VIRTUAL REALITY ASSESSMENT OF COGNITIVE FUNCTIONS: A PROMISING TOOL TO IMPROVE ECOLOGICAL VALIDITY

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Introduction

Military service in Iraq and Afghanistan comes with the risk of exposure to improvised explosive devices (IEDs), vehicle borne IEDs, rockets, mortars and other blasts. Vehicle roll-over accidents, small arms fire and other non-battle injuries also occur. Accordingly, service members deployed in support of Operation Iraqi Freedom and Operation Enduring Freedom are at increased risk of traumatic brain injuries (TBIs). Since 2000, over 169,000 service members have been diagnosed with a TBI[1] (Department of Defense, 2010) and the RAND Corporation reported that nearly one in five service members who deployed to Iraq or Afghanistan reported a probable TBI (Tanielian and Jaycox, 2008).[2]

Although mild TBIs, or concussions, typically result in full recovery following a brief period of time, more serious injuries can result in new symptoms or changes in functioning and behavior. Some of these changes occur in cognitive domains such as attention, memory, executive functions, language, spatial abilities and psychomotor skills. These changes are usually documented with paper and pencil tests that compare the service member's cognitive performance to that of their peers. For the comparison to be valid, these tests must be administered in a similar manner to that used to determine the norms — typically quiet, well-controlled environments that minimize distractions and maximize best effort. Cognitive tests can serve a number of clinical purposes including accurate diagnosis, informing the level of care a patient requires, treatment planning and treatment evaluation (Lezak, et al., 2004).[3] Repeated assessments can also characterize the nature of the injury and document any changes over time.

Providers in both civilian and military contexts have increasingly been asked to use neuropsychological test performances to make recommendations about patients' everyday functioning (Lynch, 2008).[4] In the civilian sector, these questions may relate to driving or activities of daily living, whereas clinicians working in the deployed environment or at military treatment facilities may use cognitive assessments to inform questions related to fitness for duty. For example, deployed commanders may have referral questions related to the safety of personnel to perform basic tactical skills. On the home front, military neuropsychologists may be consulted as part of a "fitness for duty" evaluation that is conducted when impairments significantly interfere with work performance. In addition, there is increasing interest in the assessment of the severity of functional impairment following TBI.

The complexity and lethality of modern warfare place great demands on a service member's neurocognitive resources. At varying levels of threat, service members must be able to exercise control of cognitive functions. It may be challenging to interpret the results of traditional cognitive assessment tools to answer military specific questions. With tremendous individual variability in responses to stress, how well does performance during a well-controlled cognitive assessment predict performance during the stresses of war? It is not known, for example, how well a service member with low average mental efficiency or processing speed following a TBI will react to fire during a tactical convoy. Is this individual fit for combat duty? What kind of performance is required on cognitive tests for a service member to be judged fit to man an automatic weapon during a convoy? Following a mild TBI, how do we assess the functional impairment of service members whose occupational environment has significant, unpredictable low and high intensity stress? Hence, for a measure to be relevant to an assessment of service member neurocognitive functioning, it should provide some indication of a service member's cognitive performance within high and low threat settings.

Questions such as these relate to concerns about tests' ecological validity — the degree to which performance on cognitive tests accurately predict future behavior in the real world. Although some tests have demonstrated evidence of ecological validity[5] (Strauss, et al., 2006). developments in the area of virtual reality may offer new opportunities to improve ecological validity and inform key questions related to the post-TBI assessment of service members.

Virtual Reality Assessment

Virtual reality leverages computers, immersive visual displays, naturalistic navigation devices, and a range of other peripherals to provide the user with the sense of participating in a 3D computer-generated environment. Virtual environments allow systematic presentation of stimuli as well as recording and quantification of user behavior. The possibility of incorporating visual, auditory, olfactory and haptic stimuli may be very well suited to improving the ecological validity of cognitive assessments. Virtual environments can be created to reflect a wide range of job relevant contexts and can be built to precisely test performances that are related to occupational demands. Tasks with specific relevance to military duties in a deployed setting can be created with emphasis upon the particular cognitive demands of deployed personnel.

Virtual Reality Cognitive Performance Assessment Test

The University of Southern California's Institute for Creative Technologies (ICT) has developed an adaptive virtual environment for assessment and rehabilitation of neurocognitive and affective functioning. The first iteration of the adaptive virtual environment is a Virtual Reality Cognitive Performance Assessment Test (VRCPAT 1.0) that includes a battery of neuropsychological measures (e.g., attention, spatial abilities, memory, executive functions and higher-level language and reasoning abilities) for diagnostic assessment of service members with neurocognitive deficits. The National Center for Telehealth and Technology and ICT are collaborating on an initial pilot study to validate the VRCPAT 1.0's cognitive assessment tests with active duty military personnel.

