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Virtual Reality Paced Serial Assessment Test for Neuropsychological Assessment of a Military Cohort

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Abstract. The assessment and treatment of traumatic brain injury (TBI) has become a difficult challenge for the DoD medical health system. Clinical neuropsychologists are being asked to make statements regarding a soldier's functional skills, ability to return to active duty, and competence in tasks of community living. Given the increasing prevalence of blast injuries to the head, and the fact that many brain injuries may have no external marker of injury, there is need for researching innovative assessment methods in detecting blast-related brain injury. To address these issues, two virtual reality-based Paced Auditory/Visual Serial Addition Tests (PA/VSAT) were developed that involve the participant being immersed in a Virtual Middle Eastern City as serial addition stimuli are presented. This study is an initial validation of the VRPASAT and VRPVSAT as assessments of neurocognitive functioning. When compared to the paper-and-pencil version of the test, as well as the Automated Neuropsychological Assessment Metrics, the VRPASAT and VRPVSAT appear to have enhanced capacity for providing an indication of a participant's performance while immersed in a military relevant simulation.

Keywords. Virtual Reality, Paced Serial Assessment Test, Neuropsychological Assessment, Military.

Introduction

Military service members deployed in support of Operation Iraqi Freedom and Operation Enduring Freedom are at increased risk of traumatic brain injuries (TBIs). The RAND Corporation reported that nearly one in five service members who deployed to Iraq or Afghanistan reported a probable TBI [1]. Further, 12-20% of Service Members report symptoms of TBI during re-deployment [2]. Blast injuries often produce symptoms similar to classical TBI, thereby complicating detection, diagnosis, and treatment [3]. Military service members with TBI experience problems in efficiently and successfully completing work tasks and some find it difficult to even return to work [4].

The neuropsychological examination is one of the methods used by military neuropsychologists to diagnose acquired disorders of brain function. One of the most

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widely used assessments of TBI is the Paced Auditory Serial Addition Test (PASAT) [5]. The PASAT requires the patient to successfully complete a variety of cognitive functions: sustained attention, working memory, and the simultaneous time-constrained performance of multiple neurocognitive tasks [6]. There is also a Paced Visual Serial Addition Test (PVSAT) that presents the digits visually on a computer screen [7]. A number of studies with various patient groups (e.g., TBI; and multiple sclerosis) have found PVSAT performance to be superior to PASAT performance [8]. Additionally, there are computerized neuropsychological assessments that have been developed to automate the paper and pencil assessments. For example, the Army gives the Automated Neuorpsychological Assessment Metrics (ANAM) battery to all soldiers prior to deployment.

Although tests like the PASAT and ANAM are widely used, providers in military contexts have increasingly been asked to use neuropsychological test performances to make recommendations about patients' everyday functioning [9]. 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? 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 a service member's neurocognitive functioning, it should provide some indication of a service member's cognitive performance within high and low threat settings.

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 environments (VEs) allow for creation of simulated realistic environments in which performance can be tested and trained in systematic fashion. By designing VEs combined with allied computer-based assessment tests we can create "virtual assessment environments" that incorporate challenges based on functional behaviors bringing greater ecological validity to assessment and rehabilitation methods. Within such a VE, the experimental control required for rigorous scientific analysis and replication can still be maintained within simulated contexts that embody the complex challenges found in naturalistic settings.

1. Methods and Materials

This study was designed as an initial validation of the VRPASAT and VRPVSAT in a military cohort. The University of Southern California and a large Army installation in the continental U.S. are collaborating on an initial pilot study to validate the

VRPASAT and VRPVSAT with active duty military personnel. We compared paper-and-pencil PASAT, ANAM, VRPASAT, and VRPVSAT on behavioral measures. Our primary hypotheses were: 1) the VRPASAT (but not the VRPVSAT) would be significantly correlated with the paper-and pencil PASAT; and 2) the VRPASAT and VRPVSAT would be correlated with ANAM subtests assessing mathematical processing and procedural reaction time.

1.1. Participants and Procedure

The University of Southern California's Institutional Review Board approved the study. A total of 49 (94% were male) military service members participated in the study. Fifty percent of participants had 3 years or less of military service experience, and years of experience ranged from 1 to 24 years. All participants were fluent English speakers and had normal or corrected to normal vision. Each participant gave informed consent prior to participation in this research study. After informed consent was obtained, basic demographic information was recorded. Next, participants were assessed on the PASAT; ANAM, VRPASAT, and VRPVSAT.

Paced Auditory Serial Assessment Test: The Paced Auditory Serial Addition Test (PASAT) assesses auditory information processing speed and flexibility, as well as mathematical calculation ability. The PASAT is auditorially presented to control the rate of stimulus presentation. Each participant was presented with a series of single digit numbers, in which the two most recent digits must be summed. For example, if the digits "2", "6" and "3" were presented, the participant was to respond with the correct sums: "8" and then "9". Practice trials occurred prior to the first trial. Stimuli are presented at four different rates (2.4 s, 2.0 s, 1.6 s, and 1.2 s). The duration of each digit was approximately .4 s.

