Chapter 9
Neurocognitive and Psychophysiological Interfaces for Adaptive Virtual Environments

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ABSTRACT

The use of neuropsychological and psychophysiological measures in studies of patients immersed in high-fidelity virtual environments offers the potential to develop current psychophysiological computing approaches into affective computing scenarios that can be used for assessment, diagnosis and treatment planning. Such scenarios offer the potential for simulated environments to proffer cogent and calculated response approaches to real-time changes in user emotion, neurocognition, and motivation. The value in using virtual environments to produce simulations targeting these areas has been acknowledged by an encouraging body of research. Herein the authors describe (1) literature on virtual environments for neurocognitive and psychophysiological profiles of users' individual strengths and weaknesses; and (2) real-time adaptation of virtual environments that could be used for virtual reality exposure therapy and cognitive rehabilitation. Specifically, the authors discuss their approach to an adaptive environment that uses the principles of flow, presence, neuropsychology, psychophysiology to develop a novel application for rehabilitative applications.

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INTRODUCTION

While standard neurocognitive measures have been found to have adequate predictive value, their ecological validity may diminish predictions about real-world functioning. Traditional neurocognitive measures may not replicate the diverse environment 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., 2004a; 2005). Although today's neurocognitive assessment procedures are widely used, neuropsychologists have been slow to adjust to the impact of technology on their profession. While there are some computer-based neuropsychological assessments that offer a number of advantages over traditional paper-and-pencil testing (e.g., increased standardization of administration; increased accuracy of timing presentation and response latencies; ease of administration and data collection; and reliable and randomized presentation of stimuli for repeat administrations), the ecological validity of these computer-based neuropsychological measures is less emphasized. Only a handful of neuropsychological measures have been developed with the specific intention of tapping into everyday behaviors like navigating one's community, grocery shopping, and other activities of daily living. Of those that have been developed, even fewer make use of advances in computer technology. Some promise has been found in virtual and augmented reality environments that aim to increase the ecological validity of neurocognitive batteries through using simulation technologies for diagnosis and treatment planning. A potential drawback of using such ecologically enhanced simulations is that scientific progress necessitates greater emphasis on experimental control. One way that researchers have attempted to move beyond this impasse is the use of psychophysiological assessments. Ultimately, the success of the virtual reality and psychophysiology research paradigms has led to a psychophysiological computing approach, in which psychophysiological data gleaned from persons interacting within a virtual environment are used to adapt the virtual environment in real-time.

The plan of this chapter will be as follows. In Section 2 we describe the potential of virtual environments for increasing the ecological validity of neurocognitive assessments. Of note, however is the fact that simply increasing the verisimilitude of the neurocognitive assessment is not enough. Without an increase in veridicality, virtual environments run the risk of having poor experimental control. In Section 3, we consider psychophysiological assessment as a way to enhance experimental control in virtual environments that are being used for clinical applications. Psychophysiological metrics provide an excellent measure of presence and autonomic arousal. Hence, they provide a profile of the user state and a validation of the impact of the virtual environment on the user. In Section 4, we look at psychophysiological computing as the next logical step in the evolution of the use of psychophysiological and neurocognitive profiling of user's responses while immersed in virtual environments. Psychophysiological computing represents an innovative mode of human computer interaction (HCI) wherein system interaction is achieved by monitoring, analyzing and responding to covert psychophysiological activity from the user in real-time. In Section 5, we turn to adaptive virtual environments and and four interrelated objectives or Technical Areas that are necessary for developing an adaptive environment. Next, in section 6, we discuss our development of an adaptive environment that uses the principles of flow, presence, neuropsychology, psychophysiology to develop a novel application for rehabilitative applications. Finally, in conclusion, we briefly summarize the main ideas of this chapter. From our perspective, adaptive virtual environments offer the potential for a broad empowerment process within the flow experience induced by a high sense of presence coupled with improved ecological validity

INCREASING ECOLOGICAL VALIDITY

To establish ecological validity of neurocognitive measures, psychologists focus on demonstrations of either (or both) verisimilitude and veridicality (Franzen & Wilhelm, 1996). By verisimilitude, ecological validity researchers are emphasizing the need for the data collection method to be similar to real life tasks in an open environment. For the neurocognitive measure to demonstrate veridicality, the test results should reflect and predict real world phenomena (Chaytor, & Schmitter-Edgecombe, 2003; Silver, 2000; Ready, Stierman, & Paulsen, 2001).

Virtual Environments for Increased Verisimilitude

Virtual reality (VR) is as an advanced computer interface that allows humans to become immersed within a computer-generated simulation. Potential VR use in assessment and rehabilitation of human cognitive processes is becoming recognized as technology advances. Since virtual environments allow for precise presentation and control of dynamic perceptual stimuli (visual, auditory, olfactory, gustatory, ambulatory, and haptic conditions), they have the potential to provide ecologically valid assessments that combine the ecological verisimilitude that reflects real life situations and veridical control of laboratory measures. Such simulation technology appears to be distinctively suited for the development of ecologically valid environments, in which verisimilitude is actualized through the presentation of three-dimensional objects to a given user in a consistent and precise manner. As a result, subjects are able to manipulate three dimensional objects in a virtual world that proffers a range of potential task demands. Although much of virtual reality research emphasizes verisimilitude over veridical control, the enhanced computation power of virtual environments may be harnessed to allow for a range of the accurate recording of neurocognitive and psychophysiological responses in a perceptual environmental that systematically presents complex stimuli.

Virtual reality applications that focus on component affective and cognitive processes are now being developed and tested. Some of the work in this area has addressed affective processes: anxiety disorders, pain distraction and posttraumatic stress disorder (see Parsons & Rizzo, 2008b for review). Other work has assessed neurocognitive processes (see Rizzo et al., 2004). Further, psychophysiology is increasingly being incorporated into research using virtual reality environments (see Pugnetti et al., 2001 for review). The use of psychophysiological measures in affective and neurocognitive studies of persons immersed in high-fidelity virtual environment scenarios offers the potential to develop current physiological computing approaches (Allanson & Fairclough, 2004) into affective computing (Picard, 1997) scenarios.

