Neuroscience and Simulation Interface for Adaptive Assessment in Serious Games

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Abstract--While advances in military relevant simulations provide potential for increasing assessment of Soldier readiness to Return-to-Duty (e.g., following a blast injury), little has been done to develop these simulations into adaptive virtual environments (AVE) for improved neurocognitive and psychophysiological assessment. Adaptive assessments offer the potential for dynamically adapting the difficulty level specific to the patient's knowledge or ability. We present an iteration of the Virtual Reality Cognitive Performance Test (VRCPAT) that proffers a framework for adapting scenarios in the Virtual Battlespace 2 (VBS2) game engine based upon the user's neurocognitive (task performance) and psychophysiological (e.g., heart rate, skin response, heart rate, and pupil diameter) states.

I. INTRODUCTION AND RELATED WORK

Military clinicians are increasingly being asked to make statements regarding a military service member's ability to return to active duty. 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 the serious games community to research innovative assessment methods. Current "Return-to-Duty" assessments are based upon the "Return-to-Play" guidelines found in Sports Medicine. Both have incorporated the Automated Neuropsychological Assessment Metrics (ANAM) to aid in decisions related to resuming activities following a concussion. Unfortunately, the ANAM was not developed with the intention of 1) adapting the difficulty level specific to the patient's ability; or 2) tapping into everyday behaviors like navigating a Middle Eastern city or gathering supplies for a mission.

Some promise has been found in serious gaming environments that aim to 1) incorporate adaptive assessments that dynamically adapt the difficulty level specific to the user's performance; and 2) increase the ecological validity of neurocognitive batteries through the use of simulation technologies for assessment and treatment planning [1]. The success of virtual reality-based neuropsychological assessment and psychophysiology research paradigms may lead to a psychophysiological computing approach, in which such data gleaned from persons interacting within a military relevant simulation may be used to develop adaptive virtual environments (AVE) for training and rehabilitation [2].

At the heart of psychophysiological computing are the tools available to measure activity within the brain. Psychophyhysiological measures offer indirect measures of brain activity such as cardiorespiratory activity, for example heart rate (HR) and heart rate variability (HVR), as well as measures of electrodermal activity such as skin conductance and galvanic skin response (GSR), respiration, and pupilometry. For a psychophysiological sensor to be useful it must be sensitive to an aspect of patient state that has cognitive or performance implications (i.e., arousal; cognitive workload). A key aspect of cognitive workload is the relation between the task and the user's abilities. Previous studies [3], [4] have shown that psychophysiological indices can be useful in adapting difficulty settings in games. Our framework leverages these advances to provide a more sophisticated performance assessment platform. An adaptive environment allows the soldier's performance to be evaluated over a specific range of stress levels.

Research on stress and performance has revealed that arousal is closely related to a subject's performance in mental tasks. According to the well-known Yerkes-Dodson Law [5], performance is a nonmonotonic function of arousal. Performance increases with arousal when the arousal level is low, then reaches its peak at the optimal arousal level, and then decreases as arousal continues to increase. So, in an adaptive virtual environment that aims to improve the user's performance in mental tasks, such as learning and cognitive workload, it is very important to be able to identify the user's optimal arousal level and to recognize whether or not the user's actual arousal level is close to that optimal level.

In earlier work [6], we modified the X-Box game *Full Spectrum Warrior* to develop a Virtual Reality Cognitive Performance Assessment test. The current iteration of VRCPAT uses Virtual Battlespace 2's (VBS2) [7] visual scenario editor and scripting language to develop the scenarios: virtual Iraqi/Afghani scenarios (City, Checkpoint, Humvee). The VBS2 engine was used due to its robust fidelity simulation, ease of modification, and adoption by many military forces.