Automated Neuropsychological Assessment Metrics: The Automated Neuropsychological Assessment Metrics (ANAM) is a psychometrically validated tool designed to detect speed and accuracy of attention, memory, and executive function [10]. ANAM software includes a timing mechanism to insure accuracy across computer platforms and supports immediate analysis and report generation. The ANAM records an individual's performance through a series of responses to computer-based prompts. ANAM has been widely used by the U.S. Department of Defense and allows for serial assessment [11]. The following ANAM subtests were given in the order presented: TBI Questionnaire; Sleepiness Scale; Mood Scale; Simple Reaction Time; Code Substitution; Procedural Reaction Time; Math Processing; Matching to Sample; and Go/No-Go.

Virtual Reality for Cognitive Performance and Adaptive Training: At the University of Southern California's Institute for Creative Technologies, we have developed an adaptive virtual environment for assessment and rehabilitation of neurocognitive and affective functioning. This project brings together a team of researchers to incorporate cutting edge neuropsychological and psychophysiological assessment into state of the art interactive/adaptive virtual Iraqi/Afghani scenarios (City, Checkpoint).

Two primary goals define these virtual and adaptive environments: 1) a Virtual Reality Cognitive Performance Assessment Test (VRCPAT 1.0) that includes a normative database drawn from a battery of neuropsychological and psychophysiological measures for diagnostic assessment and treatment of Soldiers with affective disorders, brain injury, or neurocognitive deficits; and 2) a Virtual Reality for

Cognitive Performance and Adaptive Treatment (VRCPAT 2.0) that develops an adaptive environment, in which data gleaned from the assessment module (VRCPAT 1.0) is used for refined analysis, management, and rehabilitation of Soldiers who have suffered blast injuries (varying levels of traumatic brain injury) and/or are experiencing combat stress symptoms [12]. For the current study, we focused on results from 1) a Middle Eastern City; and 2) a checkpoint in a Middle Eastern City. For the VRPASAT (a virtual reality variation of the traditional PASAT), we assessed soldiers while they virtually ambulated through a Virtual Middle Eastern City. After following a fire team to 6 zones, the participant was tested on navigation and spatial memory by being instructed to turn around and find the way back through each of the zones in reverse order (see Figure 1).

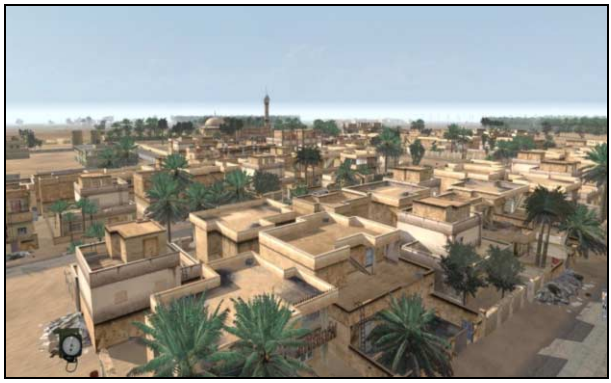

Figure 1. Middle Eastern City.

For the VR version of the Paced Visual Serial Addition Test (VRPVSAT), soldiers experienced a checkpoint in a Middle Eastern City. An area of the Middle Eastern City has been constructed to resemble a traffic checkpoint with a variety of moving vehicles arriving, stopping and then moving onward into the city (see Figure 2).

Figure 2. Middle Eastern Checkpoint.

Participants listened to a virtual trainee as the trainee classified passing vehicles. In between vehicle presentations, the user was exposed to visual PASAT stimuli. Herein the numbers are presented against an Iraqi checkpoint background [7].

1.2. Data Analytics

Correlations were run between the three types of PASAT, and the virtual reality based PASATs were also correlated with various tests from the ANAM. In particular, we were interested in the relationship of the participants' performance on the PASATs and the mathematical processing and procedural reaction time tests.

A separate set of analyses were conducted to assess differences in participants' performance on the various PASATs employed. A 3 (PASAT type) by 2 (session) repeated measures ANOVA was utilized to serve this purpose. Separate ANOVAs were employed to test differences between the virtual reality PASATs in comparison to the paper and pencil version during the first two sessions, and the second two sessions.

2. Results

Correlations between performance on the VRPVSAT and tests in the ANAM test battery revealed that VRPVSAT performance is correlated with mathematical processing, $r = 0.50$, $p < 0.001$, as well as performance on the procedural reaction time test, $r = 0.41$, $p < 0.01$. Likewise, the VRPASAT was also correlated with both mathematical processing, $r = 0.43$, $p < 0.01$, and procedural reaction time performance, $r = 0.47$, $p < 0.01$.