The increased ecological validity of neurocognitive batteries that include assessment using virtual scenarios may aid differential diagnosis and treatment planning. Within a virtual environment, it is possible to systematically present cognitive tasks targeting neuropsychological performance beyond what are currently available using traditional methods (Rizzo et al., 2004). Reliability of neuropsychological assessment can be enhanced in virtual environments by better control of the perceptual environment, more consistent stimulus presentation, and more precise and accurate scoring (Rizzo & Buckwalter, 1997). Virtual Environments may also improve the validity of neurocognitive measurements via the increased quantification of discrete behavioral responses, allowing for the identification of more specific cognitive domains (Rizzo & Kim, 2005). Virtual environments could allow for neurocognition to be tested in situations that are more ecologically valid. Participants can be evaluated in an environment that simulates the real world, not a contrived testing environment (Riva et al., 2004).

Virtual Environments and Veridicality: Potential Loss of Experimental Control

The application of VR to neurocognitive assessment is considered by a growing body of researchers to be distinctively important because it represents the potential for more than a simple linear extension of existing computer technology for human use (Campbell et al., 2009; Carelli et al., 2009; Riva et al., 2004). For such researchers, it is important that VR does more than simply automate the paradigms of the past (Penn et al., 2009). Instead, virtual environments should provide a paradigm shift for the future. This desire reflects Neisser's (1978) contention that the findings from many traditional cognitive assessments have not been demonstrated to generalize beyond the narrow laboratory context. However, there is an essential tension between persons striving for ecological validity and persons interested in maintaining experimental control. For example, Banaji and Crowder (1989) have contended that the ecological approach to neurocognitive research is inconsequential and that scientific progress necessitates greater emphasis on experimental control. This seems to hold especially true for much of the work that has been done in virtual and augmented reality because the focus of ecological validity tends to be upon verisimilitude and not veridicality. As Banaji and Crowder have challenged, if neurocogitive measures fail to establish internal validity, then one can conclude nothing from study findings. Likewise, if VR-based neuropsychological assessments do not take seriously the importance of veridicality, we have attractive simulations (i.e., verisimilitude), but do not have an ability to reliably and validly predict a person's performance on real-world activities (i.e., veridicality).

There are a number of researchers that would agree with Neisser that there are legitimate concerns about the verisimilitude (or ecological validity) of neurocognitive assessments. However, while the issue of ecological validity has been discussed in the literature, little has been done to remedy this situation. Instead, there are attempts to simply enhance the external validity of neurocognitive assessments. The concepts of external and ecological validity are related but not interchangeable. External validity involves the extent to which findings from research studies can be generalized across a variety of persons, times, and settings as well as to generalizations to specific persons, times, and settings. Given that traditional paper-and-pencil neurocognitive measures were developed for localization and the focus was upon double dissociation, enhancements tend to reflect endeavors to increase external validity. Hence, they do not typically require experimental conditions to mirror real-life conditions. Neurocognitive measures are quite basic in their presentation and do not appear concerned with the level of verisimilitude found in virtual environments. Instead, they strive to be externally valid—to be consistently predictive of behavior exhibited in the real world.

As mentioned above, though, Banaji and Crowder have contended that the ecological approach to neurocognitive research is insignificant and that scientific progress necessitates greater emphasis on experimental control. Unfortunately, much VR research supports this dichotomy. While verisimilitude is a major emphasis in reported studies using VR for psychology and neuropsychology, much less emphasis is placed upon veridicality—reliability, validity, and psychometric properties. In a recent meta-analysis of VR studies, Parsons and Rizzo (2008a) sought to examine the magnitude of changes in affective functioning that occurred following virtual reality exposure therapy (VRET). Although the results of the meta-analysis revealed that VRET had statistically large effects across affective domains, findings must be interpreted with caution given the inconsistencies in the research designs across studies. Many of the VRET studies did not include control groups, and many were not randomized clinical trials. As a result, the authors had diminished confidence that affective enhancements were directly related to or caused by VRET. Additionally, even though Parsons and Rizzo attempted to identify possible moderators of affective improvements, this was not possible because necessary information was either not reported or on occasions where it was reported it was done so in insufficient detail. This lack of information related to affective improvements and presence, immersion, anxiety and/or phobia duration, demographics (e.g. age, gender, and ethnicity) may reflect a limited range of values given the selection criteria employed by most studies. Thus, the findings of this meta-analysis may not generalize to patients with anxiety disorders in general. Similarly, a host of other factors that could not be directly analyzed might moderate affective regulation, including differences among treatment centers in terms of beliefs about best practices concerning VRET, timing of sessions, and concurrent psychopharmacological treatment.

Assessment of the impact of the virtual environment on the user is often difficult. Numerous studies exclusively employ subjective response questionnaires to draw conclusions about the user-state during virtual environment exposure (e.g., Carlin et al., 1997; Hodges et al., 1996; Renaud et al., 2002). Self-report data, when used in isolation, are highly susceptible to influences outside the subject's own targeted attitudes (Schwarz, 1999). The item's wording, context, and format are all factors that may affect self-report responses. Knowledge of the user-state during exposure to the virtual environment is imperative for development and assessment of virtual environment design. Individuals will invariably have different reactions to a given virtual environment, and without an assessment tool that can be employed online, the researcher will experience difficulties in identifying the causes of these differences, which may lead to a loss of experimental control of the research paradigm. A user may become increasingly frustrated with some aspect of the environment, but without proper measurement techniques to detect this frustration while it occurs, the user's sense of presence, or feeling of "being there," (Witmer & Singer, 1998) may be diminished. While virtual environments offer the capability of presenting a realistic simulation of the real world, online assessment of the user's reactions to that environment is vital to maintain an understanding of how the environment is affecting the user to preserve experimental control.