The VRCPAT Memory Module requires the user to learn 10 verbal pieces of information (e.g., blue vehicle with bullet holes in the windshield, intact barrel with a U.S. Army label) without any instruction on how this information will be used. The user then dons a head-mounted display, which essentially is a headset with a screen for each eye. This device includes head orientation tracking such that movements in the real world are replicated in the virtual environment and users navigate by manipulating a gaming joystick. A Middle Eastern city environment is presented and the user is instructed to follow a virtual sergeant who will guide them to a series of zones where two of the previously learned targets are incorporated into the environment. The user is instructed to find and photograph the items in each of the five zones. While virtually ambulating to each zone, the user is presented a virtual reality paced auditory serial attention test that is a virtual reality variation of the traditional paced auditory serial addition task (Diehr, et al., 1998).[6] The virtual reality paced auditory serial attention test involves auditory presentation of numbers (1 through 9) in a randomized format. Subjects are instructed to attend and respond with the sum of the number just presented and the number presented immediately prior to that, all the while attending to the next incoming number of the auditory series. Background ambient noise is present during this task (e.g., idle of a military vehicle, conversations). After photographing as many of the items as they can recall and locate, the user removes the head-mounted display and is asked to recall the whole list of 10 items.

Another virtual environment was developed to test the impact of simulated combat stressors on attention and executive functions. The virtual Humvee stroop test involves the presentation of the color-word interference test stimuli[7] (Delis, et al, 2001), superimposed on the virtual windshield of a Humvee. Specifically, users are asked to respond as quickly and accurately as they can and identify the color of red, green, or blue stimuli that appear on the windshield. The second trial asks the user to read words ("red," "green" or "blue") that appear on the screen. The third task is the color-word interference test that requires identification of the color of the font that the stimuli are presented in, ignoring the word. Performance on this task is systematically assessed during a simulated convoy with stretches of the road that include low threat contexts with no combat stimuli and higher threat contexts that include computer-generated IEDs, smoke, small arms fire, enemy combatants directing fire at the vehicle, etc.

A third virtual environment involves a simulated vehicle check point in a Middle Eastern context. The user is dismounted at the checkpoint and receives a "newbee" whose performance the user is judging. The computer-controlled virtual service member proceeds to classify incoming vehicles as either U.S. military, Iraqi police, Iraqi civilian or possible insurgent. After classification, the user determines whether or not the response is correct. In between vehicle presentations, the user is exposed to the virtual reality paced visual serial addition test, in which number presentation is visual instead of auditory. As in the virtual reality paced auditory serial attention test, the virtual reality paced visual serial addition test requires the participant to add pairs of numbers so that each number is added to the one immediately preceding it; however, numbers are presented on a head-mounted display screen (white numbers with an Iraqi checkpoint background) (Fos, et al., 2007).[8]

