Abstract

Heart Rate Variability Biofeedback and Executive Functioning in Individuals with Chronic Traumatic Brain Injury

By Sonya Kim

This study sought to determine if individuals with neurological damage can be trained to regulate their emotions through psychophysiological processes and thereby can learn to improve executive functioning and enhance clear thinking. Participants were drawn from AHRC, a community-based structured day program in New York City that provides long-term rehabilitation services for individuals with severe brain injuries who are past the post-acute phase of rehabilitation. Contrary to commonly held beliefs that further rehabilitation or recovery is impossible for such a population, one key premise of this study is that given appropriate training, people with chronic brain injury can continue to make substantial improvements in their functioning. This study used a non-randomized experimental design with repeated measures at 3-time-points. The primary training tool was HeartMath Institute's heart rate variability (HRV) PC- emWave. This study provides one of the first empirical demonstrations of psychophysiological self-regulation training applied to individuals with severe brain injuries who were on the average 24 years post-injury. Because this study provides empirical evidence that the brain and emotions are connected in the body – as opposed to operating in the separate domains created by the traditional mind/body divide – it also presents the possibility that this connection could be used to train individuals with brain injury to better self-regulate their behavior and thereby control disinhibition and impulsivity. Evidence is also presented that even individuals who sustained severe brain injuries and are long past the post-acute phase of rehabilitation can learn new techniques, respond to biofeedback, and greatly increase coherence in heart rate variability. The results show that the participants made dramatic improvements in the heart rate variability indices, even though neither functional improvements nor improvements in neuropsychological testing were observed. However, the results of this experiment show that HRV may hold promise as being an effective neuropsychological tool that can offer guidance on how to assess and treat behavior.

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by

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Dedication

I dedicate this work to the memory of my mother, Myung Ja Kim.

And to my sisters, Una, Kathy, and Helen.

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Chapter I

Introduction: Background and Significance

The purpose of this study is to propose a novel treatment that will address self-regulation deficits in individuals with chronic brain injuries. This study seeks to test the hypothesis that training individuals with brain injuries through psychophysiological treatment will improve regulation of emotion and, as a result, will be most effective in helping individuals to solve problems that arise in daily life (Rath, Simon, Langenbahn, Sherr, & Diller, 2003). This treatment model targets two predominant challenges that arise in retraining individuals with severe brain injuries: 1) their difficulty with learning new material; and 2) their difficulty with generalizing from what they learn across different situations.

For the purposes of this study, “problem solving” is the self-directed cognitive-behavioral process by which a person attempts to identify or discover effective or adaptive solutions for specific problems encountered in everyday living. Problem solving involves conscious, rational, effortful, and purposeful activity (D’Zurilla & Nezu, 2001). But studies have shown that because an individual’s response to problems has ramifications for personal happiness and needs, emotions are crucial to the problem-solving process (Epstein & Meier, 1989).

Successful problem solving involves a complex interaction of emotions and cognition. In view of this reality, finding an effective model for training individuals with TBI how to solve problems has significant implications: for clinicians, for the profession, and for the individuals with brain injuries and their families.

This study has the potential to make a meaningful contribution to the mental-health profession because TBI is a disorder that has a significant negative impact on public health. The 1998 National Institutes for Health (NIH) report on traumatic brain injury estimates that 2.5 million to 6.5 million individuals suffer from TBI. The incidence rate is 100 per 100,000 persons, with 52,000 annual deaths related to TBI. According to the Centers for Disease Control and Prevention (CDC) (2010), an estimated 1.7 million people sustain a TBI annually, with 52,000 deaths that result from TBI. TBI is a contributing factor to a third (30.5%) of all injury-related deaths in the United States. Males are more likely than females to sustain a TBI with males aged 0 to 4 having the highest rates for TBI-related emergency department visits, hospitalization and deaths. Age groups most at risk for TBI are children under 4 years old, teenagers aged 15 to 19, and adults aged 65 years and older. Leading causes of TBI include falls (35.2%), motor-vehicle accidents (17.3%), direct blows to the head (16.5%), and assaults (10%), and other or unknown (21%) (CDC, 2010). From 2002 to 2006, there was an increase in fall-related TBIs among adults aged 65 and older: 46% increase in emergency department visits, 34% increase in hospitalizations, and 27% increase in TBI-related deaths (CDC, 2010). Blast injury is the most common type of injury in the current war field (Warden, 2006), with 88% of those injured having suffered a closed-head injury. TBI can cause impairments that affect physical, cognitive, and psychosocial functioning in people of any age (CDC, 2006, 2010; NIH, 1998). Given the scope and severity of the problem, the results of this study can have important implications.

Chapter II

Review of Literature on Self-Regulation

This chapter will cover a wide scope of theoretical views on self-regulation, beginning with a definition of executive functioning. Executive functions are generally viewed as cognitive processes that *direct* other cognitive operations to achieve a goal (Kennedy & Coelho, 2005; Kennedy et al., 2008; Stablum, Umilta, Mazzoldi, Pastore, & Magon, 2007; Ylvisaker, Szekeres, & Feeney, 1998). Essential to these directive functions is identifying the goal that the individual wants to attain. According to Stablum et al., the abilities common to executive functioning include the abilities to focus and sustain attention, draw upon short-term memory, modify expectations and behavior, and adapt both to changed circumstances. Adaptation, in turn, includes the abilities to learn from feedback and overcome habituated response to situations.

Fundamental to executive functions is the notion of self-regulation. Self-regulation can be defined as control, or direction by or of oneself which implies the ability to exercise restraint, adapt as needed, and turn passive experience into productive activity (Oxford English Dictionary). Botvinick, Braver, Barch, Carter, and Cohen (2001) see self-regulation as a fundamental feature of an individual whose set of controls include both regulative and evaluative mechanisms. For Botvinick et al., successful self-regulation implies both knowing when to exercise control and knowing how to "modulate" control, depending on the demands of the task at hand. Botvinick et al. found that the core brain structure involved in the self-regulating process is the anterior cingulate cortex (ACC), which is activated by tasks that require attention. This finding indicates that *attentional* adjustments are important and necessary for successful performance (Kolb & Whishaw, 2003).

Self-regulation is a process of control achieved by intact attentional skills at multiple levels. The role that attention plays in this complex process as it relates to autism is informative. Attentional problems and related regulation deficits arise in the context of higher level conceptual processing. The core deficits that individuals with autism manifest do not involve directing attention to simple stimuli, but to complex attentional processes that require executive functioning. Impaired shifting of attention in autism was found to be caused by faulty processing of information (Goldstein, Johnson, & Minshew, 2001).

As executive functioning has come to be defined as involving the *self-regulation* of goal-directed behavior, deficits often become defined as involving impulsive, hostile, or confused reactions that are manifested without forethought or planning (Feifer & Rattan, 2007). Self-regulation is a significant deficit in individuals with brain injuries (Bechara, Damasio, H., & Damasio, A. R., 2000; Duncan, 1986; Duncan, Hazel, & Williams, 1996; Tate, 1987). Given the complex of abilities implicated in executive functions, especially self-regulation, it is not surprising that executive dysfunction for individuals with TBI has been identified as a key impediment to their re-entry into social life. These individuals have difficulty meeting unexpected or novel situations calmly. No matter what the challenge is — for example, making travel arrangements, handling money, or arguing with a friend — the individual with a brain injury struggles to respond in a focused way. According to the profession, inner calm and orderly thinking are essential to solving problems, and inner calm must be present before mental clarity can be achieved. As a result, regulating emotions has been identified as a prerequisite for the efforts of anyone, and especially someone with a brain injury, to think clearly, draw from prior experience, abstract principles, and act logically with good judgment (Gordon, Cantor, Ashman, Brown, & Whyte, 2006; Rath et al., 2003).

In the literature on self-regulation, three divergent perspectives are most prominent with respect to defining executive functional deficits involving self-regulation. The role that "attentional" skills play in self-regulation is of particular interest in these three theories or perspectives and have significant implications for treating individuals with brain injuries in the area of self-regulation. Reviewed individually below, these theories are known as 1) Goal Management Training, 2) Social Problem Solving, and 3) Somatic Hypothesis: Integrating Mind and Body.

Training in How to Manage or Achieve Goals

For Duncan et al. (1996), because self-regulation is reflected in achieving a stated goal, dysregulation is reflected as neglecting a stated goal. Duncan et al. define "goal neglect" as disregarding the requirements of a task even though the requirements have been understood. Theoretically based on Duncan's concept of "goal neglect," Levine et al.'s (2000) Goal Management Training (GMT) is an approach for addressing disorganized behavior related to executive and attentional impairments that interfere with an individual's ability to achieve a known goal. For Levine et al., maintaining goal-directed behavior is a key part of executive functioning in that it reflects an individual's ability to regulate behavior to achieve a goal. Having goals brings coherence to human behavior. Success is derived from and often depends on the person's ability to weigh alternative actions, discard the less useful ones, and trying out new actions as events unfold. More specifically, GMT views executive dysfunction as a byproduct of failures in attention. Patients are taught to become aware of their *lapses* in attention. Patients are taught to "stop" in order to interrupt automatic behaviors that typically coincide with lapsed attention. Once their *attention* has been "controlled," patients are then taught to focus on the goal of the task and to divide the tasks needed to achieve the goal into manageable steps. They are also taught to check their work in the process.

Derived from Robertson (1996), Goal Management Training (GMT) has been described by Levine et al. (2000) as comprising five stages: 1) assessing a particular situation (current state of affairs) to become aware of goals that the situation gives rise to; 2) selecting goals; 3) selecting steps or tasks related to the goals; 4) remembering the goals and related steps; 5) evaluating the outcome of one's behavior in trying to attain the goals. The entire training based on these five steps lasted one hour. After training individuals in the five stages of goal-directed behavior, Levine et al. found that compared to a cohort group that received motor training, the experimental GMT group improved in being able to achieve goals. However, the individuals in the experimental group slowed down in completing the tasks that were given to them for the purposes of this study (paper and pencil exercises such as proof-reading). The authors explain that a slowed pace is to be expected because applying the five stages of GMT requires more deliberate and therefore slower steps in order to control disinhibition –- a hallmark of executive dysfunction.

Finally, it is interesting to note that Levine et al. (2000) believe, citing Stuss, Shallice, Alexander, and Picton's (1995) work, that attention and executive functions are intimately related. But the GMT training is different from training strictly focused on improving attention. Training individuals to improve attention involves tasks that are highly structured and are assigned and completed under constraint of time. Training individuals to improve their ability to achieve goals involves tasks that are unstructured and untimed. Levine et al.'s position is that attention training can improve goal management behavior. The connection drawn by Levine et al. between attention and the larger field of executive functioning has not yet been explained by Levine and colleagues. But the connection remains an open, suggestive question for the profession.

The significance of the GMT perspective is that it proposes that individuals with brain injuries have difficulty with executive functioning and achieving goals because they have deficits in cognitive processing. They are, for example, unable to attend to problems that arise and are distracted by irrelevant information. Thus the concept of a GMT is to organize behavior by training the individuals to develop a list of goals using the 5-stage model. A list of goals is expected to help retain attention and constrain distractibility.

Along these lines, Nieuwenhuis et al. (2004) note that "goal activation" is a hallmark of executive functions, while the inability to fully or consistently maintain attention on the task and what it requires is a hallmark of executive dysfunction. Three factors have been offered for measuring an individual's ability to attain a goal: 1) how much support is available for help; 2) how many other tasks are competing for attention; 3) how much "tightly focused attention" the task demands. Nieuwenhuis et al. never define what they mean by "tightly focused" attention, though they imply that it refers to the ability to sustain attention and stay "on task." At the end of their study, they ask what explains the fluctuation or lapses in focused attention that cause "goal neglect." Their question bears directly on the similar question raised by the current study: What underlies the manifestation of self-regulation deficits in individuals with TBI and what could be an effective treatment for such deficits?

Social Problem Solving: Solving Problems that Arise in Social Life

"Problem solving" should not be defined apart from a social setting (Rath, 2000). Solving a problem on a test in a room with other people taking the same test must be defined apart from solving a problem with a family member or a friend. For someone with a brain injury, what is "social problem solving" about? Social problem solving can be defined as solving problems that occur in a person's everyday environment. This definition draws on studies about cognition and emotions. Fundamental to this definition is the notion that problem solving requires two independent processes. The first process is orientation to the problem. Orientation involves the person's attitude, motivation, and affect. By "affect" we mean the emotions or response that include a set of beliefs, assumptions, appraisals, and expectations concerning life's problems and one's ability to solve them (Nezu & Perri, 1989).The second process involves the actual solving of the problem by using skills and templates to think about and apply solutions (D'Zurilla & Nezu, 2001).

While Levine et al.'s (2000) GMT regards cognition as the only process involved in goal-directed organized behavior, theorists of social problem solving regard both cognition and the emotions as being important to executive functioning. Studies on the relationship between executive functioning and the emotions have shown how emotions are part of the executive-functioning construct. Anatomically, the pathways that interconnect regions of the prefrontal cortex (a primary area of executive functions) also connect with emotional structures, specifically the amygdala (Feifer & Rattan, 2007; Godefroy, 2003). This connection explains why Feifer and Rattan found that executive functioning is critical to social pragmatics, since this executive functioning allows individuals to monitor their emotional impulses and regulate their responses, verbal or nonverbal.

For Rath (2000), the theory of social problem solving theory best explains the core deficits that individuals with brain injury experience. Social or real-life dilemmas or conflicts involve unstructured conditions without pre-specified rules. Behavior must be defined and interpersonal conflicts or "pressures" must be negotiated – all with good speed (Rath). Assessment of self-regulation of individuals with brain injuries in "testing" conditions may misrepresent the behavioral problems that arise under more unstructured situations. The central problem for higher functioning individuals with TBI is deficits in the domain of emotional self-regulation (problem orientation) (Rath et al., 2003). Drawing from D'Zurilla and Goldfried (1971) D'Zurilla and Nezu (1982), Rath et al. (2003) note how treatment for individuals with TBI needs to address factors that disrupt intent and motivation and thereby interfere with problem-solving performance. For Rath et al. (2003a), the social problem-solving perspective stresses the motivational, attitudinal, and affective aspects of real-life problems. Attention problems due to "information overload" that occur in the face of unexpected problems can cause emotional dysregulation and impulsive decision-making. Examining and resolving problems that arise in daily life require the control of both emotions and cognition. The patients do not speed up their information processing. Rather they learn to expect, understand, and accept their acquired slowness as they process information, and they learn strategies to compensate for their slowness. And this learning helps them to regulate their emotions — to *tame* them — in order to implement a more systematic approach to solving problems.

A more recent experiment in treating problem solving dysfunction in individuals with brain injuries draws upon theories of cerebral function and organization, cognitive behavioral therapies, and learning. The premise of this experiment (which began in 2006 and continues) holds that individuals with TBI need to be taught to attend to internal and external events while they are being trained to generate and analyze possible solutions to problems (Gordon et al., 2006). Therefore, training in how to regulate emotions and training in how to implement appropriate strategies should be given together — as part of one program — not as two training programs, one after the other. But even with such simultaneous emotion-cognition training, the theoretical assumption that drives the experiment is the need to tame or suppress certain emotions for the sake of clear thinking.

Regardless of whether cognitive functions are restored neurologically, or remediated with strategies, and regardless of what principles or philosophy one espouses, the premise that runs throughout the literature on problem solving is either 1) that emotions are <u>not at all</u> relevant to clear thinking or 2) that emotions impede clear thinking (Gordon et al., 2006; Rath et al, 2003). Where the second premise is concerned, insight into how emotions affect cognition can be found in theories relating to “positive” emotions and their affect.[1] By applying the dopaminergic theory of positive affect, Ashby et al. (1999) posit an association between positive affect and cognition. They propose that positive affect is mediated by the same neural mechanisms that make us feel happy when we are rewarded. They cite literature that has shown that the experience of getting a reward of some kind triggers a release of dopamine from several brain sites; furthermore, the increase of dopamine is correlated with creative problem solving. Positive affect increases a person's ability to organize ideas in multiple ways and to see things from multiple perspectives. Clore and Huntsinger (2007) found in their study that when people were happy, they engaged in *global* relational processing; when they were sad, they engaged in "*local* item level stimulus specific processing." For example, positive affect increases the likelihood that individuals involved in a negotiation will adopt a problem-solving approach that leads to an improved outcome for all participants involved. Positive affect does not improve performance on all tasks, especially where the outcome may depend on the kind of cognitive skill that the task demands (Ashby et al., 1999; Philippe et al., 2002). But positive affect does enable *flexible thinking*; it inspires a desire to think about a wide range of tasks, and it enhances an increased attempt to cope with negative events (Ashby et al.).