PSYCHOPHYSIOLOGY TO ENHANCE EXPERIMENTAL CONTROL IN VIRTUAL ENVIRONMENTS

Psychophysiological metrics provide a number of advantages over self-report for the enhancement of experimental control in virtual environments. The psychophysiological signal is continuously available, whereas behavioral or self-report data may be detached from the virtual environment and presented intermittently (Allanson & Fairclough, 2004). The continuous nature of psychophysiological signals is important for several reasons. First, it allows for greater understanding of how any stimulus in the environment impacted the user, not only those targeted to produce behavioral responses. It also follows that a break in the user's sense of presence is not necessary, because the signal is measured continuously and noninvasively, and as Slater et al. (2003) report, it is even possible that psychophysiological measures can be used to uncover stimuli in the virtual environment that cause a break in presence. It is also important to note that psychophysiological responses can be made without the user's conscious awareness, creating an objective measure of the user's state, which can include measures of cognitive workload (e.g. Berka et al., 2007; Brookings et al., 1996; Kobayashi et al., 2007), varying stress levels (Branco & Encarnacao, 2004; Fairclough & Venables, 2006), task engagement (Pope et al., 1995; Seery et al., 2009), and arousal (Bradley & Lang, 2000; Cuthbert et al., 1996; Cuthbert et al., 2000) among others. Additionally, multiple channels of psychophysiological data can be gleaned from various sensors continuously, which further increase experimental control by providing a combination of measures, so that one measure alone is not the sole basis for design decisions (Hancock & Szalma, 2003). To summarize, psychophysiological metrics provide a means of obtaining objective and ongoing measures of user-state through noninvasive and non-conscious methods to improve experimental control. Virtual and augmented reality scenarios offer the potential for simulated environments to proffer cogent and calculated response approaches to real-time changes in user emotion, neurocognition, and motivation processes. The value in using simulation technology to produce virtual environments targeting such processes has been acknowledged by an encouraging body of research.

The incorporation of simulation technology into neuroergonomic and psychophysiological research is advancing at a steady rate (see Parasuraman & Wilson, 2008). New discoveries and techniques are demanding a more rapid and advanced paradigm. In response to the demands, a wide variety of simulations have been developed. The range and depth of these simulations cover a large domain, from simple low fidelity task environments to complex high fidelity full immersion simulators. All of these simulators rely on some type of representation of the real world. An important issue for research into simulation for social and behavioral sciences is the determination of how advanced the simulator needs to be to adequately assess and/or train a particular individual or team. While high-end simulations can train a variety of user types, the cost associated with these devices can be difficult to justify (Langhan, 2008).

While the determination of the level of scenario fidelity will be relative to the questions asked and the population studied, one important component to most evaluations would be the extent to which level of fidelity impacts the users' experience of presence (Slater et al., 2009). In this paper, we follow a generally endorsed view that "presence" be considered as the propensity of users to respond to virtually generated sensory data as if they were real (Sanchez-Vives & Slater, 2005). In the same way people experience physiological responses to stimuli in the real world, researchers seek to quantify presence by measuring responses evoked by stimuli in an immersive virtual environment. A low fidelity virtual environment may be preferable in studies where a maximal amount of control is desired because such environments may increase psychometric rigor through limiting the number of sensory variables available. Contrariwise, high fidelity environments are preferable for studies desiring increased ecological validity because they recreate more of the real world environment—better capture the subject's performance as it would occur in a real world setting. It is important to note that the fidelity tradeoffs in the virtual environments may mimic the issues related to real world assessments—psychological measures in controlled settings and behavioral ratings based upon naturalistic observations do not proffer consistently parallel findings. Further, dissimilar cognitive and affective components may be dissociated both by psychological measures in controlled settings and behavioral ratings based upon naturalistic observations (Gordon et al., 2006).

Discussions of the level of fidelity needed for a virtual environment should go beyond simple discussions of the "immersive" qualities of the environment to an understanding of the impact upon the perceived feeling of "presence" of the individual while immersed in the environment (Slater, 2005). A number of discussions of the distinction between the terms "immersion" and "presence" can be found in the literature (Draper et al., 1998; Slater, 1999; Slater & Wilbur, 1997). This distinction is important for the current study because issues of fidelity tend to reflect levels of immersion, while levels of presence reflect the user's experience relative to the level of fidelity/immersion. By immersion, we mean that which the overall virtual environment can deliver (e.g., the level of fidelity in representing the real world; the field of view, the number of sensory systems it simulates, the frame-rate, and latency). Hence, the level of immersion is an objective property of a virtual environment that in principle can be measured independently of the human experience that it engenders. Presence, however, is the human user's response to the virtual environment.

While the vast majority of research on presence has represented the concept as a subjective state or feeling that is accessible and measurable by questionnaires (see Draper et al., 1998; Witmer & Singer, 1998), a quite different view seems to be emerging, in which presence is treated as something rooted in activity (Sanchez-Vives & Slater, 2005). As such, researchers may study presence by looking at the psychophysiological responses of users to their surroundings and their ability to actively modify those surroundings (Flach & Holden, 1998; Meehan, et al., 2002; Pugnetti et al., 2001). The recording of psychophysiological variables while participants operate within virtual environments has produced useful results in studies examining immersion and presence (Jerome & Jordan, 2007; Macedonio et al., 2007; Parsons et al., 2009b; Wiederhold & Rizzo, 2005). As such, the VR assets that allow for precise stimulus delivery within ecologically enhanced scenarios appears well matched for this research.

PSYCHOPHYSIOLOGICAL COMPUTING

Psychophysiological computing represents an innovative mode of human computer interaction (HCI) wherein system interaction is achieved by monitoring, analyzing and responding to covert psychophysiological activity from the user in real-time (Parsons et al., 2009a,b; Allanson and Fairclough, 2004). Psychophysiological computing represents a means of creating for the computer system a more empathic link to the user. The goal is to allow for the computer to have an understanding of the user's state and to adjust and adapt to better address the specific needs of the user. Allanson (2002) notes that much of human-human interaction is influenced by largely unconscious emotional cues, which can be tapped into through psychophysiological measurement of the user's state to provide a computer with some of the same knowledge that allows humans to intelligently interact with other humans.

Psychophysiological computing has many applications and proffers numerous advantages for improving HCI. Research on adaptive automation uses psychophysiological feedback from the user (e.g. pilots and military personnel) to assess engagement and cognitive workload in order to provide assistance when a lack of focus or an overload of task difficulty occurs (Allanson & Fairclough, 2004; Byrne & Parasuraman, 1996; Middendorf et al., 2000). Brain-computer interfaces relying mainly on electroencephalographic user responses have been utilized to assist patients with motor disorders, providing what has been called a "mental prosthesis" (Donchin et al., 2000; Farwell & Donchin, 1988). Psychophysiological computing has also been used to vary task difficulty to improve training scenarios (see Coyne et al., 2009 for review).