II. THE NORMATIVE DATABASE (VRCPAT 1.0)

We first developed VRCPAT 1.0, which includes a "normative database" drawn from VE-based neuropsychological and psychophysiological measures of Military Service members [8]. Given the fact that blast injuries may cause a user's values to deviate from the norms found in the normative database, a user specific "General Cognitive Index" (GCI) is developed through comparison with a baseline assessment (see "Profile Module" below). The GCI is the standardized score that represents how far the user deviates from the norm. Cognitive workload resource capacity (as measured by the GCI) essentially represents how much information can be maintained and manipulated in working memory. Individual differences in cognitive workload

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capacity are consistently found and these differences are strongly correlated with performance on a number of different cognitive tasks.

III. THE ADAPTIVE FRAMEWORK (VRCPAT 2.0)

We have also developed an AVE: Virtual Reality for Cognitive Performance and Adaptive Treatment [2]. The VRCPAT 2.0 aims to progress the user from suboptimal cognitive and affective states toward an optimal state that enhances the user's performance. The simulation classifies adapts to the observed state of the user [9]. The application utilizes the NeuroSim Interface (NSI) developed in the Neuroscience and Simulation Laboratory (NeuroSim) at the University of Southern California. The NSI is used for data acquisition, stimulus presentation, psychophysiological monitoring, and communication between the psychophysiological recording hardware and the virtual environment. Configuration parameters are saved to files using the NSI and automatically loaded through its control module, allowing the experimenter to rapidly switch configurations in order to perform specific experimental sequences. The NSI also enables the sending of event markers from the stimulus presentation computer to the data recording device. Finally, the NSI compiles scripts to filter the incoming psychophysiological data in real-time. The VRCPAT 2.0 is composed of three modules.

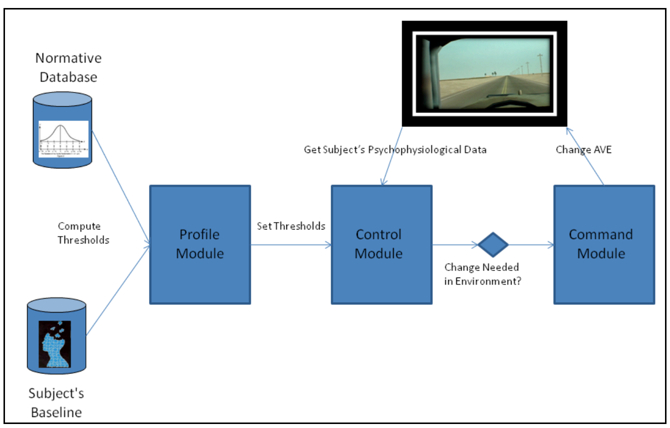

Fig. 1. The VRCPAT 2.0 Adaptive Framework. Users first establish set points during the profile module and then enter the adaptive simulation where the control and command modules guide the simulation based on the user's performance.

A. <u>Profiling Module (PM)</u>: The PM uses a baseline assessment that places the user in a simplified VE consisting of both high and low stress zones. Determination of whether the user's arousal level is above or below pre-established (normative database) thresholds is done using a comparison of features extracted from psychophysiological indices:

1) *Cardiorespiratory Activity* - Interbeat intervals (IBIs) are scored as the time difference in seconds between successive R waves in the ECG signal. Median IBIs for each window experienced in a given VRCPAT scenario serve as the features for analysis. A higher median result indicates a higher level of arousal in the user.
2) *Electrodermal Activity* – skin conductance response levels (SCLs) are calculated for each zone and analyzed, as are spontaneous fluctuations (SFs) in the skin conductance trace. SFs were defined as an increase of greater than 0.01 μS, with a peak amplitude coming within a window of 1 to 3 seconds following the initial increase in the signal. The number of SFs occurring in each sample within a window are calculated. Higher median responses indicate higher levels of arousal.
3) *Respiration* — Interbreath interval (IBrI) is recorded from the respiration data, and is scored for each sample within a window by calculating the median interval in seconds between peak amplitudes in the raw data signal, signifying one full breath cycle. A higher median result indicates a higher level of arousal in the user.
4) *Pupilometry* — (electrooculographic; EOG) the median pupil radius (measured in mm) for all samples within a window. The EOG signals are evaluated by laboratory-developed software that detects blinks and provides interblink intervals. Higher EOG responses indicate higher levels of arousal.