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[1] Clore and Huntsinger (2007) define *affect* as representation or sign and *emotions* as affective states, reflecting an underlying *appraisal* of a particular kind of situation. Fredrickson and Branigan (2001) distinguish *emotions* from *affect* with emotions representing a multicomponent response that unfolds over a relatively short time span, and *affect* representing a more general concept encompassing either positive or negative emotions. Ashby et al. never distinguish affect from emotion and use *emotional state* and *affect* interchangeably. However, for the purpose of this paper, *affect* and *emotions* will not be used interchangeably. Instead, *affect* will signify an outward representation or sign of feeling; and *emotion* will be the feeling itself.

But emotions and cognitive processes continue to be positioned as distinct processes, and there is a critical lack of attention to the health or illness of the body and how we think and how the body affects how we feel, and vice versa. Before we go forward, it is important to stop and consider a new, related point on the neurophysiology of emotions and cognition, namely the frontal network of the human brain.

According to Luria (1973), the frontal lobes are responsible for the regulation of vigilance and the control of complex, goal-directed behaviors. The frontal lobe becomes active when something new is being learned and when controlling one's behavior is critical (Stuss, 1991). More recently, studies have been conducted to specify in what skills the separate regions of the frontal lobes—dorsal lateral vs. ventromedial—are involved. Studies have found that dorsal lateral was associated with planning, organizing, attention, and working memory; the ventromedial was responsible for processing emotions and making decisions in a social context (Baena et al., 2010; Bechara et al., 2000; Damasio, 1994; Damasio, 1996). For Duncan et al. (1996), patients with damage to the frontal system show a mismatch between what they know about the task required and what they do about it. "Lack of concern" causes *neglect* of what is required to reach a particular goal, even when what is required has been understood (Duncan et al., 1996; Stuss, 1991; Bechara et al.). Stuss observed that the frontal system also involves a show of "concern," an emotional investment towards a goal. For Stuss, the frontal system's highest function is its capacity for self-reflection and consciousness. The frontal system provides the capacity for intimacy, immediacy, and personal responsibility, that is, a concern for how one behaves and the consequences of one's behavior. When knowledge is infused with concern for consequences, it inspires a sense of urgency and personal responsibility for the future. Only in this way does knowledge then control behavior as the individual can self-regulate his or her behavior according to a sense of personal responsibility for future events. Knowledge by itself is inadequate (Stuss). Deficits in this system manifest as unconcern, the absence of self-monitoring of behavior, and impaired self-regulation of behavior under unpredictable conditions.

The capacity for intimacy with another person is what Rath and colleagues (2003) seek to re-institute in the individuals with brain injury. Their treatment, which targets emotional dysregulation and teaches cognitive templates for solving problems, focuses on trying to restrain impulsivity so that the individual can better examine and understand his or her relationship with the other person and negotiate a solution.

Somatic Hypothesis: Integrating the Mind and the Body

Damasio (1994; 1996; 1998) takes the treatment of the frontal system a step further by showing that the connection between cognition and emotion can be measured or documented in how the body reacts. This third perspective seeks to integrate theories of mind (emotions), brain (cognition), and body processes and draws upon psychophysiological processes to support its work. The work of Damasio proposes the somatic hypothesis as a way to understand human reasoning and decision-making. “Soma” means of the body; “emotion” is used to designate a response triggered from parts of the brain to the body. The end result of the collection of such responses is an *emotional state*, defined by changes within the body, changes in the body’s viscera, internal milieu, and changes within certain sectors of the brain such as the somatosensory cortices and the neurotransmitter nuclei in the brain stem (Damasio, 1998). For

Damasio, feelings and thinking meet in the body, and it is the body that provides clues and guidance in and to the decision-making process.

For Damasio (1994), a significant mark of a deficit in the frontal system is the patient's inability to have an emotional experience in response to a situation or information. According to Damasio (1996), our emotions help us choose options appropriately. In Damasio's experiment, patients with ventromedial frontal damage failed to react emotionally, and this failure corresponded to poor decision-making. Damasio (1994) stresses the important role that emotions play in decision-making. Specifically, emotions play a role in communicating meanings to others and thereby provide guidance in making decisions; "feelings" offer you something extra. Feelings remind us of previous situations that may have been similar.

But even for Damasio (1994), *attention* still plays an important role in this process of social problem solving, because acquiring knowledge requires two conditions. First, we must be able to draw upon attentional skills that allow us to select and then prioritize the information we need to focus on, while we block out other non-relevant information. Second, we must have a working memory in order to sustain multiple related but discrete images or information that will ultimately help us to sort out options for possible solutions. Both skills or mechanisms of attention and memory are necessary for reasoning (Damasio, 1994; 1996). Attention and working memory are both activated (or "boosted" as Damasio [1996] says) and driven by preferences. The emotions and the somatic signs that a situation inspires within a person are what spur on an appropriate level of attention and working memory needed for a particular situation. This association that cognitive skills have to an individual's capacity for feelings is critical to understanding Damasio's somatic hypothesis. Damasio observes that for healthy individuals, the somatic markers – signals or signs in the body of the feelings that the situation inspires – activate the attention and working memory needed for reasoning. Patients with damage in the ventromedial region lack the capacity to react emotionally to a situation, and thus the reasoning and problem solving processes are compromised. Fundamental deficits in individuals with frontal lobe damage result in reasoning that is *disembodied* (Bechara et al., 2000; Damasio, 1994; 1996).

In sum, the literature devoted to these three perspectives has established that self-regulation is a significant deficit in individuals with brain injury and has been found to be a profound barrier to their ability to resume participating in their community. A plethora of theories have been posited on what causes behavior to become disorganized or dysregulated. Some say that the cause is purely cognitive, such as impaired executive attention (Duncan et al., 1996; Levine et al., 2000). Others say that disorganized behavior is caused by a combination of impaired cognition and emotional flooding, with the flooding usually coming first and interfering with cognitive processing (Rath, 2000; Rath et al., 2003; 2003a). But what is not fully addressed is how brain injury disrupts the regulatory processes of the whole person, both neuro-psychological and physiological. As Keren et al. (2005) observe, TBI research has strictly focused on the "nonautonomic nervous system." But the primacy given strictly to the non-autonomic processes contradicts research findings that show how autonomic dysregulation is connected to brain injury. Cognitive behavioral therapy is rooted in the notion that changing thoughts will change emotions (Beck, 2004). Literature on positive emotion describes the transformative process inversely: changing emotions will change thoughts. Damasio and colleagues offer the somatic hypothesis as a paradigm for understanding how effective decision-making is done. They observe how the brain and mind meet in the body, and they stress the need to investigate cognition, emotions, and the physical body all at the same time in order to understand how reason works.

However, while Damasio et al. (1994**)** use skin conductance as a psychophysiological measure to prove their somatic hypothesis, they do not suggest that psychophysiology can also offer a way to treat deficits in self-regulation, both emotional and cognitive. A fourth perspective, which is the subject of this study, comes from the literature on biofeedback, and shows that the functions of the body transform both emotions and thoughts (Collet, Vernet-Maury, Delhomme, & Dittmar, 1997; Gorman & Sloan, 2000; Karavidas et al., 2007; Lehrer, Sasaki, & Saito, 1999, 2002; Lehrer, Vaschillo, & Vaschillo, 2000; Porges, 2001; Wilhem, Werner, & Roth, 2001).

Heart Rate Variability (HRV) Biofeedback

Biofeedback is a comparatively novel method of treatment. A literature search on the combined terms of biofeedback, HRV, brain injury, and executive functions revealed no papers that considered these topics together**.** It seems that to this date, psychophysiological training to improve executive functions, specifically self-regulation, has never been tested in a clinical trial for individuals with TBI. However, heart rate variability (HRV) is a technique that can be easily introduced and integrated into rehabilitation facilities. Neither equipment nor training in its use is costly. Furthermore, such techniques can provide an alternative to pharmacological treatment of mood disorders secondary to TBI, thereby making rehabilitation goals more achievable.

Heart rate is not constant but oscillates around a mean value. Heart rate variability (HRV) refers to the naturally occurring variation in heart rate that occurs during a breathing cycle. HRV also refers to the changes in sinus rate (sinus arrhythmia). HRV measures fluctuation in autonomic influence or inputs to the heart. Heart rate variability (HRV) is a measure of the heart rate (HR) oscillations that are caused primarily by the activity of the autonomic nervous system (ANS) (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). The absence or withdrawal of parasympathetic activity (high frequency power) and an extreme flood of sympathetic activity (predominantly low frequency power) will lead to a reduced variability of HRV (Task Force). The fluctuations in heart rate and blood pressure are meaningful rhythmical fluctuations that provide useful information about autonomic regulation (Seydnejad & Kitney, 2001). Changes in physical, mental, and emotional states correspond to changes in the patterns and operations of both branches of the autonomic nervous system (ANS) (Cohen, Matar, Kaplan, & Kotler 1999; Collet et al., 1997). In light of this fact, interventions for emotional self-control through HRV training would seek to decrease sympathetic symptoms and increase parasympathetic systems, thereby altering the sympathovagal balance. The main objective of my experimental intervention (see description in Chapter IV) involved using HRV biofeedback to address the autonomic imbalance of my participants to improve emotional self-control.

Definition of terms.

The following terms are important to this study and are defined in the following ways.

The *Heart* is a muscular organ enclosed in a fibrous sac. Heart rate is determined by the sinoatrial node (SA node). The SA node is located in the posterior wall of the right atrium. The rhythmic beating of the heart occurs regardless of or in the absence of any hormonal or nervous influences on the SA node, due to the autonomic discharges of the SA node. Many parasympathetic and sympathetic fibers end at the SA node. For the purposes of this study, special interest lies in the influence of the autonomic nervous system (ANS) on heart rate. Continuous influence from both branches of the ANS result in the variations of heart rate and the resulting patterns of HRV.

The *Baroreflex* is a homeostatic reflex that modulates blood pressure through stretch receptors in the aorta and carotid arteries. These receptors respond to changes in blood pressure and communicate the needed blood supply to the brain. Heart rate is marked by rhythmical variability related to various reflexes associated with physiological regulation. Thus, heart rate variability (HRV) is related to a variety of health indices that measure the body's health (Guyton and Hall, 1997; Lehrer et al., 2003; Vaschillo, Vaschillo, & Lehrer, 2006; Tarvanien & Nikanen, 2008).

Respiratory sinus arrhythmia (RSA) is a naturally occurring variation in heart rate that occurs during a breathing cycle. Heart rate increases during inspiration and decreases during expiration (Lehrer et al., 2000).

Entrainment is the process whereby two interacting oscillating systems, which have different periods when they function independently, assume the same period. For Demos (2005), it is a natural tendency for two or more rhythms beating simultaneously to move towards the alignment of entrainment. For example, striking an "E" tuning fork, Demos observes, will cause a second nearby “E” tuning fork to vibrate. The two oscillators may fall into synchrony, but other phase relationships are also possible. As they assume a more stable phase relationship, the amounts of energy gradually reduce to zero. In the realm of physics, entrainment appears to be related to *resonance*.

Resonance is a fundamental phenomenon in the field of biofeedback, and so much more time will be spent on defining this term. According to the Oxford English Dictionary, resonance is defined as reinforcement or prolongation of sound by reflection or by the synchronous vibration of a surrounding space or a neighboring object; resonance is also a property of an object or giving rise to this phenomenon; a sympathetic response. Hammer and Saul (2005) define resonance as occurring when a stable linear system can produce sustained constant amplitude oscillations, if the system exhibits certain characteristics (breathing at a certain pace). Resonance for the purposes of this paper refers to the tendency of a system to *oscillate at maximum amplitude.* This maximal “swing” is attained only at certain rates known as the system's *resonant frequencies* (Lehrer et al., 2000). According to Lehrer et al., when an individual is instructed to breathe slowly, as guided by HRV biofeedback, *resonance* is created in his or her cardiovascular system. Increases in the peak-valley amplitude of the HRV sine waves increase the baroreflex efficiency.

According to Jovanov (2008), resonance is defined as a physiological state and it is quantified in power spectral analysis as Low Frequency/High Frequency, where high ratios indicate greater resonance. According to Malpas (2002), resonant frequencies are derived from the time delay between the stimulus and the blood pressure response, and refer to the frequencies at which the *stimulus* and *response* are in *phase.* According to

Vaschillo et al. (2008), resonant properties considerably amplify HRV responses to stimulation by producing very high amplitudes of HR oscillations. High amplitude HR oscillations have been demonstrated with paced breathings *set at the unique resonant frequency of the individual.*

Related to resonance is the term coherence. As used in brain electrophysiology, co*herence* is defined as the average similarity between the waveforms of a particular band in two locations (Thornton, 2003). In other fields, such as biomedical engineering, coherence is defined as "synchronization of coupled oscillators" (Pradines, Osipov & Colins, 1999). The key concept for the purposes of this paper is "similarities" or "synchronization" of waveforms. As it pertains to HRV, the definition and concept of coherence common to all the definitions noted above from various professions is consistency of heartbeat oscillation, which would also reflect a balance between the two branches (sympathetic and parasympathetic) of the autonomic nervous system (ANS). According to McCraty, Atkinson, Tomasino, and Bradley (2006), coherence is a term borrowed from the physical sciences that describes two or more of the body's oscillatory systems, such as respiration and heart rhythms; these rhythms become entrained and oscillate at the same frequency; these rhythmic patterns, also referred to as "waves" – because that is what gets graphed and depicted on the computer monitor – are phase – and frequency-locked. Visual feedback of coherence is conveyed by a smooth sine wave pattern of the heartbeat that appears on the monitor screen (McCraty, Atkinson, &

Bradley, 2004).[2] For the purposes of this paper, *resonance* and *coherence* will be used interchangeably to designate the same psychophysiological phenomenon

HRV and the emotions.

An examination of HRV shows how profoundly the body, brain, and emotions interact The literature is not specific with respect to demarcating the brain from the body, and definitions of mind and emotion are vague. But because it is important to try to arrive at a working definition of these systems, for the purposes of this paper, Damaio's (1994, 1998) distinction between brain, body, and emotion will be used. According to Damasio, the brain is the nervous system, and the body constitutes everything minus the neural tissue (central and peripheral components of the nervous system). Emotions are a collection of responses triggered from parts of the brain to the body, and from parts of the body to the brain. How emotions emerge involves evaluation as well as disposition, but the essence of emotions is that they are felt and the body changes in response to feelings. As for "mind," according to OED (Oxford English Dictionarhy), the mind is the element of a person that enables him or her to be aware of the world and their experiences, to think intellectually, and to feel emotionally; the faculty of consciousness and thought.

Havet-Thomassin, Allain, Etcharry-Bouyx, and Le Gall (2006) define impairments of social intelligence primarily as the inability to infer the thoughts and emotions of others. (This ability is also referred to as deficits in "theory of mind"). Likewise, for Bibby and McDonald (2005) a hallmark of deficits in social intelligence is

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[2] *Coherence* is also referred to in the literature as *flow* (Sime, 2003), and as *resonance (*Lehrer et al., 2000). In this paper, I will use coherence and resonance interchangeably to indicate some psychophysiological state in which an individual's autonomic system is balanced or harmonious**.**

the inability to discern other's people mental states, or form theories about other people's "mind."

According to Wilhem et al. (2001), respiration is a physiological function that connects the mind and body. Wilhem defines the "mind" as "everything in excess of the body." Damasio is more specific. For Damasio (1994), the "mind" represents "perception" which includes 1) the brain receiving signals from the enviroment and the 2) body sensing its environment. The "mind" arises from the activity of both the brain and the body (Damaiso).

Taking this definition of perception further, according to Havet-Thomassin et al., 2006, "mind" then represents the ability to recognize other people's mental states and use this information to understand and predict the behavior of others. For the purposes of this paper, what is most important is that according to the above definitions, the "mind" emerges from emotions and thoughts.