The current research is concerned mainly with utilizing psychophysiological computing to adapt a virtual environment in real-time based on the user's emotional and cognitive state. A biocybernetic loop between the user and the VR system is the key component of the adaptive system (Fairclough, 2009). The loop consists of psychophysiological and behavioral data gleaned from the user by use of sensors placed on the body, which can record continuous signals and be fed into an interface. The data are then processed in real-time to assess the particular psychological state in which the user currently resides, such as engaged, frustrated, afraid, etc. The interface uses algorithms designed to assess patterns of response based on the multiple data channels, such as skin conductance, heart rate, and respiration, to determine the user's emotional, cognitive, or motivational state. The interface then sends a signal to the virtual environment to allow adaptation of the environment to fit the needs of the user to occur. For example, if a user is experiencing an ambush in a virtual war scenario resulting in intense levels of stress, the interface may send a signal to decrease the intensity of the ambush being experienced. The biocybernetic loop is completed when the user then responds to the changes that have been made in the environment and the process begins again.

Such an addition to a virtual environment would allow for a neurocognitive assessment system that would operate by transforming neurocognitive and psychophysiological data into a control signal (or an input to a control signal) without a requirement for any overt response from the user. A psychophysiological computing addition to a virtual reality-based assessment of cognition would capture spontaneous and subconscious facets of user state, opening up bandwidth within the virtual reality system by enabling an additional channel of communication from the user to the virtual environment. Information exchange between a user and the virtual environment would be rendered symmetrical as the virtual environment constructs, consults, and responds to a dynamic representation of the user.

Optimally developed psychophysiological metrics for a virtual environment will adapt the simulation to the dynamic link between the user's neurocognitive and affective systems and the ways in which these systems work together to process information and execute action (Cacioppo and Berntson, 1999). Evidence suggests that motivations associated with approach/withdrawal behaviors may be linked to cognitive processing (Sutton and Davidson, 1997) and many studies have examined the relations between neurocognitive performance and affective style (Ackerman et al., 1995; Bell and Fox, 2003; Davidson, 1995; Schaie et al., 1991; Waggett and Lane, 1990).

Picardian Affective Signals and Systems

There have been attempts to establish thresholds and signals for affective models. Picard's (1997) models describe the relationship between stimuli and a subject's emotional responses, represented by physiological signals. For simplicity, we consider only one physiological signal each time. Following Picard, one may apply a stimulus to the subject, and measure his/her physiological response (e.g., heart rate). The goal is to find a model such that given a sequence of stimuli, one may compute the corresponding physiological response. Picard's model assumes that the user's affect is nonlinear and time-invariant, and models the affective signals and affective systems separately.

In order to simplify the meaning of these assumptions, Picard draws a parallel between physiological responses and the ringing of a bell. If a bell were to represent a linear system, then a soft strike to the bell would cause a certain level of ringing, while a strike that is exactly twice as forceful would cause exactly twice the level of ringing. However, if a bell is tapped too lightly, no sound will occur at all, and if it is struck too forcefully the bell may crack and not ring properly. Thus, the bell represents a non-linear system. A person's affective responses are similar, in that a given an auditory stimulus may cause a skin conductance response, but playing that auditory stimulus twice as loud will probably not cause a skin conductance response that is exactly twice as large.

If a system is time-invariant, it will respond the same way regardless of when the stimulus is presented. If one was to ring a bell with a given force today, it will respond with the same with the exact same level of ringing if one was to ring the bell with the same force tomorrow. However, if one was to continuously ring the bell without giving it time to stop ringing, it may begin to have an additive effect on the volume of the ring. If a person is startled today, they jump in the same way if startled by the same stimulus tomorrow. However, if the person is repeatedly startled, the response would diminish due to habituation. Affective response systems are thus nonlinear, and are not time-invariant.

Picard describes two explain how given inputs will result in varying outputs in human affective systems. First, a sygmoidal function curve is used to describe the output responses of an affective system. Stimulus intensity is mapped into an affective stimulus intensity by considering the nonlinearity when a subject perceives a stimulus. The model is a sigmoidal nonlinearity expressed by the equation: $y' = \frac{g}{1 + e^{-(x - x_0)/s}} + y_0$, where: *x*: is the input (i.e., the actual stimulus intensity to the subject). y': Is the affective stimulus intensity for the input *x*. It is the input to the Affective Systems Model. *g*: Is a parameter determining the range of y'. x_0: Is a parameter to ensure that a tiny stimulus does not produce a noticeable effect. *s*: The steepness of the sigmoid, representing how fast y' changes with *x*. A smaller *s* gives a steeper sigmoid. y_0: Is a bias that moves the sigmoid up and down; it can be understood as the mood of the subject.

A second model is used to show the decay of the response over time due to habituation. It is expressed mathematically by this equation: $y = y'e^{-bt}$, it describes the relationship between the physiological response *y* and the affective stimulus intensity y' over time. It is modeled by an exponential decay function, where the physiological response (e.g., heart rate), will decay over time depending on the stimulus intensity and a constant determining the speed of the response decay.

Finally, note that the above response decay model only considers the effect of one stimulus. If there is a sequence of stimuli, then the effects of stimuli before the current stimulus should also be taken into consideration.

Limitations of Picard's Models

Although Picard's models account for many of the properties of behavior in an emotion system (e.g., response decay, temperament and personality influences, nonlinearity, saturation, background mood, etc.), we have found that some modifications are needed for our representation of the user for adaptive control of the virtual environment. First, we desire increased consideration of all possible causes of saturation of a response system. Although the sigmoidal nonlinearity considers the saturation when a single stimulus is very large, repeated large stimuli may still make the overall response curve increase without bound. Second, since affect tends to be time-variant, we feel that it is desirable to be able to adaptively update the parameters of the models. The following revised models for affective signals and systems are proposed to overcome these limitations.

Affective Signals Model

Following Picard's model, our revised model again converts an actual stimulus intensity to an affective response intensity, which is the input to our new Affective Systems Model. Instead of considering each stimulus independently and then combining their corresponding response curves, as found in Picard's approach, we compute the affective response by incorporating the effects of all stimuli before and at the current time instant. Then, in the Affective Systems Model we no longer need to combine the decaying response curves for previous stimuli. In this way we can handle more forms of saturation.

