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VIRTUAL ENVIRONMENTS (VES): THE POTENTIALS AND CHALLENGES FOR USE IN COGNITIVE REHABILITATION OF INSTRUMENTAL ACTIVITIES OF DAILY LIVING (IADLS)

Lehman, L[1,2]

[1]*Center for Innovation on Disability and Rehabilitation Research, VA Medical Center, Gainesville, FL 32608*

[2]*University of Florida, Gainesville, FL 32610*

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INTRODUCTION

Everyday tasks have physical, cognitive, and emotional components.[1, 2] A simple stop by the grocery store to pick up bread and milk requires a variety of physical skills (i.e., ability to drive, walk, use one's hands, etc.). Once in the store, the cognitive challenges abound. One must be able to remember what one came for and the layout of the store. One must be able to identify the product of interest, carry out the process to pay for the items, and do all this in a timely manner. Although, a trip to the grocery store might seem ordinary and not one to elicit emotional reactions, think back to a time you were in a hurry to get home and had to wait in a long line or the store was out of the one item you desired. A simple stop at the grocery store can prove challenging for someone without cognitive impairment, but compound these challenges with deficits that come with traumatic brain injury (TBI), post-traumatic stress disorder (PTSD), and a wide range of possible diagnosis with cognitive components and a simple stop at the grocery can become anxiety producing, hazardous to one's health, and potentially impossible.[3] Rehabilitation therapists (i.e., psychologists, occupational therapists, etc.) seek to enable people with these types of challenges to overcome obstacles associated with daily tasks. Evidence supports the proposition that practice helps individuals acquire skills that assist them in making everyday tasks possible even in the face of cognitive impairment.[4, 5] However, often it is unsafe or impractical to practice daily living skills in the real-world environment.[6]

Virtual environments (VEs) can offer the advantage providing safe, controlled environments in which to practice daily living tasks. VEs are computer-generated immersive, interactive simulations.[7] They provide unique places in which it is possible to parametrically vary physical, cognitive, and emotional demands for rehabilitation populations. Several VEs exist today that assist in the rehabilitation of individuals with various physical, cognitive, and emotional challenges.[8] Table 1 highlights several of these environments, the tasks that have been used in each environment, findings in regards to the usability of the environment and validity of tasks in the environment, and a listing of published studies relating to findings for each environment.