Feature extraction from the raw psychophysiological signals is performed using a sliding window starting every second with a total length per window of fifteen seconds. The median values for each of the psychophysiological features are then computed across all windows occurring in each zone. These values form the thresholds to determine how to change the adaptive environment. After the profiling run, the user is placed in the AVE.

B. <u>Controller Module</u>: During the simulation, all psychophysiological features are computed across a fifteen second sliding window. To combine all psychophysiological features, we use an approach similar to [10], in which the user is said to be in a hyper- or hypo-aroused state if and only if all psychophysiological features indicate that level of arousal. The severity of the stimuli can be tailored to how far the psychophysiological features exceed the mean for arousal state. For example, if the features are within one standard deviation of a hypo-aroused state then the explosion would be minor. If the features are two standard deviations below the mean for a hypo-aroused state, then the explosion would be severe and cause side effects such as briefly impaired vision. Stimuli can also be inhibited for several seconds to prevent the user from reaching a hyperaroused state.

Throughout the simulation, cognitive performance is assessed using a Humvee following simulation. Game players are instructed to maintain their initial separation from the lead vehicle (LV) despite changes in speed of the LV. The driver's vehicle is positioned 23 meters behind the LV and s/he is instructed to maintain the distance through acceleration and deceleration. The complexity of the task can be adjusted through variance of the lead vehicle's acceleration and deceleration. As in the arousal assessment above, cognitive performance metrics (distance headway between the LV and the following vehicle) are computed across a fifteen second sliding window. Herein, the user is said to be performing at expectation or deviating (above or below) from expected performance relative to the user's ability to maintain the 23 m distance from the LV. If the user is unable to maintain the 23 m distance relative to the LV, then the LV decelerates and maintains speed. If the user is consistently able to maintain the 23 m distance, then the LV's speed can become more variable.

Using the third-party networking software package ActiveMQ [11], this module then transfers neurocognitive and psychophysiological profile data to "command" signals. Values of the command correspond to changes in position and appearance of objects in the user's view of the VE and the instantiation or inhibition of immersive stimuli. The signals are fed to the "Command Module" to be processed by the VE.

C. Command Module: We developed a C++ plugin for the VBS2 engine that polls incoming ActiveMQ messages once per game frame. When a command signal is detected, the environment can then be adapted via scripting calls within the VBS2 engine. For our AVE, we scripted a number of stimuli for the high stress zones:

1) Improvised explosive device blasts near the in-game avatar of the user.
2) Insurgent AI characters who fire at the in-game avatar of the user.
3) Changing the in-game weather to be cloudy and rainy.
4) Activation of a scent machine to release smells similar to gunpowder in the environment.

The types of stimuli presented to the user are logged along with the user's neurocognitive performance and their raw psychophysiological readings. These logs are then parsed to score the neurocognitive functioning of the test subject.

The VRCPAT 2.0's "Command Module" has been designed to offer an adaptive virtual environment that can be explored by Military Service members under the supervision of a military psychologist. This virtual adaptive assessment and rehabilitation system aims to place the injured Military Service member into a state of optimal experience defined as "flow" to trigger a broad recovery process [12]. According to Csikszentmihalyi [13], "flow" is best understood as an optimal state of consciousness that is characterized by a state of concentration so focused that it results in complete immersion and absorption within an activity. Following the work of Fairclough [14], we partition the "flow" state of the Military Service member into four quadrants or "zones" (see Figure 2).

