Handheld Computerized Neuropsychological Assessment in a Virtual Reality Treatment Protocol for Combat PTSD

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Abstract

In this paper we introduce a new handheld computerized neuropsychological assessment system, i.e., BrainCheckers. This test system includes the Mental Efficiency and Workload Test (MEWT) designed for Primary Care and Pharmaceutical research, a Concussion Toolbox, and our Combat Stress Assessment (CSA). Focus will be on the CSA. It has been designed for assessment of injuries such as concussion due to blast exposure and/or Post Traumatic Stress Disorder (PTSD). It is presently being implemented as a key assessment instrument by the Virtual Reality Medical Center, San Diego, CA in a Virtual Reality (VR) treatment program for veterans from Iraq who have been diagnosed with PTSD.

BrainCheckers runs on handheld Palm® personal digital assistants (PDA). It includes a library of 20 tests that have been modeled after the Automated Neuropsychological Assessment Metrics (ANAM). Tests assess attention and concentration, working memory, mental flexibility, spatial processing, cognitive processing efficiency, memory recall, mood, and fatigue. It includes norms, and new tests such as an Emotional Stoop (E-Stroop). Our E-Stroop has been designed specifically for repeated assessment of PTSD treatment outcomes for veterans who have experienced psychological combat trauma in Iraq.

This system is presently being used in a variety of medical settings including military and Veterans Administration medical hospitals where efficient, cost-effective, and repeated assessments are essential.

Keywords: Neuropsychological assessment, Palm OS; ANAM; ARES; PTSD; Virtual Reality; Concussion; Combat; Stress
Introduction.

Computerized neuropsychological testing has predominantly used desktop or laptop computers and/or the Internet to administer tests. Such systems are suited for controlled research and clinical environments, but are impractical in operational medicine settings such as an Emergency Room, a desert field environment such as Iraq, or in general medical clinics/exam rooms. Further, very few systems have been designed for reliable serial assessment as is required in tracking treatment effects and recovery of patients with concussion and/or PTSD. Our solution has been a re-engineering of a validated computerized test system, i.e., the Automated Neuropsychological Assessment Metrics (ANAM) (Reeves, et. al., 2007), for use on handheld computers. The latest generation of development in this line is BrainCheckers. It includes a library of test modules that have been configured into standardized batteries for three specific product lines. They are: 1) a diagnostic Concussion Toolkit for assessments in Sports Medicine and of Blast Concussion; 2) a Mental Efficiency and Workload Test (MEWT) for primary care and pharmaceutical research; 3) and a Combat Stress Assessment (CSA) that includes a brief neuropsychological screen and PTSD assessment metric.

The BrainCheckers system is designed to provide precise measurement of cognitive processing efficiency in a variety of contexts. A prototype of BrainCheckers (i.e., ANAM Readiness Evaluation System, ARES), (Elsmore et. al., 2007), was tested in a field medical unit in 2003 in Iraq. It proved well suited for use in that hostile and sandstorm environment. Since then, hardware and software engineering has been completed along with concurrent validity research and development of a normative database.

Technical Information.

BrainCheckers includes a library of 20 ANAM tests that have been adapted for the Palm OS version of the C++ programming language. It runs only on Palm® handheld (PDA) computers. It requires Palm® OS, Version 4.1 or higher. The system is designed to run tests in flexible batteries to meet specific clinical, operational, and research goals. BrainCheckers operates on a wide range of color Palm OS PDAs; the Tungsten/E2 is our recommended full-featured unit. The system includes a Windows support program for communication between Windows PCs and the PDAs for data downloading, viewing, and archiving of data. Communication between PDA and desktop can be via direct serial link, USB, or landline and wireless modems. At the end of each test session, data are stored on the PDA in a Palm® database. Additionally, this includes a Microsoft® “.mdb” Access database file. All input for BrainCheckers CSA requires a PDA stylus.

History of BrainCheckers.