This new affective system model will better describe the relationship between the physiological response and the affective stimulus intensity. Picard models it by an exponential decay function without delay. We think that it is more reasonable to incorporate the delay because every physical system needs some transition time. The response curves for different physiological signals, e.g., heart rate, EMG, etc, may assume different shapes. Here is an intuitive method to identify, for example, the response curve for heart rate: we first generate some response curves starting from the relaxed state and then find a function to approximate these curves. We require that a subject maintain a relaxed state before a response curve is generated to ensure that the response curve is not complicated by cumulative responses from previous stimuli. For example, if emotional pictures are used, then a long time interval may be needed before showing each new picture to the subject so that the subject can calm down, and return to a baseline level of responding. Once enough response curves are obtained, we can observe their shapes and find a function to approximate them. Using emotional pictures with delays between them, allows for an estimation of the range of responses that are typical of a given subject. It is important to have an understanding of each individual's response patterns, as each subject will respond somewhat differently to various stimuli. The range of responses determined by this baseline procedure would then be inputted into an algorithm that will allow for changes to the environment to be made based on the specific pattern of the individual's response systems.

An example of a procedure to determine response patterns of individuals before entering an adaptive environment was carried out by Haarmann, Boucsein, and Schaefer (2009). A virtual flight simulator environment was utilized, and the difficulty of the task that subjects were asked to perform was dependent on the subjects' physiological responses to the current task. To determine each individual subject's range of response, the participants were first subjected to a baseline scenario in which the plane would fly in a blue sky with no turbulence, to determine low levels of response, and then undergo a period of high levels of turbulence in order to determine high levels of responding. From the responses generated by this procedure, the researchers were able to assign a setpoint of response for each individual participant. If responses in the adaptive environment were to reach levels above the setpoint, the task would become more manageable, whereas, if response levels were to dip below the setpoint, the task would become more difficult. We are currently designing our own such baseline procedure to assess both high and low levels of responding in order to adapt the intensity of the stimuli presented in our virtual environments to each individual's level of arousal when immersed in the environment.

Applications in a Virtual Environment

We are currently constructing our models. Once constructed, given the intensities of stimuli in terms of the levels of arousal and valence, we aim to estimate a person's neurocognitive and psychophysiological responses. On the other hand, given a person's physiological responses to a baseline procedure, we can also estimate the levels of arousal and valence. These levels can be used to assess the person's psychological health status. Additionally, the models can be used in biofeedback control. Because our models can compute the quantitative levels of arousal and valence, the error signal for the controller can be quantified, and hence precise control laws can be developed.

ADAPTIVE VIRTUAL ENVIRONMENTS

Given the advances in virtual environments (see Stanney, 2002; and Durlach and Mavor, 1994) and psychophysiological models (Scerbo et al., 2001), researchers are increasingly exploring adaptive environments, in behavioral, biological, and/or psychophysiological information about the user are collected, as well as data about the situation in which the human is immersed and interacting with a machine. The resulting information is processed in real time to draw reliable inferences about the then current state of the user's condition in order to dynamically alter and improve the nature of the information and control characteristics of the human-machine interface. Such adaptive virtual environments aim to construct an extensive communication channel between a virtual environment and the user. Such a communication channel enables the virtual environment to detect the then current state of the user and thereby adjust the activity in the virtual environment to facilitate the attainment of some specific behavioral goal (e.g., Bennett et al., 2001; Scallen & Hancock, 2001).

In our own work, we are currently modifying various virtual environment scenarios to provide an adaptive user interface for clinical populations. For example, we have a Virtual Iraq that we use for neurocognitive and affective assessment of persons with both combat stress symptoms and blast injuries (Rizzo et al., 2006). Another example is our virtual reality classroom that we use for assessment and treatment of children with neurocognitive disorders impacting frontostraital functioning (e.g., autism and attention deficit hyperactivity disorder; Parsons et al., 2007). Further, this work has been applied to pediatric rehabilitation (Parsons et al., 2009c). For our work, the development of adaptive interfaces is anchored on four interrelated objectives or Technical Areas (TAs): TA-1) Develop indices that represent the user's neurocognitive and psychophysiological profile through assessment of user affect (i.e., psychophysiological responses) and associated neurocognitive performance (i.e., performance on neuropsychological assessments). TA-2) Develop signal processing algorithms for functional validation of psychophysiological indices. TA-3) Translate thresholds/signals into commands that may be instantiated in virtual environment. TA-4) Validate the enhanced adaptive virtual environment for neuropsychological assessment and training.

Development of Indices (TA-1): User's Neurocognitive and Psychophysiological Profile

Profiling individual differences in neurocognitive and psychophysiological processing of virtual environment stimuli is a primary concern for extending the virtual environment. The virtual environment's neuropsychological (i.e. neurocognitive) and psychophysiological assessment (or array of affective assessment measures) should provide an accurate representation of relevant neurocognitive and affective dimensions (e.g. mental effort, task engagement, frustration). However, such isomorphism is often problematic because the linkage between performance on neuropsychological assessments (i.e., neurocognitive tasks), assessments of affect, and physiological metrics may be contaminated by the fact that variables drawn from any of these areas may reflect a response to other psychological elements besides the desired one (Picard, 1997; 2003). Perturbation of feedback may impair adaptation of the virtual environment and, in the context of the learning, impair cognitive, affective and psychomotor learning. Hence, it is important to develop virtual environment profiles that take into consideration the range of individual differences in different parameters of neurocognitive and affective reactivity.

Individual Differences in Neurocognitive Performance

A typical neuroscience approach to assessment of neurocognitive functioning involves the administration of psychological tests to develop cognitive models that may be evaluated against data that have been averaged or aggregated across subjects. Individuals are typically modeled as invariants, not as individuals. A number of examples of neurocognitive profiling models developed to address diverse neurocognitive function can be found in the literature: category learning (Berretty, Todd, & Martignon, 1999; Tenenbaum, 1999); stimulus representation (see, e.g., Shepard, 1980; Tversky, 1977); and memory (e.g., Anderson & Schooler, 1991; Laming, 1992).

An unfortunate result of averaging is that the resulting neurocognitive profile (i.e., model) assumes that there are no individual differences between subjects. As there are substantial individual differences in cognitive ability in the general population, simply comparing a user's test performance with the relevant test norms will be of little value. A particular test score can represent an entirely average level of functioning for one individual and yet severe deficit for another. Therefore, it is necessary to compare current performance against an individualized comparison standard (Lezak, 2004). Hence, good neuropsychological tests are sensitive to a range of functioning, both at very low levels of cognitive functioning as well as in people with above-average cognitive abilities. Extensive normative datasets are available for the widely used neuropsychological tests (Lezak, 2004; Mitrushina, 2005; Strauss et al., 2006).