Respiration, which is rooted in the body, can be shaped by emotions and thoughts. Respiration usually operates automatically, but it can be brought under voluntary control, at least briefly. Respiration is essential for life and is subject to complex homeostatic mechanisms; derangement of its regulation can have severe health consequences. For example, mild anxiety is often thought to be accompanied by bodily changes such as heart racing. Many of the psychological symptoms associated with panic disorder are thought to be produced by hyperventilation. As a consequence, respiratory instability is not necessarily a sign of physical injury, but could reflect stressful thoughts (Wilhem et al., 2001). But despite the connection between body and "mind" in psychological disorders, as Wilhem et al. observe, treatment of these disorders rarely if ever includes awareness of physical changes. The authors call for teaching patients how their symptoms can be produced by an interaction of both psychological factors <u>and</u> specific physiological processes (sympathetic nervous system activation).

The “mind” turns out to be a vague term used to express something in excess of the individual systems of the brain, body, and emotions. But ultimately HRV training works on all these systems, and the study of respiration has shown why HRV is affected by and can work on all these three systems. Below is a review of research that demonstrates how the body, brain, and emotions are connected and of treatment that integrates these three systems.

For Collet et al. (1997), the autonomic nervous system responds to emotions in specific ways. Citing previous studies, Collet et al. note that in particular, heart rate, and respiratory frequency are usually considered reliable in studying human emotions. Changes in mental states correspond to changes in ANS function (Cohen et al., 1999). Karavidas et al. (2007) found major depressive disorders (MDD) to be related to decreased vagal activity and increased sympathetic arousal.

From a physical health standpoint, emotions, high levels of stress or depression, anxiety, and hostility alter autonomic functioning; that is, emotions occasion a loss of normal ANS control of heart rate and rhythm, which results in low heart rate variability. Gorman and Sloan (2000) conclude that a person with a psychiatric disorder could develop cardiovascular disease. Patients with anxiety disorders have chronically reduced HRV. Decreased HRV has been found to be a predictor of cardiac illness and reflects an individual’s inability to adapt psychologically to the demands and conditions of daily life (Gorman & Sloan). The current literature on HRV focuses on the connections between

1) how we feel emotionally; 2) how this feeling affects the body; and 3) how both body and emotions are marked by patterns of the heart beat (HRV)—not necessarily in this sequence.

From a neurobiological standpoint, corticotropin releasing factor (CRF) – 41 amino acid neuropeptides that influence neuroendocrine and autonomic responses to stress – raises plasma levels of norepinephrine and epinephrine, increases oxygen consumption, elevates mean arterial blood pressure and heart rate, and *shapes* an individual's behavior. Cohen and Benjamin (2006) did a spectral analysis of HRV that offers a reliable non-invasive technique to assess cardiovascular autonomic regulations. CRF plays an important role in regulating cardiovascular action by activating the sympathetic nervous system, when internal processes of an individual call upon the regulatory mechanism of the CRF. This finding is important because it shows that HRV can be an assessment and treatment tool for anxiety disorders. For Cohen and Benjamin, HRV measures open a window onto the sympathetic and parasympathetic interactions.

Autonomic afferents are crucial to stressful situations (Porges, 1995). The autonomic nervous system is involved in the physiological expression of stress. Shifts in the ANS activity that disrupt the *homeostatic* processes define stress from a physiological perspective. That is, ANS deals with both internal and external demands placed on the individual. Thus according to Porges (1995), the measure of parasympathetic tone can serve as a measure of the level of stress being experienced and the individual's vulnerability to stress.

Paul Lehrer and colleagues in particular have done significant research on HRV. A review of their writings can help clarify how HRV reflects the interaction between the body, brain, and emotions. The body's homeostatic processes require exercise for optimal function. It is clearly not beneficial to stay in bed all day. Lehrer and Vaschillo (2003) ask: "Why should the reflexes that modulate stress be different in this regard?" Heart rate variability biofeedback can exercise the body's baroreflex and thus train this important homeostatic mechanism, while strengthening both parasympathetic control and the modulation of parasympathetically controlled reflexes. According to Lehrer et al. (2000), respiratory sinus arrhythmia (RSA) is the variation in heart rate that accompanies breathing. Heart rate increases during inhalation and decreases during exhalation. RSA is one of several oscillatory mechanisms in heart rhythm. Citing Porges (1995), Lehrer et al. (2000) point out that RSA is related to self-regulation, from both an emotional and physiological standpoint. The amplitude of RSA waves tends to be depressed in people who suffer from emotional disorders. The occurrence and complexity of these HRV rhythms are related to the physiological systems that maintain cardiovascular stability and the individual's ability to adapt (physically and emotionally) to demands.

People can learn to produce very large increases in RSA by using biofeedback techniques. Such increases yield increases in the amplitude of baroreflex, and this exercise of the baroreflex will ultimately yield greater reflex efficiency and hence great modulation of autonomic activity. High amplitude stimulation of the baroreflex by breathing at resonant frequency will exercise this reflex and make it more efficient or improve regulation of the body. HRV biofeedback targets the baroreflex system and thereby helps strengthen this reflex, which is one of the body's self-regulatory reflexes. Slow breathing at 0.1 Hz, or 6 breathes per minute, increases heart rate variability. Breathing at this resonant frequency produces large oscillations in heart rate and improves pulmonary function. Training individuals to breathe at this frequency of 6 breaths per minute also may apply to treating anxiety, depression, and other disorders associated with autonomic dysfunction.

According to Lehrer, Sasaki, and Saito (1999), in HRV, greater amplitude and complexity (of HRV) suggests a greater variety of more active homeostatic reflexes and thus may be an index for adaptive capacity, both physical and emotional. Drawing from published studies such as Porges (2001) and his “polyvagal theory,” Lehrer finds HRV to be a strong indicator of adaptive capacity, homeostatic control, and other indications of functional capacity and general resistance to physical and emotional stress. This baroreflex activity stimulated by biofeedback exercises can increase our system’s efficiency; and with practice, this efficiency becomes characterized by high amplitude oscillations of HRV during biofeedback practice, and eventually, at rest for the individual.

HRV and cognition.

Critchley, Melmed, Featherstone, Mathias, and Dolan (2001) examined the extent to which brain networks and structures were involved in autonomic responses of the body. They sought to identify how cognitive processes influence states of physical arousal. The authors found a relationship between specific brain regions and decreases in sympathetic arousal. In the authors’ study, the anterior cingulate cortex, the globus pallidus, and the inferior parietal lobule were found to be involved in tasks that required participants to relax through biofeedback. There was also an association between the right medial temporal lobe activity (anterior and inferior to the amygdala) and autonomic relaxation. Activity in the amygdala was associated with strong emotional states, such as fear. The amygdala's association with or influence on the autonomic system's response and sympathetic arousal is thus consistent with its connection to emotions. Overall, Critchley et al. confirm that brain structures responsible for emotions are involved in autonomic arousal and relaxation. Critchley et al. illustrate how cognition and emotions are intertwined and how cognitive and emotional processing involves the brain and takes place or is experienced in the body.

HRV and brain injury.

The review so far has focused on HRV as it pertains to individuals with no neurological injuries. But the main interest of this paper relates to the benefits of psychophysiological training as it applies to individuals with brain injuries; so, the review now focuses on recent studies in this newly developing area.

The objective of the study by Tan et al. (2009) was to see if dysregulated autonomic nervous system activity manifested in depressed heart rate variability (HRV) in veterans who were diagnosed with PTSD and TBI. They found depressed HRV (depressed SDNN [standard deviation of all normal beat-to-beat interval measures between consecutive sinus beats]) in the veterans who were referred to the Poly-Trauma Center for treatment of PTSD, pain, and mTBI (mild traumatic brain injury). Tan et al. conclude that given the overly depressed HRV in veterans with this triad of symptoms, it would be useful to develop treatment to increase the veterans' HRV. Supporting evidence of dysregulation of the ANS due to severe TBI comes from both King, Lichtman, Seliger, Ehert, and Steinberg (1997) and Wijnen, Heutink, van Boxtel, Eilander, and de Gelder (2006). According to Wijnen et al. damage to higher cortical structures that regulate the ANS (such as the anterior cingulate cortex and the insular and medial temporal lobe structures, i.e., the amygdala and hippocampus) causes the ANS to be dysfunctional. In addition, neurotransmitters involved in autonomic activity have also been implicated in cognitive deficits associated with severe TBI.

Su, Kuo, Kuo, Lai, and Chen (2005) evaluated heart rate variability of individuals with TBI and attempted to distill patterns that correlate with severity of brain injury as measured by the Glascow Coma Scale (GCS). They found that increases in the LF/HF ratio and decreases of HF indicated increased sympathetic and decreased parasympathetic systems. A decrease in overall variability indicates severe brain injury; in particular, they found that HF was reduced in conjunction with greater severity of head injury.

Citing prior studies, Biswas, Scott, Sommerauer, and Luckett (2000) claim that TBI has been associated with significant autonomic dysfunction. Severe brain injury not only may impair sympathetic signals to the cardiovascular system but also may interrupt the autonomic cardiovascular pathways, thereby causing brain death. The LF/HF ratio was used as an *HRV marker of sympathetic modulation* of heart rate. Biswas et al. conclude that improvements in autonomic tone (balanced interaction between sympathetic and parasympathetic signals) may help the course of recovery taken by an individual with TBI after the initial onset of the injury. They claim to have thus shown an association between HRV and the severity of head injury, as well as an association between HRV and the functional outcome obtained by the injured individual.

Galluzzi et al. (2009) evaluated the association of HRV with white matter lesions (WML) in patients with mild cognitive impairments and found that reduced RMSSD (a time-domain measure of HRV representing the square root of the mean of the squares of differences between adjacent NN intervals [normal heart beats]) was related to WML. This association between RMSSD and WML suggests that a direct link exists between cardiac autonomic dysfunction and cognition. According to Baguley, Nott, Sleva-Younan, Heriseanu, and Perkes (2006), analysis of heart rate variability (HRV) revealed significant dysautonomia following severe traumatic brain injury. The dysautonomia group had significantly reduced LF power and greater LF/HF ratio variability compared to the non-dysautonomic group. For Galluzzi et al., HRV is a marker of cardiovascular autonomic function. In fact, reduced HRV has been associated with Alzheimer's disease. Thayer, Hansen, Saus-Rose, and Johnsen (2009) proposed that HRV could be a measure of an individual's performance in tasks that involve executive function such as attention, memory, and inhibitory control.

Heart rate variability training has been shown to be important to individuals with brain injury. Studies have found that TBI can cause significant reductions in HRV, which make individuals with TBI at risk for cardiovascular disease (Keren et al., 2005; King et al. 1997; Su et al., 2005). Executive functioning involves regulation of emotions and cognition, and it has been associated with sinusoidal patterns (coherence, resonance) of heart rate variability (HRV). Individuals with TBI suffer from autonomic dysfunction and typically exhibit incoherent (low variability or amplitude) HRV patterns (Baguley et al., 2009; Tan et al., 2009). Therefore, a review of the literature across the field suggests that addressing autonomic dysfunction and improving HRV in individuals with TBI can have significant consequences for their physiological, emotional, and cognitive health.

Chapter III

Rationale for the Study and Unique Contributions

The premise of this study is that the brain and emotions meet in the body. Specifically,cognitive factors and emotions reciprocally influence each other negatively and positively (Goleman, 1995). This study draws on psychophysiological research that emphasizes the importance of facilitating the emotion-cognition, heart-brain connection through psychophysiological techniques.

HRV biofeedback methods train individuals to regulate their emotions through psychophysiological processes *in order to think clearly*. Biofeedback methods are referred to as a psychophysiological treatment because they target physiological manifestations of psychological states and attempt to modify these physiological symptoms by bringing about changes in both physiology and psychology (Lehrer & Vaschillo, 2003). One type of biofeedback measure is heart rate variability (HRV). HRV measures the variation in time between heartbeats. According to Jorna's (1992) description, the cardiovascular system supplies the brain and other organs with necessary elements, such as oxygen and other nutrients. The brain in turn has the ability to prepare the cardiovascular system for particular actions and needs particular support and feedback from the cardiovascular system. Heart rate variability (HRV) can be a measure of how much action the brain is demanding from the heart in order for the whole organism to respond to something perceived by the brain as requiring a response. And therefore, HRV can be a measure of the psychological state

Specific Aims and Goals

The aims of this experiment were: 1) to determine if individuals with neurological damage (severe brain injury) can be trained to regulate their emotions through the use of heart rate variability (HRV) biofeedback methods and: 2) to find out if HRV training can enhance problem-solving skills, without a separate module of group and individual therapies that target problem-solving techniques such as those models offered by D'Zurilla and Nezu (2001). Modeled after the experiments done by Rath et al. (2003), this experiment was originally designed to be a problem-solving treatment where the individuals received biofeedback to improve emotional self-control as well as group therapy sessions involving learning skills to solve everyday problems that arise. But the protocol was changed and the experiment was simplified after a review of the baseline test scores, which showed the individuals at the day program were profoundly impaired. They attained the following scores: 1) a Halsted Reitan Impairment Index of 0.85, with 0.50 to 1.00 indicating severe brain damage; and 2) a full scale IQ at the *Extremely Low range* with a group mean of 64.62 (obtained from a chart review, which took place after enrollment into the study). A further reason for changing the protocol was that the individuals in the day program were unprepared to take notes or do homework, as the original treatment required.

The protocol was subsequently changed to focus strictly on teaching the individuals to regulate his or her emotions better with the use of biofeedback and to make the sessions strictly individual. This decision was further influenced by the Basic Skills Questionnaire (BSQ), which was developed as a tool to assign appropriate treatment levels for the patients at a large outpatient post-acute cognitive rehabilitation program (see Sherr & Langenbahn, 1992, for description). The BSQ is a behavioral rating scale that captures how well an individual can handle the following five basic criteria that are necessary for patients to benefit from cognitive training programs (Bertisch, Rath, Langenbahn, Sherr, & Diller, 2010): 1) attention/concentration; 2) note-taking and organization; 3) awareness of deficits; 4) ability to give and receive feedback; and 5) interpersonal skills (see Bertisch et al. for criteria details). For the purposes of ascertaining if participants of this study recruited from the long-term community-based day program could handle problem solving group treatment that entailed homework assignments, the preliminary BSQ test scores from the potential patients at post-acute cognitive rehabilitation program about to be assigned to a level were employed. No scores for patients functioning at "level 1" were available. According to the criteria of the BSQ, Level 1 constitutes extreme impairment. BSQ level-2 attained a WCST total error at the 12.83 percentile. The day program participants' mean WCST total error was at 2.21 percentile (1.97). According to the BSQ criteria, the day program individuals were functioning at Level 1 or below.

The study's overall goal is two-fold: First, this study seeks to contribute further to the literature that demonstrates the importance of addressing emotional control in treating executive dysfunction in individuals with brain injuries, and in the process show that individuals living with severe brain injuries for on the average 24 years can continue to profit from treatment and learn new techniques. Second, this study seeks to describe in scientific terms how the psychophysiological methods of biofeedback can be critical to brain injury rehabilitation if these methods are part of a standardized cognitive remediation protocol.

Unique to this study are the following two elements: 1) the use of HRV biofeedback methods through which individuals with severe brain injuries are trained to regulate their emotions through psychophysiological processes *in order to think clearly*. Also unique to this study is the population. The participants in this study are individuals who are past the post-acute phase of rehabilitation and are currently enrolled in a long-term community-based rehabilitation program that provides functional skills building in groups. One key premise of this study is that given appropriate training, those with *chronic* TBI can make substantial improvements in function. The study seeks to test the idea that after a certain period, further recovery is impossible. The premise of this study is in agreement with Feeney et al.'s (2001) position on the term *chronic*, which holds that given appropriate treatments, individuals who are past the "*post-acute phase,*" typically designated as a period when the individual can make spontaneous recovery, have the capacity to make fundamental improvements in regulating their cognitive and emotional states.

Some remarks about HRV measures are needed before we go on to our experiment.

Measurement

Malpas's (2002) review of the factors that influence cardiovascular variability (or HRV) conclude that there are too many forces that influence the heart rate oscillations to state conclusively that HRV is a measure of autonomic signals. While the sympathetic and parasympathetic activities (the two branches of the autonomic system) are critical to producing HRV, other nonbaroreflex or nonautonomic pathways influence HRV. Thus it is difficult at this time to distill the purely autonomic influence on the heart rate and its beat-to-beat variations (HRV). But other studies have found evidence that associate mental states to his or her HRV, and consequently, evidence to associate autonomic activity with HRV.

The Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology (1996) established standards for HRV recording and measurement. This experiment will focus on only those indices that appear to be most popular in the literature about emotion, cognition, and HRV. Time domain and frequency domain constitute two forms of HRV measurement. The simplest values to calculate are time domain indices. In particular, the standard deviation of the NN intervals (SDNN) provides an overall estimate of HRV. SDNN can be used to represent the overall level of heart rate variability (HRV) and to evaluate the general activity of cardiac autonomic regulation. SDNN also provides additional information about large-amplitude beat-to-beat changes in HR (Vaschillo et al., 2008).

However, 5-minute long recordings analyzed with frequency domain methods are preferred for short-term recordings (Task Force, 1996). The combination of these frequencies causes the “variability” of the heart, and the nature of the interaction of these frequencies on the heart results in a particular heart rate pattern, with a smooth sinusoidal wave with high amplitude (relative to the individuals’ age) representing optimal psychophysiological health.

Frequency domain analysis is done with power spectral analysis (PSA) and provides information on how power is distributed as a function of the frequency. The PSA quantifies how much activity or power is being exerted by the two arms of the autonomic system on the heart. PSA of HRV assesses the degree to which the heart rate signals are comprised by three different frequency bands, i.e., high frequency [HF] (0.15-0.5 Hz), low frequency [LF] (0.04-0.15 Hz), and very low frequency [VLF] (0.01-0-.04). High frequency is seen as a marker of vagal activity rooted in parasympathetic activity. Disagreement arises over what is responsible for low frequency, though the consensus is that LF is comprised of both parasympathetic and sympathetic activity. Very low frequency is even more difficult to define, but is generally viewed as being rooted in vasomotor activity and is involved in thermoregulatory processes.

Hypotheses And Statistical Analysis

Hypothesis I.

In a sample of adults who suffer from chronic brain injuries, attend a long-term structured day program, and are given training in heart rate variability (HRV) biofeedback, a nonsignificant difference will be observed between Time 1 and Time 2 in HRV recording; but a significant improvement in HRV will be observed between Time 2 and Time 3, which is post-treatment testing.

Statistical analysis.

To test Hypothesis 1, repeated-measure ANOVAs were conducted. To aid in the interpretation of the results, partial eta-squared effect sizes were calculated, according to Cohen (1988, pp. 284-287), effect-size conventions are: small= .01, medium = .06, large = .14.

Hypothesis II.

In a sample of adults who suffer from chronic brain injuries, attending a long-term structured day program, and are given training in heart rate variability biofeedback (HRV), a significant improvement in self-regulation will be observed in the domain of cognitive control. HRV scores will be significantly associated with these improvements. Specifically, the experimental intervention will improve the participants' attention, problem-solving, and their ability to profit from feedback, as measured by an improvement in the IVA – CPT Attention quotient, a decrease in Halstead Category Test (HCT) total error scores, reduced WCST perseverative responses, and increased WCST categories completed. In addition, the improvements in cognition will be associated with HRV biofeedback scores.

To test Hypothesis 2, a repeated-measure multivariate analysis of variance (MANOVA) was performed by comparing the participants' pre-treatment test scores at Time 1 and 2, and post-treatment testing after ten weeks of treatment at Time 3. It was predicted that the scores from the post-treatment testing would improve significantly over scores from the pre-treatment testing. If this analysis yields a significant result, then individual repeated-measure ANOVAs would be conducted for each measure separately in order to test for univariate-effects.

Hypothesis III.

In a sample of adults who suffer from chronic brain injuries, attend a long-term structured day program, and are given training in heart rate variability biofeedback (HRV), a nonsignificant difference will be observed between the participants' HRV resonance measures and informant reports of the participants' self-regulation of emotions and cognition at Time 1 and Time 2. No variance in the HRV scores will be observed. However, at post-treatment testing, Time 3, a significant association will emerge between informant reports of behavior and the participants' HRV recordings. The HRV scores will vary in relation to which participants benefit most from the treatment.

Statistical analysis.

To test Hypothesis 3, a bivariate correlation was performed to assess the significance of the relationship between HRV indices and the behavioral measures. If the association was significant, a linear regression was performed with alpha set at .05. The BRIEF scale scores were entered as criterion variables and HRV indices were entered as the predictor variables.

Chapter IV

Self-Regulation Experiment

Participants

This study included 13 individuals with moderate-to-severe brain injuries (as documented by prior neuropsychological and neurological evaluations). To participate in the study, the potential participants had to meet the following two criteria: 1) in the preliminary clinical testing with selected tests of the Halstead Reitan Battery, the potential participant had to obtain a score between 0.5 to 1.0 in the Halstead Reitan Impairment Index, with scores between 0.0 to 0.3 as normal, 0.4 as borderline, and 0.5 to 1.00 as impaired neuropsychological functioning; and 2) the potential participant had to have sufficient use of at least one hand and arm in order to participate in the *Finger Tapping* as well as the *Tactual Performance Test* (subtests that are computed into the *Halstead Impairment Index*).

This experiment was a study of the “real world,” and thus the exclusion criteria employed were minimal and flexible. For example, one participant expressed a great desire to participate. He had a pace maker implanted after having suffered a cardiac arrest in 1996. Because pace makers control variations of the heart rate, treatment effects based on increasing HRV could not be measured for this particular individual. The limited benefits of this treatment were explained to this man, but he was given the choice to enroll if he still wanted to. The participant was enrolled in the experiment, but his data were excluded for all analyses of this experiment. For the subsequent supplemental analyses, his data were included.

Brief descriptions of each participant of the study follow. The individuals are many years post injury, with minimal to no work history. Most are not independent and are mandated to have 24-hour supervision. They are presented in order of the time post-injury, longest to least number of years post-injury. Their participant numbers will be used rather than their initials.

At the time of the study, Participant-19 was 40 years post-injury. She was a 49-year-old African American female who at nine years old was in a motor vehicle accident, which put her in a coma for three months. She was hospitalized for nine months. At the time of her accident, she was in fourth grade. After her accident, the records indicate that her family attempted to have her resume studies, but without success. Instead, she enrolled in the Occupational Training Center and graduated in 1983. At the Occupational Training Center, she obtained the equivalent of a high school diploma. She had no work history and had never been married. She had lived alone in her own apartment and had a relationship with a man who also has a brain injury. She had daily close contact with her older sister who is very involved in her care. She had been attending the long-term day program since 2004 (four and one-half years).

Thirty-four years post-injury, Participant-4 was a 50-year-old Caucasian female who was in a motor vehicle accident in 1975, which put her in a coma for about nine months. At that time she was 16 years old. As a result of the car accident, she suffered a brain injury and incurred a left hemipareisis. In addition, shortly after her accident, she suffered a stroke and developed a seizure disorder. She was no longer at risk for seizures.

She was initially treated at the City Hospital in New York then transferred to Coler Goldwater for rehabilitation. She attended Coler for one and one-half years. While she was in rehabilitation, she also earned her GED. She had no work history and has\d never been married. She was living in her own apartment with supervision from an aide on a 24-hour basis. Her parents lived nearby and were very involved in their daughter's care. She had attended the day program since 1997 (12 years).

Participant-16 was 34 years post-injury. She was a 44-year-old African American female who at ten years old, fell down a flight of stairs and as a result was in a coma for six months. She was initially treated at Interfaith Hospital and then transferred to Kingsborough Rehabilitation. She finished only up to second grade in education and has never worked and has never been married. She had one grown daughter (in her 20's) who lives with her and is very involved in her mother's care. She had been attending the day program since 2003 (five and one-half years).

Twenty-nine years post-injury, Participant-11 was a 46-year-old Caucasian female who in 1980 at age 17 was in a motor vehicle accident, that placed her in a coma for five months. She had severe dysarthria, ataxia and heminanopsia (blindness in left eye), and needed to use a wheel chair. At the time of her accident, she was diagnosed with cerebral edema, brain stem damage, and dislocated left clavicle. She was a senior in high school at the time. She could not return to school but was awarded her high school diploma as a special accommodation. She had been attending the day program since 1995 (almost 14 years).

Twenty-seven years post-injury, Participant-17 was a 30-year-old African American male who at age three was hit by a car and as a result was in a coma for one month. He stayed at Downstate Hospital for one year. As a child he suffered from a seizure disorder (though he is no longer at risk for a seizure). He attended special education classes at the United Cerebral Palsy John Wayne School and is a high school graduate. He had various “supported” part-time work (not competitive employment). He lives with his family and has never been married. He had attended the day program since 2007 (two years).

Participant-22 was 25 years post-injury. He was a 29-year-old Hispanic male who sustained his brain injury when he was four years old as a result of a brain tumor. At that time, this individual was diagnosed with neuroblastoma and had to undergo four surgeries to remove the tumor; in one of the surgeries, a shunt was also inserted. As a child he suffered from a seizure disorder, but is no longer at risk for a seizure. He is a high school graduate. In addition, he attended and graduated from the Brooklyn School for Career Development and has held part-time jobs in food preparation and maintenance. The reasons that he left his jobs were not available. He has never been married and currently lives with his parents. He had been attending the day program since 2003 (six years).

Participant-18 was 23 years post-injury. He was a 23-year-old African American male who suffered anoxia at birth. His mother suffered significant complications during her pregnancy, and he was born with a serious heart condition and diagnosed with “failure to thrive.” In 2000 at age 14, this participant underwent open-heart surgery. He was a high school graduate and has no work history. He had never married, lives with his parents and one sister. He has been attending the day program since 2007 (two years and four months).

Twenty-two years post-injury, participant-20 was a 44-year-old African American male who was in a motor vehicle accident when he was 23 years old. At that time he was a senior at the NY Technical College with a 4.0 grade point average. After the accident he unsuccessfully tried to return to school. Work history and rehabilitation history were not specified. He has never married and lives with his mother. He had been attending the day program since 2003 (almost six years).

Participant-1 was 18 years post-injury. He was a 35-year-old Caucasian male who at 17 years old was hit repeatedly in the head with a baseball bat. The circumstances that prompted the assault were not clear. As a result of the assault, this participant was in a coma for four weeks and he suffered left side paralysis. He had a history of substance abuse and alcohol abuse, though he no longer abused drugs or alcohol. At the time of his assault he was attending eleventh grade. After the accident, he was unable to complete his studies and dropped out of high school. He had held various part-time jobs. It is unclear whether he was terminated or resigned from these part-time positions. But he was currently looking for a job and attended the day program's Job Club. He was currently married and lived with his wife. He was a very close relationship with his parents who live close by. He had been attending the day program since 1997 (12 years).

Participant-2 was 14 years post-injury. He was a 51-year-old Caucasian male who in 1994 jumped from an overpass onto the FDR Drive and then was struck by a vehicle on the roadway. He was 37 years old at the time. He had a history of bipolar disorder. His behavior in jumping from an overpass may have occurred because he had stopped taking his psychiatric medication. Information about how long he had lost consciousness was unavailable. Upon being hit by the vehicle, he was treated first at

Bellevue Hospital in New York City then transferred for rehabilitation to Goldwater Memorial Hospital. Later, he was admitted to Park Terrace Nursing Home for long-term care. He currently was sharing an apartment with a roommate, who also attended the day program. They had 24-hour supervision from an aide. This individual had never been married. He earned his BA from Kansas State University before this injury. He worked full-time in sales and real estate for Century 21. He did not have contact with family. He was very involved in a Presbyterian church in downtown New York; he regularly attended Sunday sermon, and participated in activities that are church-sponsored. While all the participants were given a stipend for their participation in the study, this participant refused to accept payment. Thus, an agreement with the principal researcher was reached where his stipend at the end of the study would be donated to his church. He has been attending the day program since 2000 (9 years).

Participant-23 was 14 years post-injury. She was a 24-year-old African American female who suffered from a frontal lobe tumor at age 10. Her medical history includes a seizure disorder (just as a child), hydrocephalus, and a pituitary tumor. She has had repeated brain surgeries and at one point had a VP shunt placed. She was a high school graduate. She had never worked and lives with her mother. She had attended the day program since 2006 (three years).

Participant-5 was 13 years post-injury. He was a 63-year-old Caucasian male who in 1995, at age 49, suffered a brain injury due to an intraventricula hemorrhage with hydrocephalus related to a subarachnoid bleed. He had a law degree, and he had been working as an Assistant District Attorney in the Brooklyn courts at the time of his injury. This individual also has a history of substance abuse before his brain injury. He successfully completed the chemical dependency program at the International Center for the Disabled (date unspecified). He had been diagnosed with depression and continued to see a psychiatrist. His records also indicate that he takes medication for symptoms of bipolar disorder and schizophrenia. He had never married and shares an apartment with a roommate (also attending the same day program). They both had 24-hour supervision from aides. At one point, he attended the Brain Injury Day Treatment Program at NYU Rusk Institute of Rehabilitation Medicine (dates unspecified). He had one younger brother with whom he maintains close contact. He had been attending the day program since 2002 (six and a half years).

Thirteen years post-injury, Participant-7 was a 53 year old Caucasian male who had a cardiac arrest in 1996 at age 40 suffered anoxic encephalophy. He was in a coma for two weeks and had outpatient treatment at the NYU Rusk Institute of Rehabilitation Medicine. A high school graduate, he has a commercial driver's license and was working full-time in payroll management as a truck driver for a payroll company. He lived with his son and wife. He had attended a long-term structured day program since June, 2009 (five months). Because this individual has a pacemaker that would prohibit treatment such as HRV, he was not included in the analyses of this experiment.

Participant-13 was 13 years post-injury. She was a 26-year-old black female from the Caribbean Islands. At age 13, she was diagnosed with congenital ataxic cerebral palsy and a learning disability. At the same time, she developed progressive dementia and spinocerebullar degeneration. She was a high school graduate and worked part-time for YMCA, though it was not clear whether this work with the YMCA was paid competitive employment or volunteer work. She had never married and lives with her mother. She had attended the long-term community-based [structured] day program since 2004 (almost six years).

Table 1 contains demographic data about the participants. Thirteen individuals (six women, seven men), with ethnicity of seven white non-Hispanic, five black non-Hispanic, and one white, Hispanic. The mean (standard deviation) age for the total sample was 39.54 (12.52). Seven had sustained a TBI. Six sustained their injury due to aneurysm, anoxia, ataxia or brain tumor. The mean time post-injury was 23.54 (8.10) years.

Table 1

Participant Characteristics

Variable		*n*	%	Variable	M (SD)	Range
Gender	Male	7	53.8	Age	39.54 (12.52)	23-63
	Female	6	46.2	Onset age	15.92 (13.74)	.01-49
Race	White non-Hispanic	7	53.8	Yrs post-injury	23.54 (8.10)	13-40
	Black non-Hispanic	5	38.5			
	Hispanic, White	1	7.7			

Tables 2-4 contain information on the participants' injury, education, work history and intellectual test scores as well as the baseline Halstead Reitan Impairment Index. The mean years of education was 12.31 (3.97). With respect to work history, 61.5 % (8) were unemployed with no paid employment experience, 15.4 % (2) had part-time work before their injury, 15.4% (2) were employed full-time, and 7.7% (1) was a student. The mean full scale IQ was 64.66 (10.9), verbal IQ was 69.25 (14.63), and performance IQ was 65.85 (11.70). Their Halstead Reitan Impairment index mean was .95 (.09) for both pre-treatment testing, time 1 and 2. These scores indicate that the participants as a group were functioning at the mental retardation range and were significantly impaired.

Table 2

Injury Characteristics

Variable	*n*
Loss of consciousness*	
Not TBI – not applicable	5
1-4 weeks (severe)	2
4 weeks + (severe)	4
Not available in medical record	2

** Loss-of-consciousness classification from Geffen et al. (1998).*

Table 3

Etiology

Variable	*n*
TBI	
MVA	6
Fall	1
Assault	1
Not TBI	

Aneurysm	1
Anoxia (at birth)	1
Ataxia, Cerebral Palsy, progressive dementia	1
Brain Tumor	2

Table 4

Participant Characteristics (Education, Work, IQ, and Impairment Index)

Variable	M (SD)	Range
Education (in years)	12.31 (3.97)	2 - 20
Work History		
Lawyer	1	
Salesman	1	
Variable	M (SD)	Range
College student	1	
No work experience	10	
Intellectual testing WAIS – III (*n =12)*		
Full scale IQ	64.62 (10.90)	50 - 88
Verbal IQ (*n =11)*	70.00 (15.10)	55 - 109
Performance IQ	65.25 (12.01)	54 - 100
Intellectual testing WAIS – IV (*n =1*)		
Verbal Comprehension	61	

Perceptual Reasoning	73	
Working Memory	71	
Processing Speed	62	
Impairment Index pre-treatment time 1 & 2	.95 (.09)	.70 - 1.00

Method and Procedures

This study featured a single-treatment experiment and used a non-randomized, unblinded experimental design with measures repeated at three time points: Pre-treatment test 1 (Time 1), pre-treatment test 2 (Time 2), and finally a post-treatment test 3 (Time 3). The participants of this study were drawn from a metropolitan brain injury program, AHRC, in New York City. AHRC is a community-based, structured day program that provides long-term rehabilitation services for individuals with mild, moderate, and severe brain injuries. Rehabilitation goals are worked on in supervised community settings, as well as in structured groups. Participants are provided with a full day (6-hours-per-day) of community-based, skill-development activities, and where needed, individual psychological or speech therapies, or both. The individuals can attend as many days as they choose (Monday through Friday) and for as long as needed. For some individuals, the program serves as an intermediary step to getting a job; for others, it provides life-long opportunities to learn new skills and to socialize. The key points to this community-based program are that 1) it is long-term and 2) provides support for both the individual, and where applicable, to the individual’s family, in the form of service coordination.