The correlation analysis involving all three PASATs revealed that the VRPASAT was correlated with the paper and pencil version of the PASAT, r ¬= 0.78, $p < 0.001$. The VRPVSAT and the paper and pencil PASAT were not significantly correlated, $r = 0.26$, $p = 0.07$.

The ANOVA involving all three PASATs and using the first two sessions of the paper and pencil PASAT (2.4 and 2.0 respectively), evidenced a main effect of PASAT type, $F(2, 47) = 72.54$, $p < 0.001$, such that the highest performance was found during the VRPVSAT as a paired-samples t-tests revealed that performance was significantly higher than performance on both the VRPASAT, $t(48) = 11.60$, $p < 0.001$, and the paper and pencil PASAT, $t(48) = 3.43$, $p < 0.01$. The VRPASAT was the most difficult task as performance was significantly higher on the paper and pencil PASAT, $t(48) = 11.12$, $p < 0.001$. A session main effect was also revealed, as performance on the first session was higher in general, $F(1, 48) = 39.84$, $p < 0.001$. The interaction between PASAT type and session was also significant, $F(2, 47) = 10.76$, $p < 0.001$, due to the lack of a significant difference in performance from session 1 to session 2 in the VRPVSAT (see Figure 3).

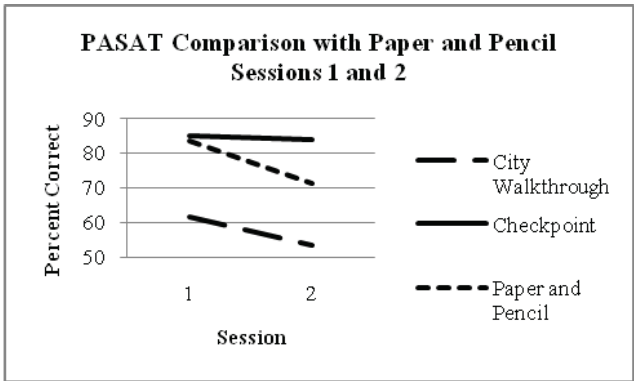

Figure 3. PASAT Comparisons (Sessions 1 & 2)

The ANOVA utilizing the third and fourth sessions of the paper and pencil PASAT (1.6 and 1.2 s respectively) evidenced the same main effect and interaction results. However, the difference between performance on the paper and pencil and VRPASAT was no longer significant, $t(48) = 0.452$, $p = 0.65$ (see Figure 4).

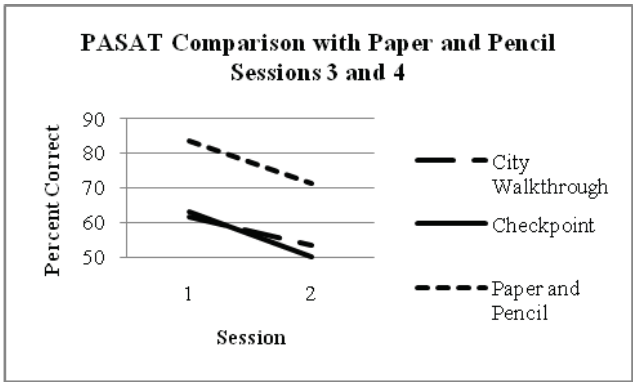

Figure 4. PASAT Comparisons (Sessions 3 & 4)

3. Discussion

The Checkpoint VRPVSAT and the City Walkthrough VRPASAT were correlated with both mathematical processing and procedural reaction time. These results are consistent with the view that the PASAT measures speed of information processing; mathematical ability, and attention [8].

Participant performance on the City Walkthrough VRPASAT had a strong positive correlation with performance on the paper and pencil PASAT, demonstrating high levels of convergent validity between the two tests. Differences in performance between the two PASATs were evidenced during the first two sessions of the paper and pencil PASAT, but not during the second two, more difficult, sessions. This result may be explained by the fact that the City Walkthrough VRPASAT includes the secondary

memory task as well as the added distracting environmental stimuli. Thus, even when the interstimulus interval involved is longer during the virtual reality based PASAT, the task is more difficult due to other stimuli requiring cognitive resources. The City Walkthrough VRPASAT may also allow for more variability in performance without adding to participant frustration by speeding up the test.

As hypothesized, the VRPVSAT and the paper and pencil PASAT were not significantly correlated. These results are consistent with the studies using various patient groups (e.g., TBI; and multiple sclerosis) that have found PVSAT performance to be superior to PASAT performance [8]. This superior visual performance is typically interpreted as representing an "interference" framework, in which the articulation of the response aurally interferes with the aural presentation of the digits. Hence, less interference exists between incoming visual stimuli and the articulated response on the VRPVSAT than on the VRPASAT. As a result, VRPVSAT may proffer a more robust measure of speed of information processing.

Future work should assess the clinical validity of the VRPASAT and VRPVSAT in a clinical population. Although further validation with an intact civilian population is needed, assessment of the difference between the VRPASAT and VRPVSAT may have important clinical implications.

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