In our work, we take three approaches to modeling the neurocognitive data for profiling of user abilities: (1) stratified norms from validation studies; (2) regression-based norms; and (3) model parameterization using stochastic approximation. For the stratified normative sets, an individual test score is compared to the mean performance of a matched norm group in our current dataset, for example, people of comparable age and education level. Next, the raw score that a user obtains on a specific task is compared to a standard score that is corrected for factors, such as age, education level, intelligence, and sex. This standard score can subsequently be interpreted using the normal distribution, which indicates the probability that a given performance is to occur in a normal population. For the regression-based norms, we compute the individual's expected score based on a number of potentially confounding cohort variables, such as age, IQ, and gender, by means of a regression formula. The difference between the individual's expected and actual score (the residue score) is then compared to a frequency table to determine the probability that this residue score is found in a normal population. Finally, we use parameterization, in which we attempt to accommodate individual differences assuming that each subject behaves in accordance with a different parameterization of the same basic model, so the model is evaluated against the data from each subject separately (see, e.g., Ashby, Maddox, & Lee, 1994; Wixted & Ebbesen, 1997).

Individual Differences in Affective Reactivity as Measured by Psychophysiology

Although typical output device correlations are acceptable for minimal understandings, they fail to provide the accuracy and range of application that are proffered by functionally-defined psychophysiological indices. Following the work of Davidson (2003), the project described herein aims to develop psychophysiological profiles that can be understood as valence specific features of emotional reactivity and affective responding. As such, specific parameters of neurocognitive and affective style are being objectively measured including: (1) response threshold, (2) response magnitude, (3) rise time to response peak, (4) recovery function of the response, and (5) response duration. The latter three are time specific and have been described by Davidson as different aspects of affective chronometry. Hence, we are developing a psychophysiological interface through the collection of psychophysiological data from the user via psychophysiological assessment sensors. These data are being filtered and quantified to operationalize relevant psychological constructs (frustration, engagement). The psychophysiologically-driven adaptive interface is being programmed to analyze these data to quantify the state of the user. Following Fairclough's (2009) work, we are considering different possibilities for user state assessment which may be made with reference to absolute (e.g., heart rate exceeds 80% of baseline) or relative criteria (e.g., heart rate has risen 20% since the previous data collection epoch); alternatively, the assessment provided by virtual environment may be categorical in nature (e.g., the pattern of heart rate activity and skin conductance level indicate that user is in a negative emotional state).

Signal Processing Algorithms (TA-2)

Individual differences have been found in intensity of both tonic and phasic reactivity in many autonomic response channels. Such differences are a potential problem for comparison of groups. A combination of individual results for statistical analysis is justified only if responses of different individuals have similar distributions. There is a need for transformation of the raw data such that the responses of different subjects will have approximately similar distributions (Parsons et al., 2009a). Although estimated range corrections have been suggested, these estimates are problematic because they require, in most cases, longer rest periods than those needed for a real-time adaptive virtual environment (Ben-Shakhar, 1985). Further, much of the signal processing found within psychophysiology involves a constrained set of signal parameters that were developed for limited neuroscience studies that are to be performed in a highly controlled laboratory setting. As a result, researchers tend to identify questions of interest and associated procedures to extract them from raw signal recordings that must yield outputs that are readily amenable to further standardized analyses and expert interpretations. Due to the long tradition of use of this lab-based paradigm in basic research in psychophysiology, this "received approach" represents a de facto standard of response quantification procedures. In our work, we have found that the translation of psychophysiology procedures from "assessment" of persons' responses to an adaptive virtual environment presents the requirement of devising scoring protocols for situations to which the existing de facto standards may not be very suitable (Iyer et al., 2009).

The "received approach" to scoring protocol parameter settings need not always be viewed as a tight requirement. Instead, they may be viewed as a flexible constraint from which a designer may make judicious use of adjustable parameters based on other application specific demands. For example, in an experimental scenario where signal-to-noise ratio is a high priority, the designer can choose the highest filter width within the "plateau" region, thus representing a consensus of the requirements of traditional psychophysiology as well as engineering considerations (Iyer et al., 2009). Specifically, our project takes data gleaned from Task 1 above and performs multi-modal offline biosignal analysis using Matlab and related signal processing toolboxes.

The investigation of patterns and signal features of biosignals allows for defining electrode montages, spatial or temporal filter designs, artifact treatment, quality control, spectral analysis, coherence, correlation, bandpower analysis, ERD/ERS analyses, visualization and data set classification. Further, we are decomposing the sequence of values into components of different frequencies. We are using various methods (e.g., Fast Fourier transform; FFT) to compute results quickly and efficiently. Increased speed of processing with a FFT can be substantial, especially for long data sets. This process allows us to enhance the command signals from the psychophysiological interface to the virtual environment (Task 3).

Thresholds/Signals into Commands (TA-3)

As mentioned above, data scoring is typically performed with ‘off-the-shelf’ scoring software, most often proprietary and provided by the manufacturers of the recording equipment. Given the need to move from a pure assessment approach in a low fidelity environment to a high fidelity virtual environment that has real-time adaptability, there is need for increased sophistication in data scoring procedures—capable of dealing with a greater variety of metrics (Iyer et al., 2009). Investigators, especially in nascent applications, need to choose parameters tailored to the application, exploiting the additional capabilities of state-of-the-art data acquisition equipment and use flexible customizable data-scoring software, typically written in MATLAB. These developments necessitate a shift from an “off-the-shelf” approach to a “drawing-board” approach in designing response quantification procedures and scoring protocol design. A further problem is the programming of two inherent dynamics—negative or positive feedback control. Negative control loops are being established to create behavioral stability by reducing the discrepancy between the input signal (real-time psychophysiological measure of engagement) and a desired standard (the desired level of engagement). Given the dynamics of high-fidelity virtual environments, the virtual environment interface is being programmed to toggle between positive and negative control dynamics. The misperception of user arousal levels may evoke inappropriate changes in virtual environment. Perturbation of feedback may impair adaptation of virtual environment and, in the context of the learning, impair cognitive, affective and psychomotor learning. Hence, it is important to develop psychophysiological profiles that take into consideration the range of individual differences in different parameters of neurocognitive and affective reactivity.