For decades the Department of Defense has been involved in the development of cognitive tests to assess and monitor changes in neurocognitive status of the war-fighter. The desktop PC version of ANAM has been the most prominent outgrowth of the Military-sponsored neurocognitive assessment systems. BrainCheckers development stemmed from a need for a portable automated neurocognitive testing system that could be used in field medical settings such as Iraq and Bosnia (Proctor, et al., 2002; Proctor, et al., 2003).
The first version of the Palm based ANAM was developed in the context of migraine research (Farmer et al., 2000). A small subset of tests was developed for the PDA and proved useful in assessing efficacy of treatment interventions for migraine. This instrument was named the Migraine Early Warning Tool (MEWT) (Farmer et al., 2001; Farmer et al., 2003). The MEWT could be administered in about five minutes to provide immediate feedback to the patient regarding possible onset of a migraine attack. This research demonstrated the sensitivity of the system to changes in the CNS and the practicality for use of a portable cognitive assessment system in clinical medicine. The second generation was developed for the military and field operation medicine. This system was called the ANAM Readiness Evaluation System (ARES). That system underwent a steady evolution and expansion and is now BrainCheckers.

The current system includes a multi-level set of batteries designed at the upper end to assess Fitness for Duty in high functioning patients, such as pilots, and at the lower end to assess and track patients with progressive dementia such as Alzheimer’s disease. The development has been guided through direct user feedback in clinical settings including medical centers such as the National Naval Medical Center, Bethesda, MD, the University of Maryland Medical Center’s Shock Trauma unit, National Center for PTSD, Menlo Park, CA, and the Naval Medical Center in San Diego. As a result, BrainCheckers modules have been "fine-tuned" for clinical use with modifications guided by patients' limitations and examiners' needs for flexibility in administration and ease of data management. Technical improvements have resulted in a mature, stable and reliable set of software modules.

**BrainCheckers Combat Stress Assessment**

The BrainCheckers Combat Stress Assessment is a neuropsychological test system designed for use in operational and clinical military medical settings. It has been designed for pre and post deployment neurocognitive/TBI/and PTSD, and repeated rehabilitative progress assessments.

BrainCheckers CSA includes five tests:

1. Sleep scale
2. Simple Reaction Time
3. Go-no-Go Reaction Time
4. Procedural Reaction Time
5. Matching to Sample
6. Mood Scale
7. OIF E-Stroop
Table 1 presents a listing of the test menu along with a listing of cognitive and emotional constructs associated with individual tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Neuropsychological Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sleep Scale</td>
<td>Subjective assessment of energy/fatigue level</td>
</tr>
<tr>
<td>2. Simple Reaction Time</td>
<td>Visual-response time—psychomotor reaction time</td>
</tr>
<tr>
<td>3. Go-no-GO Reaction Time</td>
<td>Response inhibition</td>
</tr>
<tr>
<td>4. Procedural Reaction Time</td>
<td>Sustained attention &amp; mental flexibility</td>
</tr>
<tr>
<td>5. Matching to Sample</td>
<td>Spatial working memory</td>
</tr>
<tr>
<td>6. Mood Scale</td>
<td>7 subscales assessing emotion/affect/physical state</td>
</tr>
<tr>
<td>7. ARS E-Stroop (OIF)</td>
<td>Cognitive &amp; Emotional response &amp; inhibition reaction time</td>
</tr>
</tbody>
</table>

Descriptions and illustrations of the component tests are presented in Appendix A.

The CSA was designed for repeated assessment of neurocognitive function, emotional status and hyper-reactivity. We included modules that have established validity and reliability (Bleiberg et al., 2001; Elsmore et al., 2007). Another consideration was to include measures of memory and executive function that are known to be impaired in individuals with mild traumatic brain injury and PTSD (Vasterling and Brewin, 2005).

**BrainCheckers and VR treatment for PTSD.**

At present, the Virtual Reality Medical Center (VRMC) is conducting a VR Treatment program for active duty personnel who have served in Iraq and who have PTSD. This program is funded by the Office of Naval Research (ONR) and is comparing the effects of Virtual Reality Graded Exposure Therapy (VRGET) with Cognitive Behavioral Group therapy on active-duty personnel. The BrainCheckers CSA is being implemented in this program as an objective index of emotional reactivity and cognitive processing efficacy. Within this program, we have developed an Emotional Stroop specifically for Operation Iraqi Freedom veterans.

