ video see-thru HMD.[10]

HEM Implementation

For this specific study, a depth camera (3DV Systems DMC100) and a 3d laser scanner (Riegl LMS420i) were used to capture the participant's home kitchen. The scanner and camera output was edited in 3D Studio Max. The graphical representation of the kitchen, including the textures and appliance overlays, were imported into the MRSS. These images were then seen through the Canon video see-through head-mounted display.

In addition to the 3D graphics, parts of the real kitchen were reconstructed out of plywood to provide appropriate passive haptics, matching the same dimensions and locations as in the real kitchen. Figure 1a shows a picture of the participant's own kitchen. The reconstructed mock kitchen, painted green for chroma-keying, is seen in Figure 1b. There were some differences in the dimensions, brand of appliances, and number of fixtures between the mixed reality and real kitchen. Otherwise the spatial layout of target locations and target items were identical to the participant's own kitchen.

Nonessential areas such as the stove, microwave, and dishwashing machine were all virtually represented in the MR kitchen. Essential areas, such as the plate and cup cabinets along with the silverware drawer were fully functional as were the pantry door and refrigerator. The refrigerator contained milk and other non-target items, for example orange juice. As well, the pantry contained non-task relevant boxed items such as cake mix.

Figure 1. (a) Participant’s actual kitchen. (b) Chroma-keyed mock-up. (c) Schematic of locations of target items and typical starting position of the participant.

MR Training Procedure

After receiving informed consent, the participant was videotaped performing meal preparation in his own home at his regular breakfast hour. This single measure baseline followed a modified “Goal-Plan-Do-Review” or executive function map[11] where the participant verbalized and wrote down a list of steps and materials needed to accomplish his goal. He was then asked to perform the cereal making task with the assistance of the therapist. The participant was free to perform each identified step in any order.

During each MR training session, the participant was fitted with the Canon COASTAR™ head-mount, which was coupled with an Intersense IS900 wireless mini tracker. The participant was presented with the same protocol as was performed at home. There were 5 training sessions conducted over consecutive days. The Tracker Reviewer, a Java based software capturing the tracked movements of the participant, was started once the participant was ready to begin. The facilitator remained in the MR virtual kitchen with the participant for the entire meal preparation. In addition, the facilitator monitored the participant's view of the MR on a display placed out of the line of sight of the participant. Once the participant had completed the cereal preparation task in MR, the Simulator Sickness Questionnaire (SSQ) was administered.[12]

Upon completing the MR training, the participant was videotaped in his own home performing the cereal making task. The participant generated the script sequence and proceeded to make breakfast. Only one post-training home session was recorded due to time constraints.

Data Analysis

Location errors, time to locate target items, total time to complete the task, order of item retrieval, and number of cues were recorded in the real and simulated kitchen. In addition, total efficiency of movement was captured from the head tracker via the Tracking Reviewer. Analysis of the overall location errors (total errors = 42) showed that the participant had the most difficulty remembering where the cereal (17 total errors) and the bowls (13 total errors) were kept in both his real kitchen and in the MR Kitchen.

Table 1: Time in seconds to locate target items; order retrieved; and time to complete all tasks.

Location	Target	Pre	MR 1	MR 2	MR 3	MR 4	MR 5	Post
Pantry	Cereal	58 (1)	112 (4)	76 (4)	119 (4)	80 (2)	18 (3)	8 (4)
Cabinet	Bowl	13 (2)	38 (1)	26 (1)	43 (1)	28 (3)	27 (1)	18 (1)
Refrigerator	Milk	14 (3)	44 (3)	24 (3)	12 (3)	7 (1)	14 (4)	14 (3)
Drawer	Spoon	3 (4)	15 (2)	15 (2)	3 (2)	6 (5)	5 (2)	3 (2)
Counter	Make Cereal	73 (5)	120 (5)	84 (5)	41 (5)	40 (4)	37 (5)	51 (5)
	Total Time (s)	**240**	**379**	**315**	**341**	**236**	**177**	**158**
	Total Time (m:s)	**4:00**	**6:19**	**5:15**	**5:41**	**3:56**	**2:57**	**2:38**

Table 1 displays the time in seconds that the participant needed to locate a target item. Time was measured starting from when the participant verbalized what item he was about to retrieve and ending at the time he found the item in its appropriate location within the kitchen. The numbers in parentheses represent the order that each item was retrieved. Item retrieval order during the actual breakfast making task never matched the preplanning script. However, the participant's performance retrieval order (bowl, spoon, milk, and cereal) was the same for 3 out of the 5 MR training sessions and the post-test home session.

Table 1 also shows that the participant took 4 minutes to prepare cereal in his own home during the pre-test, while he took over 6 minutes to make breakfast during the initial MR training session. By the end of the last MR training session, the breakfast task was performed in half this time. The participant's fastest cereal preparation time (2 minutes and 38 seconds) was achieved in his home during the post-test session.