In our work, we have designed a virtual environment-based neurocognitive and psychophysiological feedback system that is composed of three modules. The first module is a Profiling Module that acts as a system made up of multiple metrics gleaned from neurocognitive and psychophysiological assessment of the user while immersed in the virtual environment. The Profiling Module has three functions: (1) Extract and convert the analog psychophysiological signals into digital data; (2) assess neurocognitive functioning of the user while immersed in the virtual environment; and (3) Transfer neurocognitive and psychophysiological data to the main controller. The second module is the Controller Module, a computer, which transfers the neurocognitive and psychophysiological profile data to “command” signals. The “command” signal obtained from the main controller is fed to the third module, the Command Module, and becomes a parameter impacting the behaviors of the virtual environment. Values of the Command Module’s “command” correspond to the changes in position, appearance, and size of objects in the virtual environment, the user’s viewpoint of the virtual environment; and the instantiation or inhibition of immersive stimuli (e.g., scent machine, sounds, haptic feedback). Finally, information, such as the timing of significant events in the virtual environment (e.g., presentation of stimuli) is then transferred from the virtual environment back to the psychophysiological interface program, and logged with the neurocognitive and psychophysical data.

Interface Validation (TA-4)

It is necessary to use validated measures to establish the neurocognitive and affective correlatates of experiences within virtual environments. An issue for neurocognitive evaluations includes the fact that traditional neurocognitive measures may not replicate the diverse environment 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; Parsons, Rizzo, & Buckwalter, 2004b).

From the psychophysiological perspective, the operationalization of an affective and/or neurocognitive process using a psychophysiological inference may not respond as anticipated by the user or the designer (Fairclough, 2009). The selection of 'strong' psychophysiological candidates for a physiological computing system requires that candidate variables have demonstrated a degree of validity. Hence, it is necessary that the results from virtual environment be fully validated through tests of the quality of the psychophysiological inference. Without validation, it is not possible to know how well the psychophysiological measure predicts a neurocognitive and/or outcome based upon another set of variables. As a result, both the assessment of the user and the resulting adaptations in the psychophysiological interface will be spurious. Establishment of concurrent psychophysiological validity represents a significant challenge for the development of a physiological computing system because there is no ‘‘gold standard” to establish the virtual environment's psychophysiological assessment. In addition, there are several possible routes by which the researcher can assess psychophysiological validity, which suffer from similar flaws (a) mood induction by media or standard task may be context-specific and may not generalize to other task contexts or different participant populations; and (b) specific techniques used to induce a particular individual's state may be incorrectly identified with generic user states.

VIRTUAL REALITY FOR COGNITIVE PERFORMANCE AND ADAPTIVE TREATMENT (VRCPAT 2.0)

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 (virtual city, virtual checkpoint, virtual Humvee). Two primary goals define these virtual and adaptive environments: (1) a Virtual Reality Cognitive Performance Assessment Test (VRCPAT 1.0) that includes 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) will be 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 (e.g., post traumatic stress disorder).

While immersed in the VRCPAT a Soldier's neurocognitive and psychophysiological responses are recorded in an attempt to understand how the activation of particular brain areas is related to given tasks. It is hoped that this will allow us to better uncover the relationship between the neural correlates of neurocognitive functioning in virtual environments for generalization to real world functioning. Following the acquisition of this data, we use artificial neural networks for nonlinear stochastic approximation and model specific neurocognitive and affective processes of persons immersed in VRCPAT.

The VRCPAT 1.0 includes a battery of neuropsychological measures to assess the ways in which the structure and function of the brain relate to specific psychological processes and overt behaviors: attention-vigilance, effort, abstraction-flexibility, executive functioning, spatial organization, visual-motor processing, processing speed, visual memory, verbal abilities, and verbal memory and learning. The VRCPAT 1.0 is different from traditional paper and pencil neuropsychological tests, in that VRCPAT 1.0 allows Soldiers to experience a greater "sense of presence" as they become immersed within the computer-created environment. Further, the VRCPAT 1.0 neuropsychological and psychophysiological assessments allow task stimuli and parameters (e.g., number, order, and speed) to be consistently manipulated and patient responses and behaviors to be closely monitored and automatically recorded. Hence, VRCPAT 1.0 allows the clinician to measure complex sets of skills and behaviors that may relate closely to real-world, functional abilities. Again, this is different from standard instruments, in which components or isolated domains of cognitive function often are measured and clinicians combine data to predict real-world performance.

We are currently developing a VRCPAT 2.0 (Virtual Reality for Cognitive Performance and Adaptive Treatment), that takes the neurocognitive and psychophysiological profile information from the VRCPAT 1.0 and uses that information to drive an adaptive virtual environment. The goal is to have an adaptive virtual environment that develops neurocognitive and affective profiles from estimations of the Soldier's cognitive abilities following a blast injury (e.g., from cognitive tasks embedded in a VR-based simulation of a humvee) and affective state (from psychophysiological physiological metrics), that may enhance existing stress cognitive rehabilitation and virtual reality exposure therapy protocols. Such an adaptive virtual environment can adjust the presentation of both the difficulty (e.g., simple versus complex) and intensity (safe versus threatening) of stimuli delivered to the neurocognitive and physiological characteristics of each user.