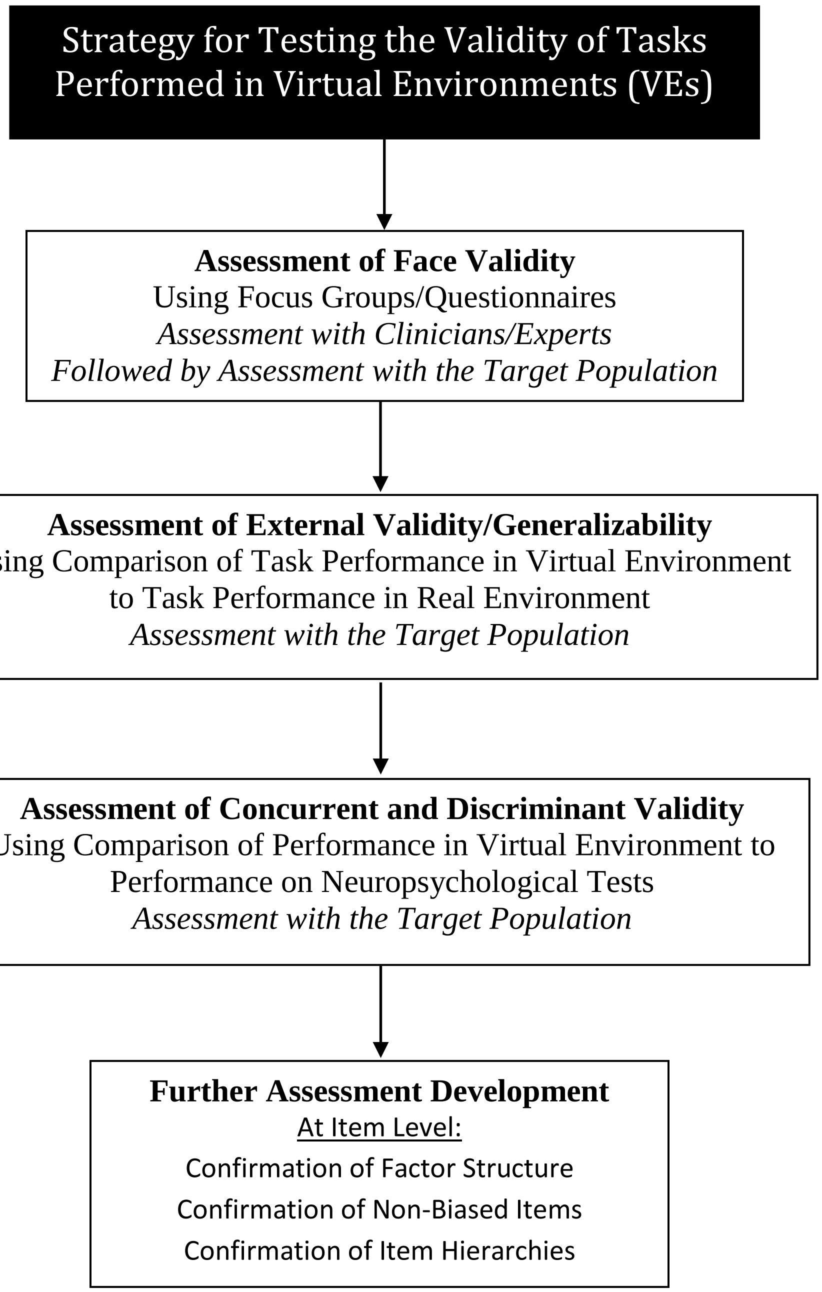
While attractive simulations (i.e., virtual environments) have been developed, what is lacking is the ability to *reliably and validly* predict a person's cognitive performance on real world activities (i.e., veridicality).[1, 9] That is, research studies with larger samples are needed to measure cognitive tasks in these VEs more systematically and in more detail.[1, 9] With much of the focus on making virtual environments seem real (i.e., verisimilitude) what has lacked is any standardization in terms of procedures for determining what is acceptable for ensuring the credibility of using a particular test in a given environment.[9]

A protocol is necessary for testing the validity of tasks performed in VEs and for confirming usability of the tasks in the VE with specific diagnoses. Following similar guidelines set forth by a group of experts funded by the National Institute of Health (NIH), Figure 1 summarizes a suggested approach to validity testing of tasks performed in virtual environments. First, face validity, the degree to which an assessment appears to be evaluating what it intends to measure,[10-14] must to be established. This is typically done through the use of focus groups initially with clinicians/experts and then with affected individuals.[15-17] With VEs this would entail first clinicians/experts going through the tasks in the environment themselves and evaluating, perhaps in the form of a survey or a group/individual meeting, the appropriateness of the difficulty and content of the tasks. Following this, the same type of assessment of the tasks in the environment would be completed by the end user (i.e. the patient, client, individual in the population for whom the instrument is intended).

Next, external validity, also referred to as generalizability needs to be assessed. This type of validity has been variously defined as the ability to generalize to other situations, contexts, or people.[10] It is essential to verify that results produced in simulated environments are similar to those in the real world.[18, 19] Assessing external validity would involve having affected individuals complete tasks both in the virtual and real environments and comparing performance in both settings. Similar performance would indicate that the virtual world was an accurate depiction of the actual one.

Finally, concurrent and discriminant validity should be ascertained. Concurrent validity determines if the results correlate well with measures of similar constructs. Discriminate validity addresses the extent to which performance on tasks is not correlated with dissimilar measures, those intended to measure something different than the assessment of interest.[10] These two types of validity must be established before use by clinicians.[20-22] This would involve identifying neuropsychological tests measuring constructs intended to be measured by tasks in the virtual environment for concurrent validity testing. Furthermore, neuropsychological tests measuring constructs that are not intended to be measured by the tasks would need to be identified for discriminate validity testing. Patients would complete both conventional neuropsychological tests and the tasks in the virtual environment and results would determine the correlation between assessments of similar and dissimilar constructs.