Preliminary results from the project are presented in the tables below. The data in these tables were derived from 15 subjects who are presently undergoing treatment. These results are from our pre-treatment baseline assessment and provide a profile of the negative impact that PTSD has on cognitive processing efficiency and executive functions.

Table 2 presents results from the Sleep Scale. The sleep scale is a subjective assessment that requires the subject to select a statement that describes their level of alertness. Scores range for 1 to 7, with 1 defined as “active, vital and alert”, and 7 defined as “very sleepy, falling asleep”. As seen in Table 2 the group mean sleep score is 3, which is defined as “relaxed, not fully alert” and indicates that our subjects were adequately alert to proceed with the remainder of the test.

<table>
<thead>
<tr>
<th>Score</th>
<th>RT (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>21.6</td>
</tr>
</tbody>
</table>
Table 3 presents results from the Mood Scale. Scores represent the strength of emotion the individual is experiencing in each of the seven categories. Scores range from 0 to 100%. Additionally, the response time to each adjective presented in this test is recorded which provides a perspective on emotion and affect available only in our scale. Results reflect general euthymia and an almost dampened affect with none of the scores exceeding 50%. The response scores indicate the subjects took time to think about their responses and response times are balanced across categories.

<table>
<thead>
<tr>
<th>Mood Scale</th>
<th>Vigor</th>
<th>Happiness</th>
<th>Depression</th>
<th>Anger</th>
<th>Fatigue</th>
<th>Anxiety</th>
<th>Restless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score %</td>
<td>44</td>
<td>43</td>
<td>35</td>
<td>36</td>
<td>38</td>
<td>45</td>
<td>49</td>
</tr>
<tr>
<td>Response Time</td>
<td>2.86</td>
<td>2.97</td>
<td>2.68</td>
<td>2.09</td>
<td>2.29</td>
<td>2.00</td>
<td>2.37</td>
</tr>
</tbody>
</table>

Results shown in Table 4 are from our traditional Stroop test, which provides a measure of the ability for response inhibition. This test is the first computerized version of the Stroop developed for use on the PDA. It has been modeled after a well validated and standardized clinical version (Golden, 1978). There are two subsets, congruent and incongruent. In the congruent subset the words red, blue and green are presented in congruent colors and the subject taps on a block at the bottom of the screen that represents the color of the letters. In the incongruent subset the words are presented in incongruent colors. For example the word red might be displayed in green letters. Here again the subject is requested to tap the block that corresponds to the color of the letters. There is a strong tendency for the subject to want to read the word and tap on the block that represents the meaning of the word instead of the color of the letters. This is the “stroop” effect and requires the ability to inhibit the response tendency to produce a correct response. Results in Table 4 clearly reveal this effect across all scores by comparing the congruent with incongruent test results.

<table>
<thead>
<tr>
<th>Test name</th>
<th>meanCorRT</th>
<th>medCorRT</th>
<th>tput</th>
<th>% correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroop Congruent</td>
<td>.89</td>
<td>.82</td>
<td>75</td>
<td>97</td>
</tr>
<tr>
<td>Stroop Incongruent</td>
<td>1.14</td>
<td>1.04</td>
<td>58</td>
<td>91</td>
</tr>
</tbody>
</table>

Our study also includes a variation of the traditional Stroop paradigm, i.e., the Emotional Stroop (E-Stroop) (Beck, et. al., 2001 and Constans, et. al., 2004). Our version is unique and the first to be specifically designed for use in the assessment of PTSD in veterans from Iraq. The test is presently in the early stage of validation in this study. It is described in Appendix A.

