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Neuropsychological Assessment of Attentional Processing using Virtual Reality

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ABSTRACT

Attention processes are the gateway to information acquisition and serve as a necessary foundation for higher-level cognitive functioning. The Virtual Reality Cognitive Performance Assessment Test (VRCPAT) focuses upon refined analysis of neurocognitive testing using a virtual environment to assess attentional processing and recall of targets delivered within the context of a virtual city and a virtual driving simulation. The 15 minute VRCPAT Attention Module and a 1.5 hour neuropsychological assessment were conducted with a sample of 12 healthy adults, between the ages of 21 and 36, that included equivalent distributions of men and women from ethnically diverse populations. No subjects had history of psychiatric or neurologic conditions. To examine scenario differences, one-way ANOVAs were performed, comparing attentional performance in simple stimulus presentations (Mean = 43.63; SD = 8.91) versus complex stimulus presentations (Mean = 34.63; SD = 6.86). The results indicated that the increase in stimulus complexity caused a significant decrease in performance on attentional tasks (F = 5.12; p = 0.04). To examine scenario differences, we compared attentional performance in low intensity (Mean = 40.01; SD = 4.06) versus high intensity (Mean = 9.25; SD = 3.70) presentations. The results indicated that the increase in stimulus intensity caused a significant decrease in performance on attentional tasks (t = 9.83; p = 0.01). Findings suggest that the increase in stimulus complexity and stimulus intensity within a virtual environment can manipulate performance on attentional tasks.

INTRODUCTION

Attention processes are the gateway to information acquisition and serve as a necessary foundation for higher-level cognitive functioning. Current methods for assessing attention performance include traditional paper and pencil tests, motor reaction time tasks in response to various signaling stimuli, flatscreen computer–delivered approaches, and behavioral rating techniques. These approaches have been criticized as limited in the area of ecological validity. While standard neuropsychological measures have been found to have adequate predictive value, their ecological validity may diminish predictions about real world functioning (Chaytor et al., 2006; Farias, Harrell, Neumann, & Houtz, 2003; Gioia & Isquith, 2004; Odhuba et al., 2005). Traditional neurocognitive measures may not replicate the diverse environment that in which persons live. Additionally, standard neurocognitive batteries tend to examine isolated components of neuropsychological ability, which may not accurately reflect distinct cognitive domains (Parsons et al., 2005).

Virtual Reality (VR) technology is increasingly being recognized as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities. The ability of VR to create dynamic, immersive, three-dimensional stimulus environments, in which all behavioral responding can be recorded, offers assessment and rehabilitation options that are not available using traditional assessment methods. In this regard, VR applications are now being developed and tested which focus on component cognitive processes including: attention processes (Parsons et al., in press; Rizzo et al., 2006), spatial abilities (Parsons et al., 2004), memory (Matheis et al., 2007), and executive functions (Baumgartner et al., 2006; Elkind et al., 2001). The increased ecological validity of neurocognitive batteries that include assessment using VR scenarios may aid differential diagnosis and treatment planning. Basic attention abilities have been addressed using VR with success and the assessment requirements for attention and other cognitive processes appear well matched to a comprehensive VR approach. Within a head mounted display-delivered virtual environment, it is possible to systematically present cognitive tasks targeting neurocognitive performance beyond what are currently available using traditional methods.

The Attention Module found within the Virtual Reality Cognitive Performance Assessment Test (VRCPAT) focuses on the refined analysis of neurocognitive testing using a virtual environment to assess attentional processing within the contexts of 1) Fixed Position in the Virtual City Test; and 2) HUMVEE Attention Task scenario. In the "Fixed Position in the Virtual City Test" scenario subjects were given both a selective attention and a working memory task. In the "HUMVEE Attention Task" scenario, attention was assessed within both "safe" and "ambush" settings: start section; palm ambush; safe zone; city ambush; safe zone; and bridge ambush. The task involved the presentation of a four-digit number that was superimposed on the virtual windshield (of the Humvee) while the subject drove the Humvee. Herein we report on scenario differences: 1) comparison of attentional performance in simple stimulus presentations versus complex stimulus presentations; and 2) comparison of attentional performance in low intensity versus high intensity stimulus presentations.

METHODS

Participants:

The study sample included 12 healthy subjects (Age, mean = 26.71, SD = 4.49; 50 % male; and Education, mean = 15.50, SD = 2.54). Strict exclusion criteria were enforced so as to minimize the possible confounding effects of comorbid factors known to adversely impact cognition, including psychiatric (e.g., mental retardation, psychotic disorders, diagnosed learning disabilities, Attention-Deficit/Hyperactivity Disorder, and Bipolar Disorders, as well as substance-related disorders within two years of evaluation) and neurologic (e.g., seizure disorders, closed head injuries with loss of consciousness greater than 15 minutes, and neoplastic diseases) conditions. Subjects were comparable in age, education, ethnicity, sex, and self-reported symptoms of depression.