Figure 1. Suggested Strategy for Testing the Validity of Tasks Performed in Virtual Environments (VEs)



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Finally, once validity is established with adequate sample sizes, further analyses involving detailed item/task analysis should be completed. Factor analytic techniques will ensure that tasks measure a unified construct. Differential item functioning will ensure that tasks are not biased by gender, culture, age group, etc. Item response theory methodologies provide accurate item/task hierarchies (i.e. order of difficulty).

Aside from standard procedures for testing cognitive domains in VEs, what is lacking is emotionally charged situations within the environments whereby emotional control and reactions to novel stimuli can be assessed and practiced. Individuals with cognitive deficits such as TBI, PTSD, autism, schizophrenia, and other anxiety disorders often find public interactions fraught with peril. The amount of sensory and social stimulation is overwhelming. These individuals have difficulty controlling emotional responses, such as inhibiting anger responses. When the challenges of daily living are too great, withdrawal and isolation into more contained and restricted environments can be expected leading to further emotional consequences and the loss of the opportunity to confront the situations needed to learn to control these behaviors.[7] VEs are the perfect environments for practice for individuals with these types of problems because they allow the therapist to select, modify, and control many aspects of the environment such as noise level, lighting, and the number and ethnicity of other people in the environment. The environment thus can be customized to fit the sensory stimulation level that is most likely to engage, but not overwhelm the participant. Positive experience can be used to build the insights and tolerances necessary to allow the reentry into public life. VEs imbued with emotional content are a glaring, unmet need and a major loss of potential for VEs.

In conclusion, these two challenges: 1) standardization of procedures for testing cognitive tasks in VEs and 2) creation and testing of emotionally challenging tasks in VEs should be the next steps on the way to making VEs commonly used in healthcare and maximally effective in creating positive treatment outcomes.

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Table 1. Summary of Virtual Environments (VEs) and Tasks Utilized in VEs