Figure 2 displays the captured tracking data of the participant as he prepared cereal in the MR kitchen during the first day of training (figure 2 a) and the last day of training (figure 2 b). The overall track data visually highlights differences in movement behavior from an efficiency standpoint between the initial MR training and the final MR training session. The track in Figure 2a is very similar to the one presented in Figure 3a, a line drawing representation of the participant's track during the pre-testing home session, suggesting that the participant carried over errors in his searching behavior to the MR kitchen. Interestingly, in the MR kitchen, the nontarget areas are virtually represented. While the participant can open the target cabinet to find the bowls inside, the nontarget virtual cabinets only display the texture seen in the real kitchen.

Figure 2b shows that the participant makes fewer location errors and more efficiently completes the task during his final training session in the MR kitchen. In his own kitchen during the post-test, the participant demonstrates more continuous movements between steps with less searching behavior as evidenced by the line drawing track shown in Figure 3b.

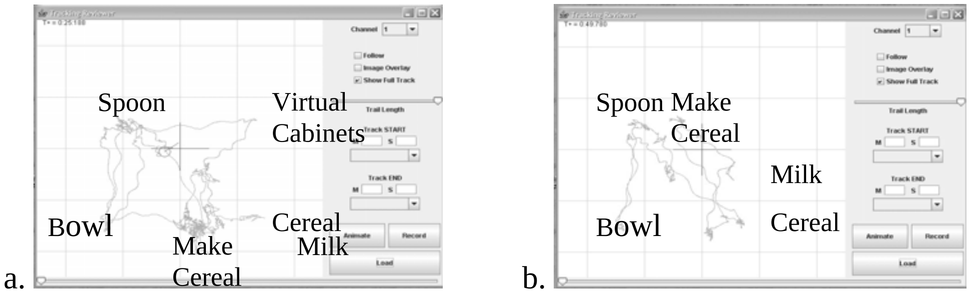

Figure 2. (a) Tracker Reviewer data from participant's first MR training session; retrieval order was bowl, spoon, milk, cereal. (b) Tracker Reviewer data form participant's last MR trainings session; retrieval order was bowl, spoon, cereal, milk. Participant made cereal in different locations on each day.

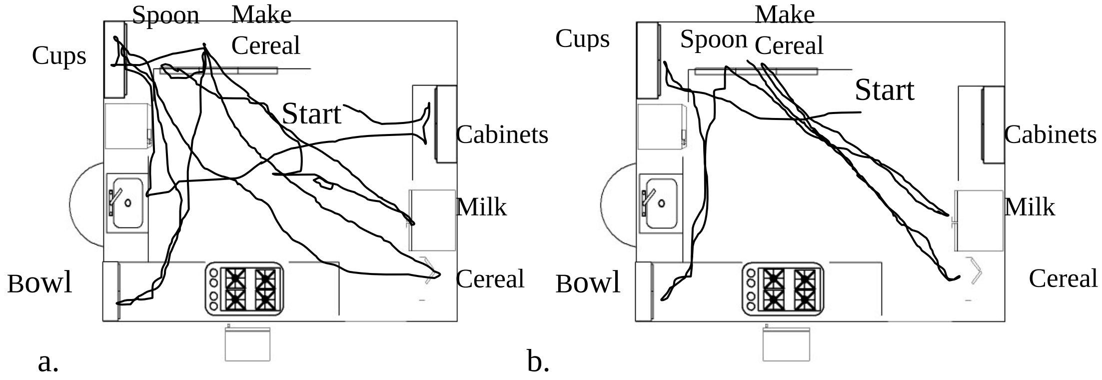

Figure 3. (a) Track at home during pre-training; order was cereal, bowl, milk, and spoon. (b) Track of post-training; order was bowl, spoon, milk, and cereal. Participant made cereal in same location each day.

DISCUSSIONS AND CONCLUSIONS

Although only a single-subject design, the participant's improvement over the five sessions of MR training suggests that the HEM mixed reality environment is an ecologically-valid environment through which to examine learning and transfer to the home environment for brain-damaged adults. The capability of the HEM to present both naturalistic contextual cues and cues that can augment the environment allows us to further explore the types of cuing necessary to facilitate retraining for different populations of acquired head injury.

In this study, transfer of learning from the MR environment to the home environment was evidenced in decreased time spent on task, decreased number of location errors, and decreased wandering behavior. The degree and extent of naturalistic cuing needed for transfer of learning are areas for further exploration.

Further, the ability of our system to visually represent movement and to track that process permits analysis of emergent trends in performance. For example, the order of retrieval of target items possibly suggests that the MR training assisted the patient in developing an internal script which then carried over to the home environment. In short, the HEM mixed reality environment afforded an interactive and flexible arena in which the participant could safely explore his functional capabilities.

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