Procedure: The University of Southern California's Institutional Review Board approved the study. Experimental sessions took place over a two hour period. After informed consent was obtained, basic demographic information and computer experience and usage activities were recorded. Subjects then completed a neuropsychological battery administered under standard conditions. Following completion of the neuropsychological battery, subjects completed the simulator sickness questionnaire (Kennedy, Lande, Berbaum, & Lilienthal, 1992), which includes a pre-VR exposure symptom checklist. Next, all participants were administered the VRCPAT as part of a larger neuropsychological test battery.

Neuropsychological Battery: The following paper and pencil neuropsychological measures were used:

To assess Attention we used Digit Span (Forward and Backward) from the Wechsler Adult Intelligence Scale –Third edition (WAIS-III; Psychological Corporation, 1997). To assess processing speed we used Digit Symbol Coding from the Wechsler Adult Intelligence Scale –Third edition (WAIS-III; Psychological Corporation, 1997), and Trail Making Test Part A (TMT; Heaton, Grant, & Matthews, 1991; Reitan & Wolfson, 1985).

To assess executive functioning we used Trail Making Test Part B (TMT; Heaton, Grant, & Matthews, 1991; Reitan & Wolfson, 1985) and the Stroop Color and Word Test (Golden, 1978). To assess verbal learning and memory we used the Hopkins Verbal Learning Test – Revised (HVLT-R; Brandt & Benedict, 2001); to assess nonverbal learning and memory we used the Brief Visuospatial Memory Test – Revised (BVMT-R; Benedict, 1997); and to assess Lexical-Semantic Memory we used Controlled Oral Word Association Test (FAS: Benton, Hamsher, & Sivan, 1994); 2) Semantic Fluency (Animals; Gladsjo et al., 1999).

Virtual Reality Measures: The following two VR-based attentional measures were designed and evolved following iterative user testing: 1) Fixed Position in the Virtual City Test (See Figure 1); and 2) Humvee Attention Task.

Figure 1: Fixed Position in the Virtual City Test

Figure 2: Humvee Attention Task

<u>Fixed Position in the Virtual City Test</u>:

In this scenario subjects were given both a selective attention and a working memory task. For the selective attention portion, each subject listened to a virtual trainee as the trainee classified passing vehicles. For the evaluation, the virtual trainee reported either “US military”, “Iraqi police”, “Iraqi civilian” or “possible insurgent”. The subject was to tell the new recruit whether he was correct or incorrect. For the working memory portion, subjects were presented a series of single digit numbers. Subjects listened for the first two numbers, added them up, and reported the answer to the examiner. When the subject heard the next number, s/he added it to the one presented right before it. Subjects continued to add the next number to each preceding one. Subjects were not being asked to give examiner a running total, but rather the sum of the last two numbers that were presented.

For example, if the first two numbers were ‘5’ and ‘7,’ subject would say ‘12.’ If the next number were ‘3,’ subject would say ‘10.’ Then if the next number were ‘2,’ subject would say ‘5’ because the last two numbers presented were 3 and 2. See Table 1 for descriptives.

Table 1 Attention Descriptives for the Fixed Position in the Virtual City Test

	Mean	SD	Min	Max
Baseline # correct classifications	12.00	0.00	12.00	12.00
Trial 1 # correct classifications	21.55	0.69	20.00	22.00
Trial 2 # correct classifications	19.36	1.36	16.00	21.00
Trial 3 # correct classifications	20.45	0.52	20.00	21.00
Baseline correct additions	8.82	1.40	5.00	10.00
Trial 1 correct additions	17.73	1.74	15.00	20.00
Trial 2 correct additions	16.64	2.84	10.00	19.00
Trial 3 correct additions	17.00	3.44	7.00	19.00
Total of all the classifications	73.36	1.86	70.00	76.00
Total of all the additions	60.18	7.10	43.00	67.00
Total of everything	133.55	6.83	116.00	140.00

Note: For all analyses, N=12.

HUMVEE Attention Task: The Humvee scenario assessed attention within both “safe” and “ambush” settings: 1) start section; 2) palm ambush; 3) safe zone; 4) city ambush; 5) safe zone; 6) bridge ambush. The task involved the presentation of a four-digit number that was superimposed on the virtual windshield (of the Humvee) while the subject drove the Humvee. Each four-digit number was presented for approximately 300 ms and was randomly selected by the computer from a database of prescreened numbers.

Table 2: Descriptives for the HUMVEE Attention Task

	Mean	SD	Min	Max
Simple 2.0 (Start Section--safe zone1)	18.70	1.83	15.00	20.00
Simple 1.5 Palm Ambush	17.20	3.91	9.00	20.00
Simple .725 Safe Z 2	6.60	3.95	1.00	13.00
Complex 2.0 (city ambush)	13.70	1.57	11.00	16.00
Complex 1.5 safe Z3	13.20	4.37	4.00	18.00
Complex .725 bridge ambush	7.10	3.60	3.00	14.00
Total of all Simples	42.50	8.54	24.00	53.00
Total of all Complex	34.00	6.55	26.00	43.00
Total of all Ambush	38.00	7.62	24.00	47.00
Total of all Safe zones	38.50	8.09	26.00	49.00
Total of Humvee	76.50	14.08	53.00	94.00

Note: For all analyses, N=12.