ENVIRONMENT	Description of Environment	Tasks Utilized in Environment	Findings in Regards to: Usability of Environment Validity of Tasks in Environment	Studies
VMall	• Developed to combine IADL training with therapy aimed at decreasing motor and cognitive impairments of persons with neurological dysfunctions • Simulates a large supermarket which provides a functional and ecologically valid setting for a variety of intervention tasks • Programmed via GestureTek's GX video-capture VR system • Shoppers view themselves on a large monitor positioned in front of shelves stocked with various grocery products. • Items are selected by hovering over them with a hand that is wearing a red glove. • The GX-VMall software responds to video gestures by placing the selected items in a shopping cart. • Selection of aisles, grocery items and other tasks encourages active movement of the affected upper extremity. • Performance of the task provides multiple opportunities to make decisions, plan strategies and multitask.	4-Item Shopping Task • Find 4 items on shopping list: a 1-kg bag of sugar, a 1-kg bag of rice, a 0.5-l bottle of soda and a 0.5-l bottle of orange juice. • Given list written in large letters on a board eliminating need to remember products • Outcome measures: time, the order of products bought, number and type of products bought by mistake Virtual Multiple Errands Test (VMET) • Buy six items • Find out four items of information • Check the contents of the shopping cart at a certain time • Outcome measures: mistakes made in categories including: non-efficiency, rule breaking and use of strategies mistakes, partial and complete mistakes of completing a task, and the total number of mistakes.	• In the VMall, the 4-item shopping task differentiated between participants with stroke (*n* = 14) and healthy controls (*n* = 93), $F(3,97)=23.28$, $p<0.000$. • In the VMall, the VMET was able to differentiate between post-stroke participants (*n* = 9), young healthy adults (*n* = 20), and older healthy adults (*n* = 20), as indicated by significant chi-squares on nonparametric tests (Kruskal-Wallis, Mann-Whitney) for types of mistakes ($p < .000$). • Post-stroke individuals (n = 4) participating in ten 60-minute sessions in the VMall over 3 weeks showed improvements on the VMET ranging from20.5% to 51.2% on most all measures. • Participants in experimental group (*n* = 6) receiving ten 45-minute treatment sessions in the VMall were compared to a control group (*n* = 6) that received ten 45-minute treatment sessions of regular occupational therapy intervention. Large effect sizes (0.51) for the percent (%) relative change on the VMET supported greater improvement in executive functioning for the experimental group.	Rand D, Katz N, Weiss PL. Evaluation of virtual shopping in the VMall: comparison of post-stroke participants to healthy control groups. *Disability and Rehabilitation* 2007; 29(22): 1710-1719. Rand D, Rukan S, Weiss P, Katz N. Validation of the Virtual MET as an assessment tool for executive functions. *Neuropsychological Rehabilitation* 2009; 19(4): 583-602. Rand D, Weiss PL, Katz N. Training multitasking in a virtual supermarket: a novel intervention after stroke. *The American Journal of Occupational Therapy* 2009; 63(5): 535-542. Jacoby M, Averbuch S, Sacher Y, Katz N, Weiss P, Kizony R. Effectiveness of Executive Functions Training Within a Virtual Supermarket for Adults With Traumatic Brain Injury: A Pilot Study. *IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING* March 2013; 21(2).
V-Store	• Immersive based tool • Designed for the rehabilitation of executive functions • Features were drawn from popular neuropsychological tests (e.g., Tower of London Test and Wisconsin Card Sorting Test)	• Individuals explore store in order to solve some sequence of tasks • 6 levels of increasing complexity (e.g., organizing pieces of fruit into partitioned baskets). • Tasks are designed to stimulate executive functions, problem-solving, behavioral control and programming, categorical abstraction, short-term memory and attention. • A series of distracting elements aims at generating time-pressure and eliciting managing strategies.	• While completing tasks participants either experienced the V-Store on a flat screen (less immersive, *n* = 6) or a head mounted device (more immersive group, n = 6) • Findings indicated: increased GSR (Galvanic Skin Response) for more immersive group, poorer performance on incidental recall for more immersive group, and no significance differences between groups on self-reported feelings about experience in store (significance determined based on *t*-tests with $p<.05$).	Lo Priore C, Castelnuovo G, Liccione D, Liccione D. Considerations on presence in virtual environments for effective neuropscyhological rehabilitation of executive functions. *Cyberpsychology & Behavior* 2003; 6: 383-388.