All procedures were conducted in compliance with the American Psychological Association's (APA) Ethical Principles in the Conduct of Research with Human Participants (1982**).** The Albert Einstein College of Medicine of Yeshiva University's Institutional Review Board and the AHRC Institutional Review Board both approved the study. The participants were made aware that participation was voluntary and that declining to participate would have no negative impact on their participation at the structured day program. An Informed Consent Form was read to all potential participants. Before any testing was administered, the consent form was signed by the participant; and where applicable, a signed Authorization to Use or Disclose Protected Heath Information for a Research Study form was obtained from the participant's "advocate."

The participants enrolled in the study first received baseline testing (pre-treatment, Time 1). Testing included five-to-six hours of neuropsychological testing and completion of self-reports. Informants completed inventories on the participants at a separate time. Then a 10-week waiting period began. After the 10-week waiting period, the participants underwent a second round of testing (pre-treatment, Time 2). At this point, they received the specially-tailored individual treatment involving self-regulation through heart rate variability biofeedback methods. (See Appendix F for detailed description of the 10-session treatment protocol).

Two of the participants were transferred to another AHRC facility (the Bronx site) after pre-treatment testing. Thus these two participants were provided with the same treatment but at their homes on Saturday mornings. They received the same post-testing measures as the other participants who received treatment at the original AHRC facility

(Brooklyn site). However, at Time 3, they were administered the computerized Category Test. Studies have shown that there is no difference between the computerized and the slide-projector administration (Choca & Morris, 1992**).**

The participants were paid $10 for participating in each five-to-six hour testing session; $5 for completing additional questionnaires after treatment ended, $5 for each individual session, and $5 extra for attaining biofeedback “reward cycles” using a portable cell-phone-size heart rate variability biofeedback gadget called “handhelds,” which they took home for practice.

Pre-Treatment Test Time 1

All the neuropsychological tests and self-reports were administered according to published standardized procedures. The items and questions of the self-reports were read aloud to the participants (they were unable to read and understand or their attention was so impaired that it would be difficult for them to accurately scan and track the items and answer the questions accurately). The questions and statements of the inventories were not elaborated and additional explanations were not offered. The choices for the questionnaires, i.e., agree, disagree, really disagree, were placed in front of the participants, and they were instructed to listen carefully to the questions or item statements that were read aloud to them and then either point to their response listed on the stimulus cue or to say it out loud.

The informant inventories were completed only at pre-treatment, Time 2 and post-treatment, Time 3. The reports were either completed by the informant and returned to the investigator or the items and questions were completed through a phone conversation with the investigator. The informants consisted of members of the family of the participant (seven participants) and members of the staff of the program (six). To account for this difference in relationship with the participant, one personal and the other professional, separate analyses were conducted (Cavallo, Kay, & Ezrachi, 1992).

Measures.

Neuropsychological tests.

Impairment Index.

The following tests were administered to obtain the Impairment Index. The Impairment Index is computed based on the seven tests originally included by Halstead in the Halstead-Reitan Battery (described below) and have been shown to be very sensitive to cerebral damage (Reitan, 1955; Reitan & Wolfson, 1993). The Impairment Index is the proportion of an individual's test scores of that are in the range characteristic of brain-damaged individuals: 0-to-.3 is considered normal, .4 is borderline, and .5 to 1 is indicative of neuropsychological impairment (Reitan & Wolfson).

Halstead Category Test (HCT).

The primary purpose of the HCT is to determine the individual's ability to use both negative and positive experiences as a basis for altering his or her responses. This test measures an individual's abstraction or concept-formation ability, flexibility in the face of complex and novel problem solving, and capacity to learn from experience (Reitan & Wolfson, 1993). The HCT measures many functions that are considered executive functions, such as working memory, attention, mental flexibility, and general organizational skills. Therefore, it is a more global measure of problem-solving skills -- not just frontal lobe functioning. The HCT has been repeatedly shown to be sensitive to the presence of brain damage (Reitan & Wolfson, 1992; 1993; Shaw, 1996).

Performance is based on the total number of errors that an individual makes on the test. Test-retest reliability is *r* = .85 for a repeat testing after 11 months (Dikmen, Heaton, Grant, & Temkin, 1999); *r* = .73 for a mean time interval between tests of 93.21 weeks (Goldstein & Watson, 1989); *r* = .70 for short-term retest reliability (three-week time interval of interest) (Bornstein et al., 1987).

Bornstein, Baker, and Douglass (1987) observe that tests that depend on novelty such as the Category Test, appear to be prone to practice effects. But they also observe that patients with brain dysfunction may have different reliabilities than normal healthy individuals, suggesting that practice effects may be less an issue for those with brain injuries. Test-retest reliability for intact individuals is *r* = .60, and reliability coefficients increase with impaired groups as the examinee's performance worsens, *r* = .72 (Matarazzo, Matarazzo, Wiens, Gallo, & Klonoff, 1976). In the same vein, Dikmen et al. (1999) also observed that practice effects are less likely for those with initially very impaired scores. Finally, Goldstein and Watson (1989) also note that even if scores improve, the change should be considered both from an absolute score basis and a relative reliability standpoint. That is, the changes may not reflect actual clinical improvement. Split-half reliability is *r* = .90 (Matarazzo et al.). The total error score of the HCT has been found to be very sensitive to brain damage (Choca, Laatsch, Wetzel, & Agresti, 1997). This test's ability to distinguish brain damaged from non-brain damaged individuals (discriminant validity) is 90.7 - 98.8% (Reitan & Wolfson, 1993). Up to age 60, an individual's years of education influences HCT scores, but after age 60, education does not seem to have an influence (Choca et al.). Finally, the HCT has been found to have significant association with problem-solving skills (Halstead, 1947; Leonberger, Nicks, Goldfader, & Munz, 1991). A score of 51 errors and above constitutes impairment.

Seashore Rhythm Test.

The Seashore Rhythm Test (SRT) contains 30 pairs of rhythmical patterns and the individual determines whether the two patterns in each pair are the same or different (Reitan & Wolfson, 1993). This test requires the ability to sustain attention and concentration under timed conditions (Jarvis & Barth, 1994). Brain damage, regardless of lateralization, adversely affects the abilities required to perform the Seashore Rhythm Test (Reitan & Wolfson, 1989). A "rank" score of 6 and above is considered impaired (raw score is first converted into a rank). The test-retest reliability is r = .76 with a three-week test-retest time interval (Bornstein et al., 1987).

Speech Sound Perception Test (SSPT).

The SSPT consists of 60 spoken nonsense words, which are variants of the *ee* sound. A man's voice speaks the stimulus – the nonsense word – on a tape recording. The examinee listens and then chooses one of the four options printed for each item on the test form, depending on which option best fits the sound the man on the recording said -- for example, *which option of the nonsense word did the man announce in the tape recording "theeks, zeeks, theets, zeets.*" The SSPT serves as good indicator of the general integrity of cerebral cortical functions regardless of location or lateralization of the brain lesion impaired (Reitan & Wolfson, 1993). An extremely poor score may reflect particular impairment of left cerebral functions. The score is the total number of errors. A score of eight errors or more is considered impaired (Reitan & Wolfson). Test-retest reliability (three-week time interval) is r = .73 (Bornstein et al., 1987).

Tactual Performance Test (TPT).

In this test, the participant is blindfolded before the test begins and is not permitted to see the board or blocks at any time. The examinee's first task is to fit the blocks into their proper spaces on the board using only the dominant (preferred hand). The examinee is asked to perform the same task again using only the non-dominant hand. Then, finally he or she is instructed to do the same task again using both hands. After the examinee has completed the third trial, the board and the blocks are removed and the examinee is permitted to take off the blindfold. He or she is then asked to draw a diagram or picture of the board with the blocks in their proper spaces. The drawing is scored to reflect the examinee's memory and localization components Success depends on kinesthesia, coordination of upper extremities, manual dexterity and an understanding of the relationship between the spatial configuration of the shapes and their location on the boards (Reitan & Wolfson, 1985; 1993).

Test-retest reliability for a 4-week interval has been reported as .66 to .74 for Time, .46 to .73 for Memory and .32 to .69 for Location (Goldstein & Watson, 1989**).** The following scores constitute impairment: 15.7 and above (Total Time), 5 and below (Memory), and 4 and below (Location) (Reitan & Wolfson, 1993).

Finger Tapping Test.

Halstead's Finger Oscillation Test (also known as the Halstead Finger Tapping Test [HFTT]) requires the examinee to work the lever arm of the mechanical counter up and down as fast as they can, by first using their index finger of the dominant hand, then using the index of their nondominant hand. The examinee is given five trials of ten seconds each. This simple test of speed of finger movement has been found to help identify patients with the brain dysfunction in comparison to normal controls as well as psychiatric patients. The HFTT is sensitive to lateralized cerebral deficits (Prigatano, Sterling, Gale, 2004). Test-retest reliability for the dominant hand was *r* = .80 and *r* = .82 for the nondominant (Morrison et al., 1979**).** Practice effects tended to be nonsignificant (Bornstein et al., 1987).

Trail Making Test (TMT), A and B.

The Trail Making test is a timed pencil and paper test, which consists of parts A and B. On each part the patient is given a sample page, which is used for practice to help the patient understand the instructions. The examiner then gives the patient part A, a sheet of paper with circled numbers (1–25) randomly arranged on the paper, and the patient is instructed to connect the circles in numerical order using straight lines as quickly as possible. In part B, the patient is presented with circles randomly arranged circled numbers (1–13), randomly arranged circled letters (A to L). The patient is instructed to connect the circles beginning with number 1, then going to A, and then to 2, and then to B, alternating number and letter in order. The patient is scored on speed and accuracy (Jarvis & Barth, 1994). Test-retest reliability for 22.9 days was *r* =. 87 for Trails A and *r* =. 94 for Trails B (Eckardt & Matarazzo, 1981**)**. Given a time interval of three weeks, Bornsetin et al. (1987) found Trails Making Test part A to have low reliability; Part B score was adequate, *r* = .75.

But whether the change between the test-retest scores is clinically meaningful may be more relevant. The TMT requires immediate recognition of the symbolic significance of numbers and letters, the ability to scan the page continuously to identify the next number or letter in sequence, flexibility in integrating the numerical and alphabetical series, and the ability to complete these requirements under the pressure of time. Speed and efficiency of performance may be a general characteristic of adequate brain functions. Thus this test is often seen as the best measure of general brain function (Reitan 1955; 1958). Scores that constitute impaired performance are completion time of over 39 to 40 seconds for Trail A, and 91 to 92 seconds for Trail B (Reitan & Wolfson, 1985).

Wisconsin Card Sorting Test (WCST).

The WCST measures the abilities to engage in logical analysis, conceptualize visual sets, and develop a flexible problem-solving plan based on feedback that is given to the examinees about their answers. The test requires strategic planning, organized searching, goal-oriented behavior, and the ability to modulate impulsivity (Heaton, Chelune, Talley, Kay, & Curtis, 1993). Of the scores WCST provides, the number of correct categories and total perserverative responses were used for this study. Perseverative response score has been found to be the most useful diagnostic measure of the WCST (Heaton, 1981). Test-retest reliability with a medium time interval of 12 days, ranging from 1-71 days has been found to be $r = .79$ for perseverative response and $r = .70$ for categories completed (Ingram et al., 1999).

The WCST involves identifying relatively simple concepts of color, shape, and number. In contrast, the concepts of the HCT are more subtle and are based not so much on attribute identification, which is more sensitive to perserverative tendencies (Perrine, 1930), but on rule learning, which requires manipulation of higher-order concepts (Bond & Butchtel, 1984; Goldstein & Watson, 1989; Perrine, 1993).

Both the WCST and the HCT have been included in this study because the two tests assess similar cognitive functions but at different levels, with the HCT being more complex. The WCST is a "good" measure of frontal activity (feedback utilization is frontal), but it is a limited measure of executive functioning (Perrine, 1993; Pendelton & Heaton, 1982). Likewise, the HCT is a good measure of executive function, but it is a limited measure of frontal lobe activity. The HCT measures novel problem solving, which does not involve a singular function, such as attention, that can be connected to a particular brain region.

Integrated Visual And Auditory Continuous Performance Test (IVA).

This continuous performance test combines visual and auditory stimuli to examine the level of impulsivity, inattention, and hyperactivity in individuals from age five through adulthood. The IVA produces quotient scores for impulsivity and inattention (Sanford & Turner, 1995). Ucok et al. (2006) found that social problem-solving skills were related to cognitive flexibility *and* sustained attention; Kim et al. (2005) and Hart, Whyte, Junghoon, and Vaccaro (2005) found that inattention in individuals with brain injuries predicted poor scores on measures of executive functions. Attentional control, especially the ability to shift one's attention at will, has been identified as a component critical to executive functions and even a prerequisite to higher-level cognitive processes such as cognitive flexibility, self-regulatory behaviors, and working memory (Feifer & Rattan, 2007). The IVA's overall accuracy in its ability to identify individuals with attention disorders (discriminant validity) was found to be significant (p = .0001) when compared to diagnoses made by a physician or psychologist who had independently evaluated the patient previously. In a study of children with ADHD, the sensitivity of

IVA was 92%. The specificity was 90% (Sanford & Turner, 1994). Test-retest reliability over a period of 1 – 4 weeks for the primary scores used for this study-- Full Scale Attention Quotient and Full Scale Response Control Quotient -- were r = .74 and r = .41, respectively.

Self reports and inventories.

Behavior Rating Inventory Of Executive Function – Adult Version (BRIEF-A).

The BRIEF–A is a self-report and informant-report measure that captures adults' views of their own executive functioning. It has a fifth grade reading level. The BRIEF-A contains 75 items and yields an overall score – the Global Executive Composite (GEC), which is a composite of two index scores -- Behavioral Regulation Index (BRI) and the Metacognitive Index (MI). The BRI is comprised of four scales (Inhibit, Shift, Emotional Control, and Self-Monitor), and the MI is comprised of five scales (Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials). Standard scores are calculated for each of the clinical scales and indices, and for the summary composite, with higher scores reflecting greater difficulties experienced by the individual. Scale scores higher than T = 65 indicate that the behavior is abnormal. Internal consistency for a sample mix of healthy and clinical adults was relatively high for the self-reports, ranging from Cronbach alpha at .80 to .94 for the clinical scales, and .69 to .98 for the indices and the GEC. For informant-reports, the Cronbach alpha for this sample was also high, with .85 to .95 for the clinical scales, and .96 to .98 for indices and the GEC (Roth et al., 2005). Test-retest correlations across the clinical scales for the self-report version ranged from .82 to .93 over an average interval of 4.22 weeks with a range of .71 to 8.57 weeks. Test-retest correlation for the informant version ranged from .91 to

.94 (Roth et al.). For this experiment, at Time 1, only the self-report version of the inventory was used. At Time 2 and Time 3, the participants and their informants completed this inventory.

Problem Checklist (PCL) version 2.