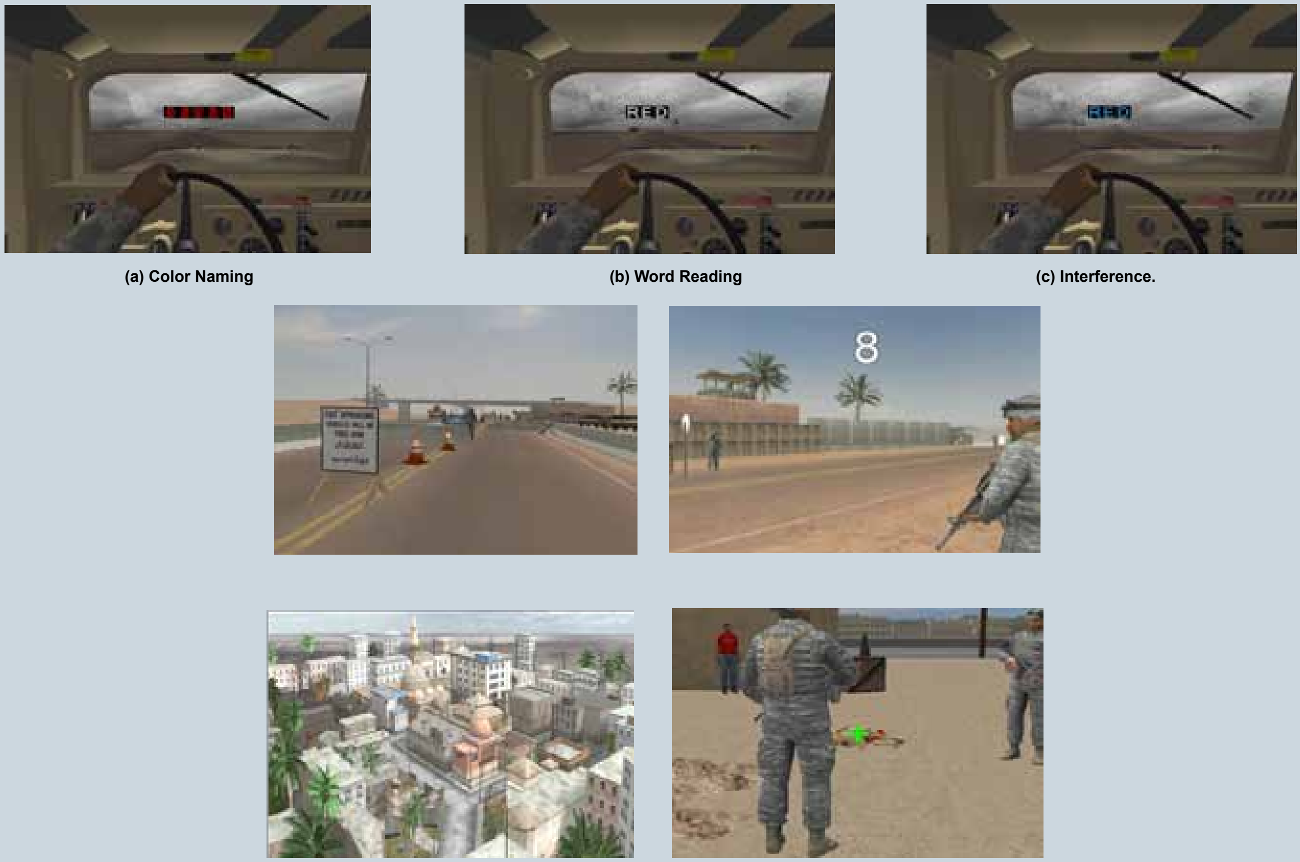
Discussion

Cognitive tests have historically been used to characterize the nature and severity of the injury, inform diagnosis or assist in localization. With increasing interest in predicting future cognitive functioning in day-to-day living, the ecological validity of cognitive tests deserves increased attention. This may be particularly relevant to the common fitness for duty questions that present in military contexts. To assist commanders in determining fitness for duty, the task may not be to determine the patient's best performance on paper and pencil tests administered under ideal circumstances in a calm and supportive testing environment. Instead, tests that actually resemble the cognitive demands of the operational environment may be needed.

One approach to improving ecological validity is developing new tests that intentionally seek to approximate real world requirements (Chaytor and Schmitter-Edgecombe, 2003).[9] Whereas it is fairly straightforward to develop ecologically valid tests for typical daily requirements such as facial recognition and map reading, it may be less obvious how to assess the cognitive tasks associated with operational environments. The characteristics of virtual reality may be particularly well-suited to meet this need. Virtual environments can be created with characteristics that are difficult or impossible to create in real assessment contexts. Multi-sensory presentations can improve the fidelity of the testing environment and these environments can be delivered in a controlled fashion with powerful behavior recording capabilities.

Future directions for this work include using the information gleaned from a VRCPAT 1.0 assessment to individually

The Humvee Stroop Scenarios. Stroop, Checkpoint and City Walkthrough Memory Module Figures



(a) Color Naming (b) Word Reading (c) Interference.

customize the complexity and difficulty of subsequent virtual reality cognitive rehabilitation tasks or to modulate the intensity of virtual reality stimuli during exposure therapy. In fact, the second iteration of this effort is the Virtual Reality for Cognitive Performance and Adaptive Treatment, which is developing an adaptive virtual environment in which data gleaned from the assessment module (VRCPAT 1.0) will be used for refined analysis, management, and rehabilitation of Soldiers who have suffered blast injuries and varying levels of traumatic brain injury.

While the VRCPAT project is in its early stages, it does represent a preliminary effort to utilize virtual reality technology to improve upon the "real life" value of paper and pencil tests in a deployed environment. Although much work remains before a validated virtual reality cognitive test is available to military clinical neuropsychologists, these innovative technologies present a new frontier in cognitive assessment research and present the hope of improved assessment for our nation's warriors.

REFERENCES

TBI Numbers: Department of Defense Numbers for Traumatic Brain Injury (2009, December). Retrieved on May 13, 2010 from http://www.dvbic.org/TBI-Numbers.aspx

Tanielian, T. L., and Jaycox, L. H. (2008). Invisible wounds of war: Psychological and cognitive injuries, their consequences, and services to assist recover. Arlington, VA: RAND Corporation.

Lezak, M. D., Howieson, D. B., and Loring, D. W. (2004). Neuropsychological Assessment, 4th Edition. New York: Oxford.

Lynch, W. L. (2008). Everyday living assessment in cognitive evaluations. *Journal of Head Trauma Rehabilitation, 23,* 185-188.

Strauss, E., Sherman, E. M. S., and Spreen, O. (2006). A compendium of neuropsychological tests: Administration, norms, and commentary. New York: Oxford.

Diehr, M. C., et al. (1998). The Paced Auditory Serial Addition Task (PASAT): Norms for age, education and ethnicity. *Assessment, 5(4),* 375-387.

Delis, D. C., Kramer, J. H., and Kaplan, E. (2001). Delis-Kaplan executive function system examiner's manual. *The Psychological Corporation.* San Antonio, TX.

Fos, L. A., Greve, K. W., South, M. B., Mathias, C., and Benefield, H. (2000). Paced Visual Serial Addition Task: An alternative measure of information processing speed. *Applied Neuropsychology, 7,* 140–6.

Chaytor, N., and Schmitter-Edgecombe, M. (2003). The ecological validity of neuropscyhological tests: A review of the literature on everyday cognitive skills. *Neuropsychology Review, 13,* 181-197.

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