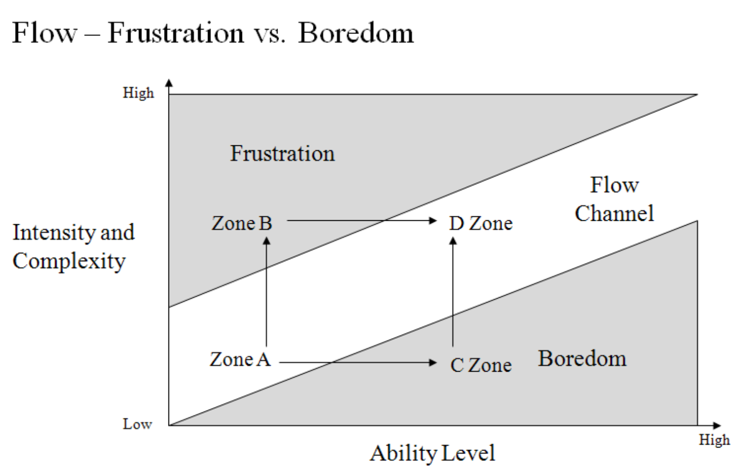
Although there are other attempts to apply adaptive virtual environments to posttraumatic stress disorder (Cosic et al., 2007; Popovic et al., 2006, 2009; Salva et al., 2009) and neurocognitive rehabilitation (see Hettinger and Haas, 2003), this work is in its earliest stages. Additionally, the VRCPAT 2.0 project is novel in that it includes both psychophysiological and neurocognitive profiles to enhance its adaptive capabilities. Further, the neuropsychological tests found in VRCPAT 1.0 include a set of neuropsychological tests that have been validated against standard paper-and-pencil, as well as computerized neuropsychological measures (e.g., Anutomated Neuropsychological Assessment Metrics). To the best of our knowledge, there is no other project that does both psychophysiological and neurocognitive profiling using the level of validation provided by the VRCPAT.

In summary, the VRCPAT 2.0 is an implementation of a neurocognitive and psychophysiologically-driven adaptive virtual environment, with its potential applications in virtual reality exposure therapy and cognitive rehabilitation, The major components of the neurocognitive and psychophysiologically-driven adaptive virtual environment and their inner workings were presented. As mentioned above, VRCPAT 2.0 Controller Module allows the clinician to immerse the Soldier into a virtual environment that offers a flexible and intuitive presentation of military relevant and context specific (Virtual Iraq and Virtual Afghanistan) stimuli to Soldiers based on specification of their neurocognitive and psychophysiological profiles found in the Profiling Module. The Profiling Module performs intervallic assessment of the Soldier's neurocognitive performance and affective state from multiple neurocognitive data points and psychophysiological signals. The Command Module modifies the presentation of virtual stimuli and either instantiates or inhibits immersive stimuli (e.g., scent machine, sounds, haptic feedback). Finally, information, such as the timing of significant events in the virtual environment (e.g., presentation of stimuli) is then transferred from the virtual environment back to the psychophysiological interface program, and logged with the neurocognitive and psychophysical data.

The VRCPAT 2.0 has been designed to offer an adaptive virtual environment that can be explored by patients under the supervision of a clinician. This virtual adaptive assessment and rehabilitation system aims to place the injured Soldier into a state of optimal experience defined as "flow" to trigger a broad recovery process (see Riva et al., 2004). According to Csikszentmihalyi (1990, 1994, 1997), "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 (2009), we partition the "flow" state of the Soldier into four quadrants or "zones" (see Figure 1).

Our approach to cognitive rehabilitation and treatment uses the assessment capabitilities of VRCPAT 1.0 to place the patient (e.g., Soldier that has experienced a blast injury and/or combat stress symptoms) in VRCPAT 2.0 at the optimal starting point for that Soldier; Zone A. It is important to note that we do not conceptualize the flow of rehabilitation/treatment to be a a static experience. A Soldier's skill level tends to be low the first time he or she is immersed in VRCPAT. As the patient's experience of the rehabilitation/treatment program increases, his or her skills increase and he or she may become bored if the challenge remains constant (Zone C). Within VRCPAT 2.0, the challenge will increase, but usually at a different rate than the Soldier's ability level. Hence, the patient (e.g., Soldier) is constantly in a state of flux between the four points shown in Figure 1. At times the patient may begin to disengage (start to experience boredom and move toward Zone C) when the challenge does not increase in pace with his or skills. At other times, the patient may move towards frustration (Zone B) when he or she 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 Soldier is engaged and his or her 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., a learning phases and/or a demanding but rewarding period

Figure 1. Two-dimensional representation of neuropsychological state of the user: Note, this is an adaptation of a couple of other graphs: Csikszentmihalyi, 1990 and Fairclough, 2009



of performance). Overall, the goal of VRCPAT 2.0 is to keep the Soldier in Zone D—continually adapting the intensity and difficulty of the environment to have the Soldier in a flow state with improved skills and being able to function at a higher level of challenge. For VRCPAT 2.0 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 Soldier's ability level has been optimized. Further, if the Soldier's results indicate that he or she is heading to Zone C, the virtual environment should adapt so that task demands be increased. This complex representation of the patinet provides the adaptive controller with greater specificity in order to target the adaptive response.

In summary, the VRCPAT 2.0 offers an adaptive environment that uses the principles of flow, presence, neuropsychology, psychophysiology to develop a novel application for rehabilitative applications. From our perspective, the VRCPAT 2.0 offers the potential for a broad empowerment process (see Riva et al., 2004) within the flow experience induced by a high sense of presence coupled with improved ecological validity.

CONCLUSION

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. As well, the flexibility of stimulus delivery and response capture that are fundamental characteristics of such digital environments is viewed as a way for Army 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 the Army.

We aim to make the virtual environment's psychophysiological interface into a well developed system that facilitates substantive advances. First, we are identifying the hierarchical or aggregational structure. Next, we will establish the unidimensional facets (psychophysiological domains of interest) and determined the content homogeneity of each of the interface's unidimensional facets. The establishment of psychometric properties (related to psychophysiologial domains) removes the possibility that results reflect correlates of the target construct but are not prototypic of it. We are also assessing the level to which all aspects of the target construct is under- or overrepresented in the psychophysiological interface's composition, and assess whether the experience of some aspects of the virtual environment introduce variance unrelated to the target construct. Following the development and validation of the psychophysiological interface, the virtual environment project aims to investigate the impact of stimulus intensity, complexity, and stimulus modality (e.g. music tempo; audio presentation; olfaction) upon users within the virtual environment.

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KEY TERMS AND DEFINITIONS

Affective Computing: An interdisciplinary field that deals with the design of systems and devices that can recognize, interpret, and process human emotions.

Flow: 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.

Immersion: The level of fidelity that a virtual reality system has in representing the real world.

Presence: The propensity of users to respond to virtually generated sensory data as if they were real, or a sense of "being there."

Psychophysiology: A branch of psychology that deals with the effects of physiological processes on mental functioning.

Veridicality: The extent to which test results reflect and predict real world phenomena.

Verisimilitude: The need for the data collection method to be similar to real life tasks in an open environment.