The PCL is a checklist of symptoms; the individual is asked to identify symptoms that cause problems and to rate the severity of the problem, on a scale of 1 to 7 (with 7 as the most severe). The checklist consists of 34 items dealing with physical, cognitive, behavioral, and affective symptoms or problems that are common after TBI. The PHI (Person with a Head Injury) is asked to rate how much of a problem each item presents and whether this rate reflects a change from before the injury. In addition, the person's significant others are asked how much strain or burden they feel as a result of this problem, also on a scale of 1 to 7, with 1 being no strain/burden and 7 being severe strain/burden. Ratings of 2-7 on the problem question were taken as an endorsement of an item and 1 (no problem) was considered a non-endorsement. Strain/burden response were considered along the full range from 1 (no strain) to 7 (severe strain) Cavallo et al., (1992). At Time 1, only the self-report version of the PCL was used. Kay, Cavallo, Ezrachi, and Vavagiakas (1995) found this instrument to have adequate reliability and validity, with Cronbach alpha ranging from .65 to .92 for inventories completed by the Person with the Head Injury. For the reports completed by the informants, the Cronbach alpha for the three factors (scales) were .89, .77, and .66. (The reader is referred to Kay et al., 1995, for detailed psychometric information).

Brief Symptom Inventory (BSI).

The Brief Symptom Inventory (BSI) consists of 53 items covering nine symptom dimensions and provides three global indices of distress: Global Severity Index, Positive Symptom Distress Index, and Positive Symptom Total. The global indices measure current or past levels of psychological distress, along with the intensity and the number of symptoms reported. Derogatis (1993) report adequate reliability and validity. For the purposes of this study. Focus falls on only two dimensions (symptoms): Depression and Anxiety. Internal consistency coefficients were good, with Cronbach alpha for Anxiety at .81 and Depression at .85. Test-retest reliability was .84 for Depression and .79 for Anxiety. (The reader is referred to the Manual, Derogatis (1993) for specific information on the psychometrics).

Heart rate variability (HRV) data collection.

After the participants completed their neuropsychological testing, their HRV was recorded. To ensure that fatigue did not confound the signals obtained, this recording was usually made on a different day or after the participant had a lunch break

For the biofeedback heart rate variability (HRV) the *Institute of HeartMath's emWave PC* (HMI, formerly the Freeze Framer Interactive Learning Program) was used, a software program with a heart-rhythm monitor. HRV waveforms in the form of R-R interval tachograms were acquired, done with the use of an infrared plethysmograph sensor. The sensor was placed on either the left or right earlobe, and a computer monitor displayed the individual's heart rate variability patterns in real time with a 1 Hz sampling rate.

There are two distinct sampling rates. One to sample the raw signal (such as the ECG or the pulse) which is high and one to sample the RR-intervals signal, which is low. HeartMath's sampling rates for the raw signal (such as the ECG) and the RR intervals were 250Hz and 1Hz respectively. (Although HeartMath claims a 2Hz-sampling rate for the RR intervals, when the signals were measured, a rate of 1Hz was obtained (e.g., a 60 seconds acquisition resulted in 60 samples). Note that both of these rates respect their individual Nyquist criterion. In the case of the raw signal, 250 Hz typically meets the Nyquist criteria of 250- 500 Hz (Task Force, 1996). The RR intervals are obtained from the sampled raw signal and contains a much smaller range of frequencies. Effectively, measuring the RR intervals from the ECG filters out most of the information contained between two heartbeats (e.g., the location of the P or T wave, etc). As a result, the frequency content of the RR-intervals signal is contained mostly below 0.4Hz (Berntson et al., 1997; Task Force, 1996). The total power definition stops at 0.4Hz because power that exceeds 0.4Hz is usually defined as "noise." Real physiological modulations may occur above 0.4 Hz, though it is rare to see meaning full signal above the 0.4 Hz threshold (M. Atkinson, personal communication, February 28, 2011). Thus, in the case of the RR interval, the Nyquist criterion therefore is 0.8Hz, and 1Hz is therefore sufficient

During the HRV recording, the participants were seated comfortably in an upright position on a chair, in a quiet room; the computer screen was not visible to them, and the volume was also turned off (to make sure that they did not get any feedback during the testing).

For the purposes of collecting baseline data of the participants' HRV, in accordance with HeartMath's standard procedure (R. McCraty, March 9, 2009, personal communication) the script below was read to the participants by the principal investigator.

For ten minutes I would like you to sit quietly with your eyes open, kind of like you are waiting at a bus stop for the bus. Please avoid using any relaxation techniques such as meditation. Also avoid any intense mental activity. I will let you know when the ten minutes are up.

HRV data transformation and analysis.

For the purpose of this experiment, a custom-made program based on the Task Force standards (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996) was developed in order to transform the R-R intervals into meaningful data for analysis and comparison with neuropsychological tests. The calculations performed by the HeartMath software were not available to the public, thus a number of specifications necessary to reproduce their results were not published, such as the window size used for the power spectral density (PSD) estimation, the definition of total power, or the amount of filtering applied to the data. Alternatives such as Kubios (Tarvanien & Nikanen, 2008) do not have the flexibility needed to introduce new indices such as HeartMath's coherence ratio. Instead, a relatively simple custom-made, in-house code was built using Matlab R2008b (The Mathworks, Nattick, MA) (see Appendix C for the codes used to process the data). Frequency domain variables were calculated using nonparametric PSD of 5-minute-long recordings of the RR intervals. The frequency bands were set according to the Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology Report (1996). Outliers from the RR intervals were removed when they exceeded the local median value by more than 200 ms. One-sided power spectral densities were obtained using the Welch method implemented in Matlab R2008b (The Mathworks, Nattick, MA). A window size of 64 seconds and a 50% overlap were used. Spline fitting was used for integration of the PSD. Peak power was identified using the formula proposed by HeartMath (Thurber et al., 2008). Maximum peak was identified in the 0.04 - .26 Hz range (+/- 0.015 Hz) with the peak power determined by calculating the highest peak in a region covering the integral in a window 0.30 Hz. Next the total power of the spectrum was derived (bandwidth of 0.0033 – 0.4 Hz).

The coherence value was defined as Peak Power/(Total Power-Peak Power) where the peak power was defined, as suggested in McCraty et al. (2006), as the integral of the PSD in a 0.03 - wide window centered at the maximum value of the PSD located between 0.04 and 0.26 Hz. Total power corresponded to the integral of the PSD between .0333 and 0.4 Hz. No bins were used. Sampling was done at 1Hz for 5 minutes equals > 300 points obtaining a resolution of 0.5Hz/150points = 0.0033333Hz. Nyquist criterion was 0.5Hz. The integration was not done by simply adding bins together (which is not optimal). Instead, integration was performing using a spline fit of the power spectrum. These integrals followed the parameters set by the Taskforce (1996) for VLF, LF, HF, and total power. Finally, in order to limit this ratio between 0 and 1, the coherence ratio was normalized (Peak Power/ Total Power). Both HeartMath's coherence measure – peak power/(total power – peak power) – and the *normalized coherence* – peak power/total power – were found to yield a significant effect size ((*partial* η^2) with training (slightly larger effect with *normalized coherence*: 0.43, p = .008 vs. 0.40, p =.011 [T2-T3]; 0.55, p = .001 vs. 0.48, p =.004 [T1-T3]). Hence, it appears that the *normalized coherence* measure that was introduced for the purposes of this experiment provides a more precise measure of resonance achieved by the participants. (In addition, the normalized coherence ratio algorithm introduced here is quantified on an easy to interpret scale that varies from 0 [no coherence] to 1[total coherence]).

The signals were processed initially by HeartMath. But in order to try to reproduce HeartMath's data transformation for clinical and research purposes, a custom-made code in Matlab, programmed according to parameters established by HeartMath, was used and the signals reproduced as described above. Then this newly processed data were correlated with data processed by HeartMath (see Table 5).

Table 5

Intercorrelations of Coherence Scores Obtained from Heartmath and Custom-Coded Algorithm Using Matlab

Time 1	Matlab custom-coded coherence ratio	Matlab custom-coded coherence ratio normalized
HeartMath's (HMI) coherence ratio	-.24 p = .40	-.23 p =.44
HMI coherence ratio normalized	-.29 p = .31	-.21 p = .48
Time 2		
HMI coherence ratio	.13 p = .67	.35 p = .22
HMI coherence ratio normalized	-.09 p = .76	.09 p =.76
Time 3		
HMI coherence ratio	.89** p = .001	.87** p = .001
HMI coherence ratio normalized	.78** p = .001	.86** p = .001

Note. ** $p < 0.01$ level (2-tailed).

Time 1 and Time 2 had no significant correlations between HeartMath and the custom-made code. But Time 3 showed significant correlations between the two sets of data. Because access to HMI's proprietary material was not available, it is not possible to explain why significant correlations emerged at Time 3, or whether this significant association is a function of how the participants performed at Time 3.

Pre-Treatment Test Time 2

After 10 weeks of the waiting period, during which time the participants continued routine activities at the day program, the measures listed above were all re-administered according to published standardized administration. One new self-report was included, the Problem Solving Inventory, adolescent version. In addition, starting at Time 2, informant ratings were also collected. All tests that were administered at this time point are listed below, but descriptions are provided for only the new measures, those tests that did not appear at

Time 1.

Measures.

Primary outcome measures.

Heart rate variability indices (LF/HF and Coherence ratio).

Behavior Rating Inventory Of Executive Function (BRIEF-A), informant version.

Secondary outcome measures: Neuropsychological tests.

Impairment Index.

Halstead Category Test (HCT).

Seashore Rhythm Test (SRT).

Speech Sound Perception Test (SSPT).

Tactual Performance Test (TPT).

Trail Making Test (TMT) A and B.

Wisconsin Card Sorting Test (WCST).

Integrated Visual And Auditory Continuous Performance Test (IVA).

Secondary outcome measures: Self and informant reports.

Behavior Rating Inventory of Executive Function (BRIEF-A), self-report version.

Problem Checklist (PCL) Version 2, self-report and significant other versions.

The individual's significant other (consisting of program staff when a family member was not available) was also asked to identify symptoms and severity levels, as well as whether the symptoms constitute a change from before the individual was injured and whether they cause a strain (Kay et al., 1995). The significant other (SO) version includes a burden scale. While the SO PCL was collected for all 13 participants, the family burden scores could be collected for only 7 of the 13 participants.

Brief Symptom Inventory (BSI).

Problem-Solving Inventory (PSI), self-report.

This inventory consists of a 35-item self-report measure in a 6-point Likert style format (1 = strongly agree to 6 = strongly disagree). This questionnaire probes an individual's attitudes towards and perceptions of his or her abilities to solve problems (Heppner & Peterson, 1982). Higher scores in this inventory reflect a negative self-appraisal of problem-solving abilities. Three separate subscale sores are derived. Problem Solving Confidence (PSC) measures an individual's self-assurance, beliefs, and trust in his or her ability to handle problems. Approach and Avoidance style (AAS) measures the tendency of the individual to either approach or avoid problems that come up. Finally, Personal Control (PC) measures the individual's emotional control when confronted with a problem. A total score is derived from these separate subscale scores. Alpha coefficient reliability is adequate for the total score (high .80's), AAS and PSC (mid .80's), and PC (.70). Internal consistency and stability over a two-week period for the total inventory were .90 and .89 respectively (Heppner, Cooper, Mulholland, & Meifen, 2001). For the purposes of this study, permission was obtained from Heppner to use the adolescent-version of the PSI, which has a sixth grade reading level (see Appendix D). Rath et al. (2003) found that for higher functioning individuals with TBI, the central deficits involved regulating emotions (problem orientation), and therefore, PSI was found to be significantly sensitive to improvements after treatment.

Problem-Solving Inventory (PSI), informant-report.

Staff members completed only those items that comprise Approach and Avoidance style (AAS) for all 13 participants. Families were not involved in this inventory.

Post-Treatment, Test Time 3

After ten sessions of treatment of self-regulation HRV biofeedback, which spanned 11-14 weeks, due to cancellations and other schedule conflicts, the participants were re-administered the measures listed above. With the exception of the Category Test, the Seashore Rhythm test, and the Speech Sound Perception Test, the other tests that constitute the Halstead Reitan Impairment Index were not re-administered, since they were not outcome measures. All other measures were retained. Below is a list of the tests; descriptions can be found at the start of this chapter under the previous sections entitled Pre-treatment test Time 1 and 2.

Measures.

Primary outcome measure.

Behavior Rating Inventory of Executive Function (BRIEF-A), informant version.

Secondary outcome measures: Neuropsychological tests.

Halstead Category Test (HCT).

Seashore Rhythm Test (SRT).

Speech Sound Perception Test (SSPT).

Trail Making Test A And B (TMT).

Wisconsin Card Sorting Test (WCST)

Integrated Visual And Auditory Continuous Performance Test (IVA).

Secondary outcome measures:Self and informant reports.

Brief Symptom Inventory (BSI)

Problem-Solving Inventory (PSI) (self-report and staff rating of Approach-Avoidance Style subscale)

Problem Checklist (PCL) Version 2, self-report and significant other.

Behavior Rating Inventory Of Executive Function, Adult Version (BRIEF-A).

Measures Used for Supplementary Analyses

A new set of analyses were done 8-10 weeks after post-treatment testing had been concluded.

Clinician's rating form of problem solving and emotional self-regulation skills, patient version and clinician version.

These rating forms for problem-solving ability and emotional self-regulation skills were developed by the Rusk institute of Rehabilitation Medicine, a short-term rehabilitation program for the patients, the families (significant other), and the clinicians who treat the patients to rate the patients' problem solving and their emotional control from a scale of 1–7 (1 = extremely poor and 7 = excellent skills). In this study, only the patient version and the clinician version were administered. The long-term day program staff completed the clinician version.

Satisfaction with Life Scale (SWLS).

The Satisfaction with Life Scale (SWLS) is a measure of life satisfaction developed by Diener and colleagues (Diener, Emmons, Larsen & Griffin, 1985). Satisfaction with life is distinguished from affective appraisal in that satisfaction with life is more cognitively than emotionally driven. A person's satisfaction with life can be assessed as a whole or according to a particular domain of life, such as work or family. The SWLS is a global measure of life satisfaction. It consists of five statements with which the individual is asked to agree or disagree on a 7-point scale, 1 = strongly disagree; 7 = strongly agree. It has acceptable internal consistency (0.87). Support for the construct validity was also demonstrated by the scale's normative data (Pavot & Diener, 1993). The higher the total score, the greater satisfaction with life the individual reports. Two month test-retest correlation coefficient was at 0.82 and Coefficient alpha at 0.87 (Diener, Emmons, Larsen, & Griffin, 1985; Corrigan, 2000).

Rosenberg Self-Esteem Scale.

The Rosenberg Self-Esteem Scale (RSES) requires individuals to respond to ten statements that reflect attitudes about themselves. The test uses a ten-item Likert scale, with the ten items answered on a four-point scale – from strongly agree to strongly disagree. The RSES has been used with the TBI population and is generally regarded as a valid, reliable measure of global self-worth. Test-retest reliability correlations have been found to be between 0.82 and 0.88, and Cronbach α's between .77 and .88 have been reported. Torrey, Mueser, McHugo, and Drake (2000) evaluated the long-term stability of the score and found that the correlation coefficient was .71 for scores at baseline and six-months and .72 for scores at six months and at 12 months. Total score ranges from 10 (highest self-esteem) to 40 (lowest self-esteem) (Rosenberg, 1965; Anson & Ponsford, 2006). Torrey et al. also conclude that, in their 18-month study, scores on the RSES changed little over time. The stability of the scores over time suggests that global self-esteem is a relatively stable personality trait similar to a sense of happiness (Myers & Diener, 1996).

Results

Principal Findings

Hypothesis 1

It was hypothesized that there would be a nonsignificant difference between Pre-treatment testing Time 1 and 2 in measures of heart rate variability but a significant improvement will be observed between Time 2 and post-treatment testing (Time 3). Two different indices of HRV were used: LF/HF and normalized coherence ratio (peak power/total power). This hypothesis was tested with a repeated-measure ANOVA.

Table 6 shows the descriptive statistics including the mean, standard deviations and the ranges of scores for each time point.