Table 5 presents results from response time tests. In this table, test results from our subjects are compared to normative values. Scores include mean response time, median response time, throughput (number of correct responses per minute) and the percent correct. Simple Reaction Time is as the name implies a simple input/output visual response time test that requires the subject to tap on an asterisk each time it appears on the screen. The Procedural Reaction Time Test presents the numbers 2, 3, 4, or 5 rapidly on the screen. When the 2 or 3 appears the subjects taps on a block labeled 2, 3. The subject is instructed to tap on the block that is labeled 4, 5 when the 4 or 5 is flashed on
the screen. This test is forced paced and is a very good measure of mental flexibility and sustained concentration. Results in our study reveal an almost universal cognitive and psychomotor slowing in our subjects’ scores as compared to normative scores for 18-33 year-old subjects (shown in parentheses).

<table>
<thead>
<tr>
<th>Response Time Tests</th>
<th>Mean RT</th>
<th>Median RT</th>
<th>Throughput</th>
<th>% correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple RT</td>
<td>.42 (.26)</td>
<td>.39 (.25)</td>
<td>163 (236)</td>
<td>Na</td>
</tr>
<tr>
<td>Procedural RT</td>
<td>.65 (.54)</td>
<td>.63 (.53)</td>
<td>86 (108)</td>
<td>95 (98)</td>
</tr>
</tbody>
</table>

Conclusions

BrainCheckers is a handheld version of the ANAM, a widely utilized neuropsychological assessment instrument that has been undergone over 15 years of development. Its validity and reliability have been well established (Reeves, et. al., 2007). The CSA has been specifically tailored for assessing the impact of PTSD and treatment outcomes within a research protocol that is directed at creating an effective VR treatment for combat PTSD. In the VR laboratory, the CSA has been proven to be a practical instrument for measuring to emotional and neurocognitive changes over repeated trials. Through our current research, our hope is that the BrainCheckers CSA will also prove useful in detecting early signs of PTSD, and a combatant’s readiness to return to duty.

The CSA is being developed as a screening and brief assessment instrument, and to augment, not replace, traditional neuropsychological batteries such as Halstead-Raitan neuropsychological test battery. It provides an adaptable and efficient tool for use in a variety of environments, in this case the VR laboratory. It includes an automated cognitive status report that compares a patient against his or her own norm, as well as standardized norms based on various populations. This unique aspect of the system allows for use as a screening and serial testing instrument.

Future applications will involve testing its use in studies that involve medics and corpsmen in combat settings. Its application for detecting mild concussion due to mechanical and blast injuries, onset of PTSD symptoms, and the readiness of troops to return to combat will be an important extension from its in-vitro clinical laboratory into the combat in-vivo environment.

References


Elsmore, T, Reeves, D, & Reeves, A. (2007). The ARES® test system for Palm OS handheld computers. *Archives of Clinical Neuropsychology, 22,* (supplement 1), 135-144.


Appendix A

BrainCheckers CSA Test Descriptions

The following is a brief description of the tests included in the BrainCheckers CSA.

**Stanford Sleepiness Scale-Revised (SLP):** This module consists of a listing of seven statements that describe states of alertness. The original version was created and validated by Hoddes and colleagues (Hoddes, Zarcone, et al. 1973). This version was derived from the WRAIR PAB (Thorne, Genser, et al. 1985). In our version, the descriptive statements have been simplified to minimize the effects of education and culture. The statements implemented in the Sleepiness Scale are presented below. An item is selected by tapping the item with the stylus. A selection must be made before the program will advance.

![Sleepiness Scale](image)

**Reaction Time and general Cognitive Processing**

**Simple Reaction Time (SRT):** Simple Reaction Time serves two purposes. The first is to provide a measure of pure visual reaction time. The importance of such a basic measure is frequently overlooked in neurocognitive assessment. The second purpose is to provide a means to partial out the effects of motor response speed from actual cognitive processing time. This test presents a simple stimulus on the screen, (e.g., an asterisk *). The participant is instructed to tap inside the dotted box each time the stimulus is presented.

![Reaction Time](image)
**Go-No Go Reaction Time (GNG):** The go-no go measures the ability to shift mental set and response inhibition. The test presents one of two stimuli on the screen (e.g. + or *). The participant taps inside the box only when the “target” stimulus is presented. For example, tap every time you see a * symbol, and do not tap when you see the + symbol.