Subjects were required to say the number out loud immediately after it appeared on the screen while the Humvee continued driving. An examiner will recorded the responses. See Table for descriptives of Humvee Attention Test.

The design consists of six Humvee attention conditions:

1. *Fixed Position: 2.0 second condition (Start Section):* In this condition, the four-digit number always appeared in a *fixed central* location on the "windshield." The numbers were presented at 2.0 second intervals. This occurred in the "Start Section" and ended just before the "Palm Ambush."
2. *Fixed Position: 1.5 second condition (Palm Ambush):* The procedure for this condition was identical to the "Fixed Position" condition described previously except that the numbers were presented at 1.5 second intervals. This occurred in the "Palm Ambush" section and ended just before the "Safe Zone" section.
3. *Fixed Position: 0.725 second condition (Safe Zone):* The procedure for this condition was identical to the "Fixed Position" condition described previously except that the numbers were presented at 0.725 second intervals. This occurred in the "Safe zone" and ended just before the "City Ambush" section.
4. *Random Position: 2.0 second condition (City Ambush):* The procedure for this condition is similar to the "Fixed Position" condition with the exception that the numbers appear *randomly* throughout the "windshield" rather than in one fixed central location. The numbers were presented at 2.0 second intervals. This occurred in the "City Ambush" and ended just before the "Safe Zone".
5. *Random Position: 1.5 second condition (Safe Zone):* The procedure for this condition is similar to the preceding "Random Position" condition except that the numbers were presented at 1.5 second intervals. This occurred in the "Safe Zone" and ended just before the "Bridge Ambush".
6. *Random Position: 0.725 second condition (Bridge Ambush):* The procedure for this condition is similar to the preceding "Random Position" condition except that the numbers were presented at 0.725 second intervals. This occurred in the "Bridge Ambush".

RESULTS

To examine scenario differences, one-way ANOVAs were performed, comparing attentional performance in simple stimulus presentations (Mean = 43.63; SD = 8.91) versus complex stimulus presentations (Mean = 34.63; SD = 6.86). The results indicated that the increase in stimulus complexity caused a significant decrease in performance on attentional tasks ($F = 5.12$; $p = 0.04$). To examine scenario differences, we compared attentional performance in low intensity (Mean = 40.01; SD = 4.06) versus high intensity (Mean = 9.25; SD = 3.70) presentations. The results indicated that the increase in stimulus intensity caused a significant decrease in performance on attentional tasks ($t = 9.83$; $p = 0.01$). Given the small sample size, we decided to not assess the construct validity of the VRCPAT Attention Modules. Hence, no attempts were made to assess correlations between standard paper and pencil tests and VRCPAT. See Table 3 for descriptives of standard paper and pencil tests.

Table 3: Descriptives of Paper and Pencil Neuropsychology Tests.

	Mean	Std.Dev.	Min	Max
Hopkins Verbal Learning Test (Learning)	29.80	3.58	24	35
Hopkins Verbal Learning Test (Recall)	10.89	1.54	8	12
Brief Visuospatial Memory Test (Learning)	29.00	3.02	23	34
Brief Visuospatial Memory Test (Recall)	10.60	0.97	9	12
Trail Making Test Part A	23.33	10.12	14	48
Trail Making Test B	50.33	5.55	41	57
Stroop Interference	93.10	17.55	69	125
WAIS Letter-Number-Sequencing	14.60	3.27	11	20
WAIS Digist Span Forward	12.70	2.54	9	16
WAIS Digist Span Backward	11.30	2.54	8	13
WAIS Digit Symbol Coding	83.00	17.92	54	107
Semantic Fluency	27.00	6.6	18	37
Letter Fluency	47.67	6.6	33	57

DISCUSSION

Our goal was to conduct an initial pilot study of the general usability of the VRCPAT Attention Module scenarios. We aimed at assessing whether the increase in stimulus complexity would result in a significant decrease in performance on attentional tasks. We also wanted to see whether an increase in stimulus intensity would result in a significant decrease in performance on attentional tasks. We believe that this goal was met as the study results indicated that: (1) the increase in stimulus complexity caused a significant decrease in performance on attentional tasks; and 2) the increase in stimulus intensity caused a significant decrease in performance on attentional tasks.

Our findings should be understood in the context of some limitations. First, these findings are based on a fairly small sample size. As a necessary next step, the reliability and validity of the test needs to be established using a larger sample of participants. This will ensure that the current findings are not an anomaly due to sample size. Additionally, the diagnostic utility of this attention assessment tool must be determined. The ability of the VRCPAT's Attention Module to accurately classify participants into attention impaired and attention intact groups based on carefully established critical values must be evaluated. This will involve the generation of specific cut-off points for classifying a positive or negative finding. The VRCPAT Attention Module's prediction of attentional deficits will need to be evaluated by the performance indices of sensitivity, specificity, predictive value of a positive test, and predictive value of a negative test.

In sum, manipulation of stimulus complexity and intensity in the VRCPAT's Attention Module caused a significant differences in performance on attentional tasks. Complementary comparisons of the VRCPAT's Attention Module with behavioral and neurocognitive tests developed to assess attentional processing are also warranted to determine the construct validity of the test.

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