Table 6

Means, Standard Deviations, and Ranges of HRV Scores

	Time 1		Time 2		Time 3	
	M (SD)	Range	M (SD)	Range	M (SD)	Range
LF/HF	0.79 (.55)	.11-2.17	0.95 (.98)	.08-3.79	4.49 (3.78)	.17-12.20
Coherence Ratio	.20 (.13)	.09-.58	.23 (.15)	.12-.63	.36 (.17)	.09-.61

In sum, the repeated-measure ANOVA supported this hypothesis. The results of the multivariate test indicate an overall significant time effect for both LF/HF and coherence ratio [LF/HF: Wilks' Lambda = .45, $F(2, 11) = 6.78$, $p = .012$, partial η^2 = .552]; [coherence: Wilks' Lambda = .34, $F(2, 11) = 10.806$, $p = .003$, partial $\eta^2 = .663$]. According to tests of within-subject contrasts, as predicted, both LF/HF and the coherence ratio measures were found to yield a significant effect size (partial η^2) with training (slightly larger effect with the LF/HF ratio: 9.88, $p = .008$, ES = .452 [T2-T3] vs. coherence ratio: 7.68, $p = .017$, ES = .390 [T2-T3]. Both measures increased dramatically from pre-training (Time 1 and Time 2) to post-training (Time 3) assessments. Neither LF/HF ratio nor the coherence ratio measure changed significantly from Time 1 to Time 2, *LF*/HF: $p = .458$; coherence ratio: $p = .308$.

Hypothesis II

It was hypothesized that the experimental intervention would improve the participants' self-regulation in the domains of cognitive control. This hypothesis was tested with repeated-measure ANOVA. Descriptive statistics including means, standard deviations and ranges of the scores for each time point are presented in Table 7.

Table 7

Means, Standard Deviations, and Ranges of Neuropsychological Tests

	Time 1		Time 2		Time 3	
	M (SD)	Range	M (SD)	Range	M (SD)	Range
IVA – Full scale Attention Quotient	62.75 (38.78) (*n* = 4)	28-108	68.5 (31.36) (*n* = 8)	35-117	62.60 (35.82) (*n* = 10)	20-116
Category Test (*n* = 13)	110 (26.63)	48-139	105 (29.36)	39-137	103.3 (31.02)	37-141
WCST peseverative responses (*n* = 13)	62.92 (39.73)	14-121	59.83 (40.23)	10-126	73.30 (48.34)	10-126
WCST categories Completed (*n* = 13)	1.15 (1.77)	0-5	1.00 (1.68)	0-6	1.23 (2.00)	0-6

An examination of the results of the repeated-measure ANOVA did not support this hypothesis. On the contrary, across Time 1 and Time 2 (pre-treatment testing), improvements were made in Category Test, suggesting the effects of practice (Bornstein et al., 1987); the improvements were not significant [$F(1, 12)=2.28$, $p = .157$, ES= .160]. Furthermore, Goldstein and Watson (1989) note that improvements in absolute value from Time 1, 2, and 3 need to be distinguished from clinically significant improvements. Thus the change in scores may not reflect meaningful *clinical* change, as is the case of the individuals at the day program: The day program group's total errors improved from 110 (T1) 105 (T2) to 103 (T3), with a cut off of > 50 errors as being impaired. No significant change (improvements or decrements) was obtained in measures of the IVA-CPT and WCST scores.

Hypothesis III

Because it was posited that the HRV training would enhance the individual's HRV resonance and this increase would have a consequent increase in function, it was hypothesized that an increase in HRV following intervention would alter behavior. While no association between HRV indices and informants' reports of the participant's ability to regulate his or her behavior would be obtained at pre-treatment testing, there would be a significant association between measures of the participant's behavior as reported by informants and the participant's HRV indices at Time 3. This hypothesis was tested by first forming two separate groups: 1) participants who had program staff as their informants and 2) participants who had family members as their informants.

The results of the ANOVA show that there were no differences between the two subgroups in age [$F(1,11) = 2.80$, $p = .12$], age of onset [$F(1,11) = 3.74$, $p = .79$], years post-injury, [$F(1,11) = .000$, $p = .984$] and years of education [$F(1,11) = 3.52$, $p = .09$]. In addition, there were no differences between the individuals with family as informants and staff as informants in their performance in the Category Test, the BRIEF scores, and HRV indices across pre and post-treatment testing, See Tables 8–12 for the descriptive data of the two groups of participants with different informants. Appendix G contains the ANOVA results.

Table 8

Means, Standard Deviations, and Ranges of BRIEF-A, Family Reports

	Time 2		Time 3	
Informant (Family) *n* = 7	M (SD)	Range	M (SD)	Range
Emotional Control	53.71 (8.24)	45-65	56.43 (8.00)	45-67

Self-Monitoring	60.86 (5.11)	54-68	59.57 (8.64)	51-75
Working Memory	72.71 (12.12)	54-85	67.43 (10.15)	51-80
Behavioral Regulation Index	57.71 (7.50)	49-69	59.29 (7.41)	51-70

Table 9

Means, Standard Deviations, and Ranges of BRIEF-A, Staff Reports

	Time 2		Time 3	
Informant (Staff) *n* = 6	M (SD)	Range	M (SD)	Range
Emotional Control	49.67 (11.06)	40-64	51.33 (10.93)	42-70
Self-Monitoring	52.17 (9.77)	40-65	59.83 (8.13)	51-72
Working Memory	63.67 (9.99)	48-79	65.67 (9.50)	64-88
Behavioral Regulation Index	53.67 (9.37)	44-69	59.33 (7.06)	54-71

Table 10

Means, Standard Deviations, and Ranges of Category Test Errors

	Time 2		Time 3	
	M (SD)	Range	M (SD)	Range
1. Participants with Family as Informants	120.57 (16.90)	98-139	116.71 (22.36)	86-141
2. Participants with Staff as Informants	95.33 (38.28)	39-131	87.67 (34.13)	37-118

Table 11

HRV Recordings of the Participants with Family as Informants

	Time 1		Time 2		Time 3	
Informant (Family)	M (SD)	Range	M (SD)	Range	M (SD)	Range
1. LF/HF Ratio	.77 (.46)	.11-1.29	1.11 (1.30)	.08-3.79	5.28 (4.40)	.58-12.20
2. Normalized Coherence Ratio	.23 (.16)	.12-.58	.29 (.19)	.12-.63	.36 (.15)	.20-.61

Table 12

HRV recordings of the participants with Staff as Informants

	Time 1		Time 2		Time 3	
Informant (Staff)	M (SD)	Range	M (SD)	Range	M (SD)	Range
1. LF/HF Ratio	.81 (.69)	.22 -2.17	.77 (.42)	.42-1.31	3.56 (3.01)	.17-8.10
2. Normalized Coherence Ratio	.17 (.08)	.09-.29	.17 (.03)	.14-.24	.37 (.20)	.09-.60

Below is the correlation matrix between the HRV indices and subscales of the BRIEF. Table 13 presents the matrix for the family informant group, and Table 14 presents the matrix of staff program acting as the participants' informants.

Table 13

Intercorrelations between HRV Indices and Measures of Behavior, Family as Informant

	Self-monitoring	Emotional control	Working memory	BRI
Time 2				
1. LF/HF Ratio	.109 p = .817	.381 p = .399	.190 p = .683	.328 p = .473

2. Normalized Coherence Ratio	.019 *p* = .968	.022 *p* = .963	.222 *p* = .633	.079 *p* = .867
Time 3				
1. LF/HF Ratio	-.769* *p* = .043	-.977** *p* = .001	.033 *p* = .944	-.814* *p* = .026
2. Normalized Coherence Ratio	-.804* *p* = .029	-.906** *p* = .005	-.660 *p* = .107	-.775* *p* = .041

Note. * p < 0.05 level (2-tailed). ** p < 0.01 level (2-tailed).

Table 14

Intercorrelations between HRV Indices and Measures of Behavior, Staff as Informant

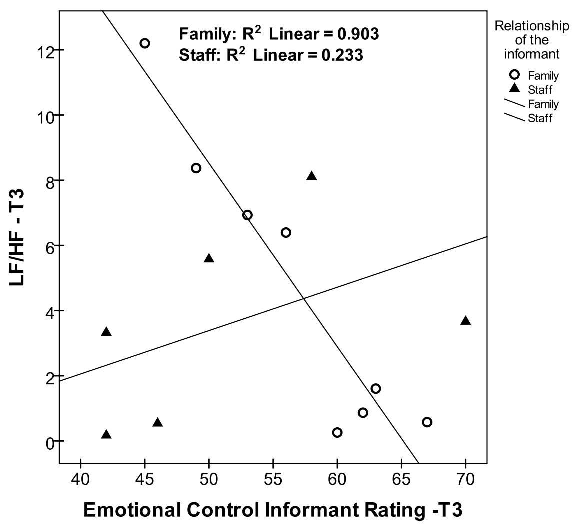
	Self-monitoring	Emotional control	Working memory	BRI
Time 2				
1. LF/HF ratio	-.529 *p* = .280	-.021 *p* = .968	-.101 *p* = .849	-.429 *p* = .396
2. Normalized coherence ratio	-.532 *p* = .278	-.297 *p* = .568	-.060 *p* = .910	-.441 *p* = .381
Time 3				
1. LF/HF ratio	. 050 *p* = .926	.483 *p* = .332	.939** *p* = .005	.409 *p* = .421
2. Normalized coherence ratio	-.607 *p* = .201	-.031 *p* = .953	-.859* *p* =.029	-.225 *p* = .668
3. Coherence ratio change score from Time 2 to Time 3	.566 *p* = .242	.036 *p* = .946	-.892* *p* = .017	-.186 *p* = .725

Note. * p < 0.05 level (2-tailed). ** p < 0.01 level (2-tailed).

In sum, the correlation matrix did not support this hypothesis. The HRV resonance scores improved dramatically, but BRIEF scores of behavioral control as rated by the informants did not change (improve) across pre-treatment (Time 2) and post-treatment (Time 3).

A Notable Correlation at Time 3

Interestingly, the reporting of the participants and the informants became significantly associated with the participants' HRV scores at post-treatment Time 3. A likely explanation of the results of significant correlation between HRV and BRIEF informant scores at post-treatment is that those capable of biofeedback and those who demonstrated the highest scores at pre-treatment learned HRV and benefited the most from treatment. Thus a linear relationship at time 3 between HRV and BRIEF informant scores were obtained: The family's rating of the participants' self-regulation ability – emotional control and Behavioral Regulation Index (BRI) – were correlated significantly with moderate to large coefficients with the Time 3 HRV indices, LF/HF ratio and coherence ratio. With respect to the staff's reports, the working memory BRIEF subscale at Time 3 emerged as significantly correlated with the HRV indices (LF/HF and normalized coherence ratio). None of these associations between HRV indices and the informants ratings (family and staff) of the participants' cognition and behavior existed at pre-treatment testing, Time 2. Figures 1-4 show that there is a strong linear relationship between the variables of interest (HRV indices and informant reports on the participants' self-regulation of behavior). Figures 1-4 also support literature that notes that the relationship the informants has with the individual with a brain injury will moderate their observations and consequent ratings of the individual's behavior and cognition.



Family: R2 Linear = 0.903
Staff: R2 Linear = 0.233
Relationship of the informant
Family
Staff
Family
Staff
LF/HF - T3
Emotional Control Informant Rating -T3
0
2
4
6
8
10
12
40
45
50
55
60
65
70

Predictors of HRV Improvements after Treatment

Furthermore, a linear regression analysis was conducted to evaluate predictors of the HRV indices at Time 3. This analysis was performed separately for each of the subgroups of participants. The family reports on the participant's skills in the domains of emotional control and his or her overall Behavioral Regulation Index emerged as predictors of which participant would attain the highest scores in HRV post-treatment. Approximately 98% and 67% of the variance of the participants' HRV indices at Time 3, LF/HF and coherence ratio respectively were accounted by their linear relationship with thei participants' emotional control score as rated by the families. Approximately 58% of the variance of the participants' HRV LF/HF index at Time 3 was accounted for by its relationship with their overall behavioral regulation index score as rated by the families.

For the participants who had the staff as their informants, while behavioral regulation scales (i.e., emotional control did not emerge as significantly related to HRV, the staff's reports on the participants' cognitive ability, specifically working memory, significantly predicted the participants' HRV scores, both LF/HF and normalized coherence ratio. Participants who attained the highest working memory scores (as reported by the staff) attain the highest scores in HRV post-treatment. Approximately 88% and 79% of the variance of the participants' HRV indices at Time 3, LF/HF and coherence ratio respectively, were accounted by their linear relationship with the participants' working memory score as rated by the day program staff.

It is also of interest that the data revealed that in order to <u>learn</u> HRV, the participants must have certain learning potential, as measured by the Category Test baseline scores. A linear regression analysis was conducted to evaluate if the Category

Test predicts which participants would improve HRV scores, as measured by LF/HF. The scatterplot (Figure 5) for the two variables indicates that the two variables are linearly related such that participants with the fewest errors in the Category Test (T2) benefited most from HRV biofeedback and made the greatest improvements at Time 3 [*F* (1, 11)=12.41, *p* = .005.]

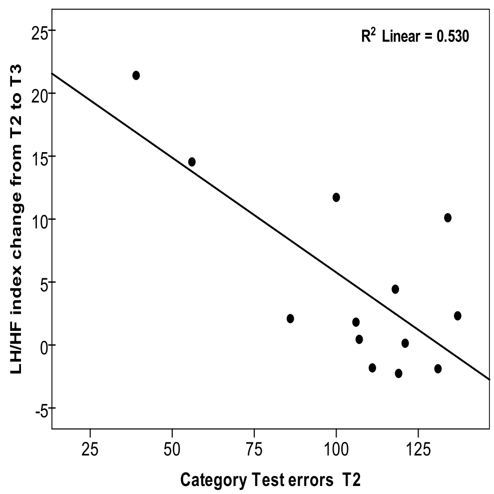


Figure 5. LF/HF HRV index improvements from Time 2 to Time 3 and Category Test errors at Time 2.

An additional finding of interest was an association between the Category Test and HRV index. At Time 2, a one-point decrease in Category Test error at baseline increases the improvement in LF/LH (across Time 2 to repeat testing at Time 3) by 0.182 (*p* = .005). Furthermore, the participants' Performance IQ [PIQ] (WAIS-III) predicted the number of errors the participants would make in the Category Test at baseline testing (Time 2), [*F*(1, 11) = 6.40, *p* = .028]. A decrease by one point in PIQ increases errors in the Category Test by 1.52, suggesting that some intellectual ability intrinsic to the individual is necessary for participants to benefit from HRV training (see Figure 6).[3]

---

[3]). Previous studies have shown a significant relationship between the Category Test and WAIS and WAIS-R scores (Holland & Wadsworth, 1976; Lansdell & Donnelly,

This finding supports papers by Duncan (1996). It also supports the premise of Bertisch et al. (2010) that basic requisite skills need to be in place for individuals to benefit from treatment.

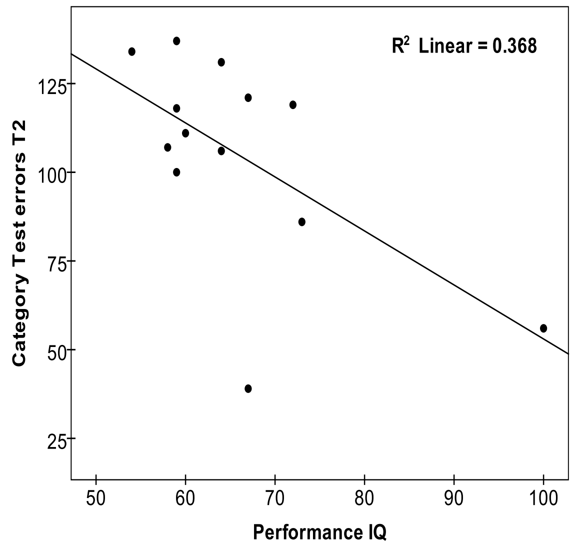


Figure 6. Category Test errors at Time 2 and Performance IQ.

HRV and Attention

At Time 3, there was a significant association between IVA-CPT Attention quotient and the participants' ability to not only sustain but increase resonance at the second segment (6-10 minutes) of their total 10 minute HRV recording, r = 0.772, p = .009. The improvement in resonance was indexed by taking the difference between the last five minutes of the recording and the first five minutes. This association was not present at Times 1 or 2. Figure 7 indicates that the two variables are linearly related such that as resonance increases, the attention quotient increases (r^2 = 0.597).

1977; Lin & Rennick, 1974; Logue & Allen, 1971; Shore, Shore, & Phil, 1971). Titus et al. (2002) found a strong relationship with moderate coefficients between the WAIS-III indices – FSIQ, PIQ, and VIQ – suggesting that the Category Test is not solely a test of nonverbal intelligence. Titus et al. found both Block Design and Similarities were the best predictors of the Category Test scores and that FSIQ accounted for 12% of the variance in the Category Test scores.