**Procedural Reaction Time (PRO):** This is a choice reaction time measure that requires the participant to differentiate between two sets of characters. The test presents a stimulus on the screen, a 2, 3, 4, or 5. The participant is required to tap a block labeled 2 or 3 if a 2 or 3 is displayed, and tap 4 or 5 if the digits 4 or 5 are displayed.
**Matching to Sample (MSP):** A 4 x 4 checkerboard-like matrix is displayed for three seconds and then disappears. After a five second interval, two matrices are displayed side-by-side. The participant indicates which of these two matrices matches the first exactly by tapping on the matching matrix.

![Sample and Matching options](image)

**Traditional and Emotional Stroop test.** The BrainCheckers Stroop test consists of 4 separate subsets. In all subsets the participant taps one of three boxes labeled as R, G, or B for Red, Green, or Blue. Instructions for all sets require tapping on the block that corresponds to the color of the letters. The first set presents words in congruent colors, the second set presents words in incongruent colors, the third set presents nonsense syllables in the three colors, and the fourth set, i.e., the Emotional Stroop present words that hold potential emotional charge for veterans who experienced psychological combat trauma in Iraq.

![Stroop test options](image)
**Mood/Affect Scale.** The Mood/Affect Scale consists of a 42-item checklist. Seven scales include Happiness, Depression, Anger, Anxiety, Restlessness, Vigor, and Fatigue. There are six adjectives per scale.

Adjectives are presented in the center of the screen with a 0-6 analog scale presented below. The participant is asked to tap on a number on the analog scale to indicate how the word describes how he/she feels at present. Responses are a two-step process. First the participant taps on a number, and then a secondary prompt appears that displays the choice and gives the participant a chance to change or affirm the response.

<table>
<thead>
<tr>
<th>Mood Scale Categories</th>
<th>Vigor</th>
<th>Happiness</th>
<th>Depression</th>
<th>Anger</th>
<th>Fatigue</th>
<th>Anxiety</th>
<th>Restless</th>
</tr>
</thead>
<tbody>
<tr>
<td>42-item, visual analog scale</td>
<td>energetic</td>
<td>good</td>
<td>miserable</td>
<td>grouchy</td>
<td>inactive</td>
<td>uneasy</td>
<td>fidgety</td>
</tr>
<tr>
<td></td>
<td>lively</td>
<td>content</td>
<td>discouraged</td>
<td>enraged</td>
<td>weary</td>
<td>alarmed</td>
<td>shaky</td>
</tr>
<tr>
<td></td>
<td>alert</td>
<td>cheerful</td>
<td>depressed</td>
<td>annoyed</td>
<td>lazy</td>
<td>insecure</td>
<td>on edge</td>
</tr>
<tr>
<td></td>
<td>spirited</td>
<td>sad</td>
<td>sad</td>
<td>angry</td>
<td>drowsy</td>
<td>afraid</td>
<td>restless</td>
</tr>
<tr>
<td></td>
<td>active</td>
<td>unhappy</td>
<td>furious</td>
<td>tired</td>
<td>nervous</td>
<td>anxious</td>
<td>agitated</td>
</tr>
<tr>
<td></td>
<td>vigorous</td>
<td>happy</td>
<td>hopeless</td>
<td>irritated</td>
<td>sluggish</td>
<td>jittery</td>
<td></td>
</tr>
</tbody>
</table>
Acknowledgements

The public domain DOS v3.11 ANAM has been the source for developing the BrainCheckers system. The first Palm® handheld ANAM was conceptualized by R. Cady and K. Farmer and constructed by T. Elsmore, D. Reeves in 1998. The Combat Stress Assessment battery was sponsored by the Virtual Reality Medical Center, San Diego, CA through a grant from the Office of Naval Research. Mark and Brenda Wiederhold were the driving force behind CSA development in the current line of research. BrainCheckers is owned and supported by Behavioral Neuroscience Systems, LLC, Springfield, MO.