ENVIRONMENT	Description of Environment	Tasks Utilized in Environment	Findings in Regards to: Usability of Environment Validity of Tasks in Environment	Studies
Virtual Supermarket	• Designed to assess and train cognitive functions involved in basic ADL. • Simulates a typical supermarket with 4 display stands, 4 refrigerators each with a door, and 2 up-opened refrigerators • To pick something up, individual must move near the object until it is highlighted by a change in edge color, then press the joystick button to "pick up" the object. • To open the door of a refrigerator, individual must stand in front of the refrigerator and press the joystick button. • After opening the door of the refrigerator, selection of goods is possible. • After selection, goods can be moved to the shopping handcart from the display stand.	• Participants can adapt to the virtual environment during an exercise stage which trains the subject to navigate and explore the virtual supermarket, and allows the subject to pick up goods and open the door with the input device. • During the main task, the subject should pick up all goods and place them in the handcart.	• Time, distance, and number of collisions with walls tended to decrease with practice (*n* = 5) • Number of goods selected and number of joystick button presses tended to increase with practice • Difficulties navigating store reported	Lee JH, Ku J, Cho W, et al. A virtual reality system for the assessment and rehabilitation of the activities of daily living. *Cyberpsychology & Behavior* 2003; 6(4): 383-388.
Virtual Environment Grocery Store (VEGS)	• Advanced computer interface allows the clinician to immerse the patient within a computer-generated simulation that reflects activities of daily living. • Allows for precise presentation and control of dynamic perceptual stimuli. • Enhanced computation power allows for a range of the accurate recording of neurobehavioral responses in a perceptual environmental that systematically presents complex stimuli. • Three-dimensional objects are presented in a consistent and precise manner. • Individuals are able to manipulate three dimensional objects in the store.	• Involves a number of brief, shopping-type errands that must be completed in a real environment following certain rules that require problem solving.	• Multiple studies planned	Parsons T, McPherson S, Interrante V. Enhancing Neurocognitive Assessment Using Immersive Virtual Reality. 17th IEEE Virtual Reality Conference: Workshop on Virtual and Augmented Assistive Technology (VAAT); 2013; p. 1-7.
Virtual Kitchen	• Developed using Softhaven computer program. • Objects such as kitchen utensils and appliances programmed to reside in usual locations • Accessed by the patient using the computer mouse • Instructions for task completion (cues, prompts) are programmed to respond to actions (or inaction) of user • For example, objects that should be focused on/selected may light up or a verbal cue may be given. • Each action performed by the subject is recorded by software for retrieval, analysis, and documentation.	• Specific daily living task • Developed for cognitive function evaluation • Stovetop meal preparation of a can of soup and a sandwich • Soup and sandwich preparation activity is divided into 81 steps and substeps • Each step is scored by using a 6-point scale • Score of 6 = correct response on first try • Score of 1 = unable to complete the step after 5 attempts • Total performance score ranges from 80 to 480 (higher score = better performance) • Rating also given indicating amount of assistance needed	• Intraclass correlation coefficients (ICCs) have been used to estimate stability of performance (*n* = 54). The ICC value for total performance, based on all steps involved in the meal preparation task, was .76 (p < 01). • Construct validity of meal preparation task in the virtual kitchen has been shown (*n* = 54) by correlating performance in the virtual environment with that in the actual kitchen (r = .63, p < 01), with an the OT evaluation (r = .30, p = .05 for meal preparation; r = .40, p = .01 for cognitive subskills), and with neuropsychologic tests (r = .56, p < .01 for the full-scale intelligence quotient; r = .40, p < .01 for the verbal IQ; r = .56, p < .01 for the performance IQ). • Multiple regression has been used to show that the virtual kitchen is a good predictor for performance in the actual kitchen (*n* = 54; β = .35, p = .01).	Zhang L, Abreu BC, Seale GS, Masel B, Christiansen CH, Ottenbacher KJ. A virtual reality environment for evaluation of a daily living skill in brain injury rehabilitation: reliability and validity. *Archives of physical medicine and rehabilitation* 2003; 84(8): 1118-24.

ENVIRONMENT	Description of Environment	Tasks Utilized in Environment	Findings in Regards to: Usability of Environment Validity of Tasks in Environment	Studies
Virtual Classroom	• HMD-delivered VR system for the assessment and rehabilitation of attention processes. • Environment consists of a standard rectangular classroom environment containing student desks, a teacher's desk, a virtual teacher, a blackboard, a large window looking out onto a playground with buildings, vehicles, and people, and a pair of doorways on each end of the wall opposite the window, through which activity occurs. • Individual assessed in terms of attention while a series of typical classroom distracters (i.e., ambient classroom noise, movement of other pupils, activity occurring outside the window) are systematically controlled and manipulated. • Participant sits at a virtual desk. • Environment can be programmed to vary with regard to such factors as seating position, number of students, and gender of the teacher.	• On-task attention is measured in the virtual classroom in terms of performance on a variety of attention challenges that can be adjusted based on the age or grade level of performance. • *Sustained* attention assessed by manipulating time demands. • More complex demands requiring *alternating* or *divided* attention can be developed. • In addition to these attention performance indicators, behavioral measures that are correlated with distractibility and/or hyperactivity components can be measured.	• Initial user-centered design evaluation on the present scenario with seven non-diagnosed children (aged 6–12) has provided encouraging usability results. • None of the children were observed to have any hesitancy interacting in the environment. • None reported symptoms of cybersickness. • All users were able to read the letter stimuli on the board and track and report occurrences of the distraction stimuli.	Rizzo A, Buckwalter J, Bowerly T, et al. The Virtual Classroom: A Virtual Reality Environment for the Assessment and Rehabilitation of Attention Deficits. *Cyberpsychology & behavior : the impact of the Internet, multimedia and virtual reality on behavior and society* 2000; 3(3): 483-99.

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