Our "Command Module" is being developed to place the patient (e.g., Military Service member that has experienced a blast injury and/or combat stress symptoms) in VRCPAT 2.0 at the optimal starting point for that Military Service member; Zone A. We do not conceptualize the flow of rehabilitation/treatment to be a static experience. A Military Service member's skill level tends to be low when first immersed in VRCPAT. As the patient's experience of the program increases, skills increase and s/he may become bored if the challenge remains constant (Zone C). Within VRCPAT2.0, the challenge will increase, but usually at a different rate than the Military Service member's ability level. Hence, the Military Service member is constantly in a state of flux between the four points shown in Figure 2.

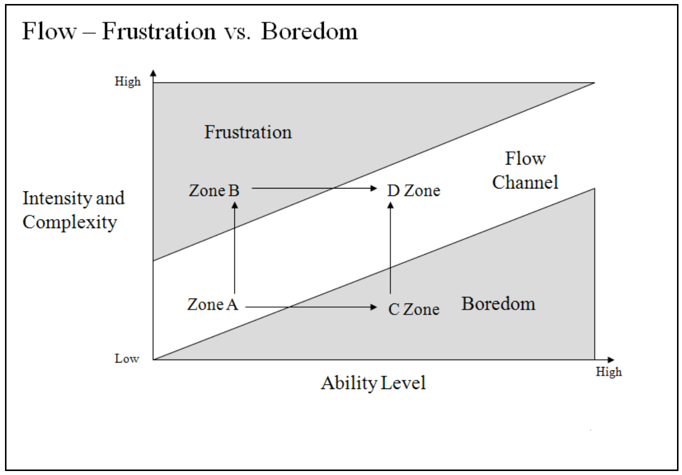

Fig. 2. Two-dimensional representation of state of the user: Note, this is an adaptation of graphs found in Csikszentmihalyi [13] and Fairclough [14].

At times the user may begin to disengage (start to experience boredom and move toward Zone C) when the challenge does not increase in pace with his or her skills. At other times, the user may move towards frustration (Zone B) when s/he is slow to learn the necessary skills. Particularly relevant to Csikszentimihalyi concept of flow states is Zone B because it represents a "stretch" zone, in which the Military Service member is engaged and ability levels are being increased as they are pushed toward frustration. Fairclough (2009) has explained that this state may be tolerated for short periods (e.g., learning phases and/or a demanding but rewarding period of performance). Overall, the goal of VRCPAT 2.0 is to keep the Military Service member in Zone D—continually adapting the intensity and difficulty of the environment to have the Military Service member in a flow state with improved skills and being able to function at a higher level of challenge. This conceptualization allows the adaptive virtual environment to make a distinction between two states of low performance, both of which require different categories of adaptive response. For example, in Zone B, the intensity and complexity of the stimuli should be reduced until the ability level has been optimized. Further, if the Military Service member's results indicate that s/he is heading to Zone C, the VRCPAT should adapt so that task demands be increased. This complex representation of the Military Service member provides the "Controller Module" with greater specificity in order to target the adaptive response.

IV. Discussion

While advances in military relevant simulations provide potential for increasing assessment of Soldier readiness to Return-to-Duty, little has been done to develop these simulations into AVEs for assessing cognitive workload. We have presented a framework to do enhanced neurocogntive assessment using an AVE that is being validated at West Point, the University of Southern California, Madigan Army Medical Center, and Tripler Army Medical Center. VRCPAT

2.0 offers a dynamically adapting functional assessment of patients.

A real-time adaptive virtual environment that is sensitive to cognitive and emotional aspects of user experience, as delineated in this manuscript, is considered to be the future alternative for devising cognitive assessment and training measures that will have better ecological/predictive validity for real-world performance.

Further, the flexibility of stimulus delivery and response capture that are fundamental characteristics of such adaptive virtual environments is viewed as a way for military psychology objectives to be addressed in a more efficient fashion for long term needs. Such flexibility would allow for this system to be viewed as an open platform on which a wide range of research questions could be addressed that would have significance to military psychologists.

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