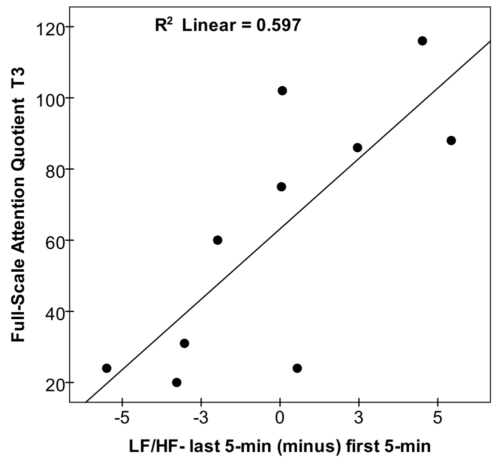


Figure 7. Full scale attention quotient at Time 3 and LF/HF index, the last five minutes of the full ten minute recording taken at Time 3.

The participants' coherence ratio at Time 3 was also significantly associated with the participants' self-appraisal of how well they monitor their ability to complete a task, $r = -.614$, $p = .026$. (See Table 15 and Figure 8).

Table 15

Self report of Self-Regulation and HRV Time 3

	BRIEF -Task Monitoring, Self Report
Coherence Ratio	-.614* *p* = .026

Note. **p* < 0.05.

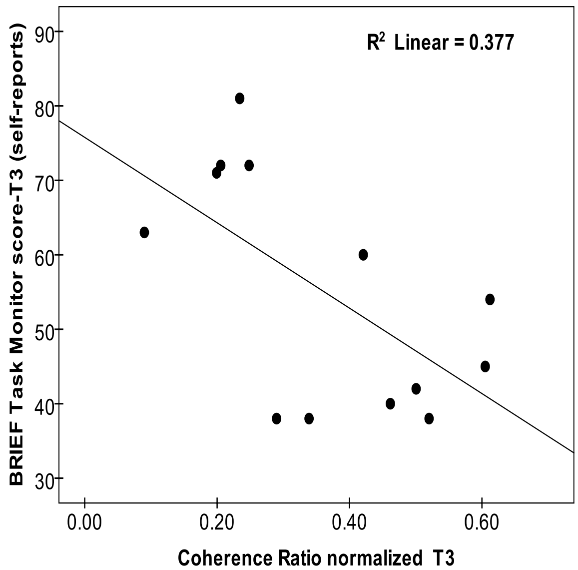
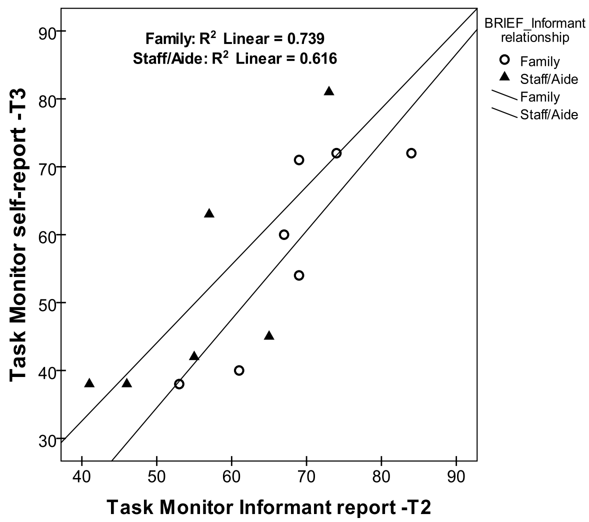


Figure 8. Task monitor scale of the BRIEF self-report and coherence ratio normalized at Time 3.

Of further interest is the following result. At pre-treatment (Time 2) and at post-treatment (Time 3), the task monitoring ratings by the informants and the individuals' self-reports (at Time 3) on their ability to self-monitor while working on a task were significantly correlated, .589, p = .034 (pre-treatment); .565, p = .04 (post-treatment), providing support to the validity and accuracy of the self-reports of the individuals (since the informants also rated them in similar fashion).

Finally, the relationship between the individual's self-reporting and the informant reporting of the individual's ability to self-monitor when performing a task was re-done, separating the individual's from staff as informants and family as informants. While the correlation between the individual's self-ratings and staff reporting was not significant (which may be because of small sample [n = 6] and an outlier), a very interesting relationship emerged with individuals who had family as informants. At pre-treatment (Time 2), no relationship was observed between families' ratings of the individuals and the individual's self-ratings on this particular ability or variable. But at post-treatment testing, not only was there a significant relationship with high coefficients between family ratings and the individual's ratings (.839, p = .012); but how the individuals rated themselves at post-treatment testing also correlated with how the families rated them at pre-treatment testing[4] with a strong linear relationship (.87, p = .013) (see Figures 9 and 10), suggesting that at post-treatment, the individual's self-ratings became more closely aligned to others' (in this case, their families') perceptions of their behavior.



executive functions and self-reports of self-regulation was used in the domains of both cognition and the emotions. A separate matrix was created to test the rating by the informants against the self-ratings by the participants. Tables 16–18 present these matrices. There was a significant correlation between neuropsychological tests, self-reports, and informant reports with moderate to large size coefficients. These associations did not exist at Time 1 and Time 2 (pre-treatment testing). While we cannot attribute HRV training to be a cause for these intercorrelations that emerged at post-treatment testing, it is noteworthy that these findings were not present at pre-treatment testing.

Table 16

Correlations between Neuropsychological Tests of Executive Functions and Self-Reports of Cognition and Behavior Time 3

	PSI Confidence	PSI Personal Control
1. Seashore Rhythm Test	-.549 .052[1]	.501 .081
2. WCST Perseverative Response	.733 .004**	.060 .846
3. Category Test	.637 .019*	-.002 .995
4. IVA Full Scale Response Control Quotient	-.552 .995	.603 .065[1]

Note. [1]A sample size greater than the current sample (n = 14). may have yielded significance.
* $p < 0.05$ level (2-tailed). ** $p < 0.01$ level (2-tailed).

Table 17

Correlations between Family Reports and Self Reports of Cognition and Behavior at Time 3

1.	GEC[1]	.805* .029
2.	Task Monitor	839* .018
3.	Initiate	.963** .001
4.	Inhibit	.826* .022
5.	Working Memory	.833* .020

Note. [1] General Executive Composite Index.
* p < 0.05 level (2-tailed). ** p < 0.01 level (2-tailed).

An examination of the results of Heppner's PSI show significant relationship between the participant's self-reports and the program's staffs' reports of their problem solving attitude (see Table 18).

For Heppner (1982, 1997, 2001, 2004), an individual's appraisal of his or her problem-solving ability is an important part of problem solving and overall psychological adjustment. Of the three scales that comprise this PSI instrument, the PSI approach-avoidance subscale assesses whether an individual tends to avoid or approach a problem and is conceptualized to reflect an individual's motivation. The PSI problem-solving confidence scale reflects or measures an individual's self-efficacy in solving problems. At Time 3, the participant's self-reports on his or her sense of self-efficacy in solving problems (PSI confidence) was significantly related with the program staff's assessment of the participant's motivation (PSI approach-avoidance) to solve problems that arise (r = .683, p = .01).

Table 18

Correlations Between Self Report and Staff Reports of the Individual's Problem Solving Behavior– Time 3

	PSI Approach and Avoidance Staff report
PSI Problem Solving Confidence Self Report	.683* .010

Note. * p < 0.05 level (2-tailed).

New Analyses at Eight-to-Ten Weeks After Post-Treatment Testing

A new set of analyses was done 8-10 weeks after post-treatment testing had been concluded. Additional questionnaires were administered to the participants of this experiment. The purposes of these additional measures were to 1) better portray and characterize how aware the participants were about their cognitive functioning and 2) to discover if and how this self-knowledge influenced their sense of self and quality of life. Below are new measures that were administered. (See the beginning of this chapter for descriptions of the measures).

Measures

Clinician's rating form of problem solving and emotional self-regulation skills, **patient version and clinician version.**

Satisfaction with life scale (SWLS).

Rosenberg self-esteem Scale.

Table 18 presents the correlation matrix of cognition and the scores from

SWLS, RSES, and PSI (Confidence scale). Overall the reports and tests are very significantly associated with moderately large coefficients (see Figures 9–15). In sum, the participants who were more satisfied with life and had greater self esteem performed better on an objective neuropsychological measure of executive functioning, the Category Test and the WCST (a decrease of perseverative responses). In addition, participants who reported being more satisfied with life also scored higher in a speeded sustained attention test. Finally, the participants' level of confidence in their problem solving ability (PSI Problem Solving Confidence) was significantly predicted by performance on the Category Test and the WCST perseverative responses, which accounted for over 40% and 54% of the variance of the PSI Confidence scores respectively. The Seashore rhythm test was nearly significantly related to the PSI Confidence score at p = .052, and accounting for about 30% of the variance of this PSI Subscale. These sets of associations between executive function and speeded attention tests, with self-appraisal of his or her confidence in solving problems in particular, demonstrates that relative to his or her own peer group, the individuals at the day program accurately rate their neurobehavioral functioning.

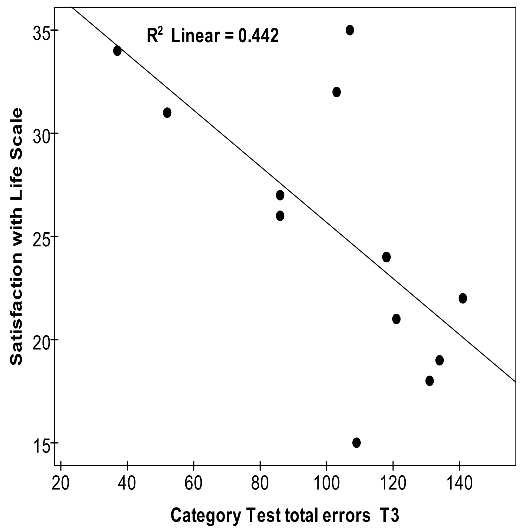
Table 19

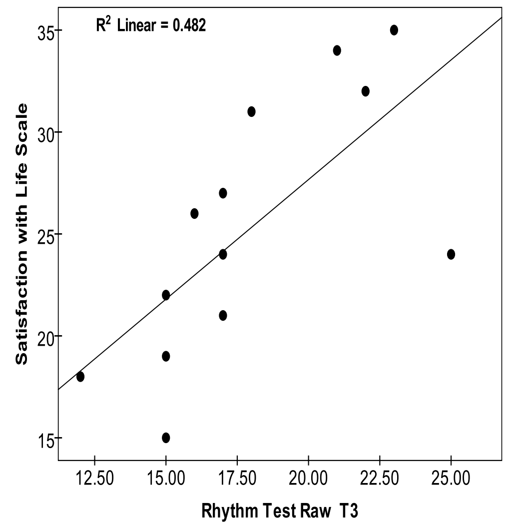
Correlations between neuropsychological tests of executive functions and self-reports of Satisfaction with Life and Self Esteem at Time 3

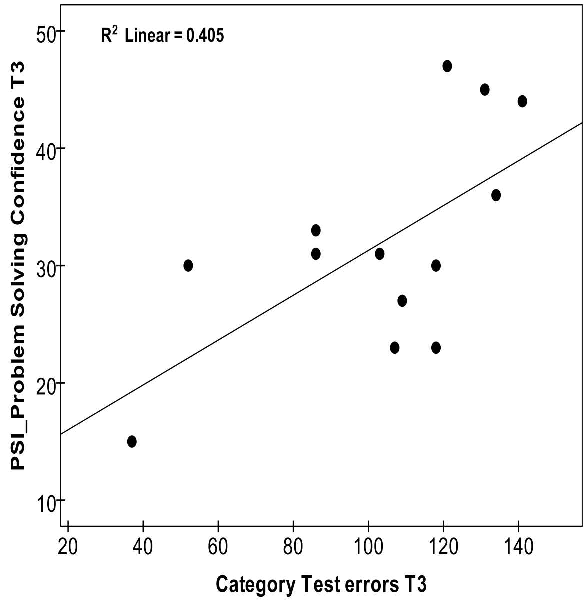
	Category Test	WCST Perseverative responses	Seashore Rhythm
1. SWLS	-.665* .013	-.397 .187	.694** .008
2. RSES	.589* .034	.718** .006	-.188 .538

3. PSI Problem Solving Confidence self report	.637* .019	.733** .004	-.549 .052

Note. * Correlation is significant at the 0.05 level **Correlation is significant at the 0.01 level.






R² Linear = 0.405
50
40
30
20
10
PSI_Problem Solving Confidence T3
20
40
60
80
100
120
140
Category Test errors T3

Chapter V

Detailed Discussion, Synthesis, and Implications of the Experiment

Hypothesis 1 stated that there would be a non-significant difference between pre-treatment testing Time 1 and Time 2 in measures of heart rate variability, but a significant improvement would be observed between Time 2 and post-treatment testing (Time 3). Support was obtained for Hypothesis 1. Two different indices of HRV were used to quantify treatment gains: LF/HF (Task Force, 1996**)** and a normalized measure based on HeartMath's coherence ratio (Thurber et al., 2008**).** As a group, the participants in this study showed very significant improvements in HRV biofeedback after a relatively short treatment of only ten sessions. In the process, they were able to learn to operate a gadget (the "handheld," a cell-phone-sized portable biofeedback instrument) and to use it sufficiently at home to do their exercises. In addition, this experiment showed that the participants who had the most intact executive functioning and overall "brain integrity," as measured by baseline scores on the Halstead Reitan Category test, benefited the most from treatment. Intellectual scores, specifically performance IQ, were associated with the Category test scores and indicated that IQ may be related to the ability to learn HRV.

Hypotheses 2 and 3 stated that the experimental intervention would improve the participants' self-regulation in the domains of cognitive ability (hypothesis 2) as measured by neuropsychological tests and behavioral control as reported by the informants (hypothesis 3); and that while no association between the participants' HRV indices and test scores or the informants' reports of the participant's ability to regulate his or her behavior would be obtained at Time 1 and 2, the significant improvements in the participants' control of executive functioning would be associated with measures of the participants' HRV indices at Time 3. Partial support was obtained for Hypotheses 2 and 3. In this experiment, the participants made no improvements in neuropsychological scores or informant inventories on behavior. Notably, with respect to Hypothesis 2, while no improvements were observed in the neuropsychological test scores, at Time 3 there was a significant association between IVA-CPT Attention quotient and the participants' ability to not only sustain, but increase resonance at the second segment (6-10 minutes) of their total 10 minute HRV recording.

With respect to Hypothesis 3, in a way that was similar to the lack of improvements observed in repeated administration of neuropsychological tests at post-treatment Time 3, the reports from informant's reports registered no improvements in the individual's control of their behavior. In fact, the informant reports of the enrolled participants' behavior indicated that the group as a whole was actually doing worse at post-treatment testing, Time 3, especially in the area of working memory.

However, the results of this experiment show that HRV may hold promise as being a useful neuropsychological tool that can offer guidance on how to assess and treat behavior. At post-treatment testing, the scores of the participants' HRV and the reports of the informants on the participants' behavior were significantly correlated: the more difficulty the participants had in self-monitoring and controlling their emotional reactions according to the participants' families, the worse they did in HRV. The reports from the staff on the participants' working memory ability became significantly correlated with scores on the participants' HRV recording taken at Time 3. The more difficulty the participants had with working memory skills according to reports from the staff, the worse they performed in the HRV recording taken at Time 3.

Studies have shown that the quality of the HRV pattern – large and regular peak-to-valley amplitudes also described as "resonance" – is connected to self-regulation of emotions, behavior, and thinking (Lehrer et al., 1999; Lehrer et al., 2000; Lehrer & Vaschillo, 2003**)**. Thus, one explanation for this phenomenon, where assessments from informants were initially unrelated to the participants' psychophysiological recordings at pre-treatment testing, is that the reports from family and staff at baseline were able to *predict* which individuals would make the most gains in HRV training; and so at Time 3, post-treatment testing, the prediction of both staff and family informants came true: their reports on the participants' behavior and the participants' HRV scores became significantly correlated. (See Table 13, Chapter IV**,** for specific BRIEF indices at baseline, which became significantly related to the HRV scores at post-treatment testing, grouped by informant relations to the participants). Moreover, given the length of time the families have *lived with* the individuals' "symptoms" of brain injury, the BRIEF reports may actually be a "trait" measure of the individuals that predict who will respond to and benefit from treatment.

The state-trait continuum offered by Spielberger (1972) to characterize the phases or faces of anxiety also may explain why neither the reports from the participants' families nor from the program staff described the participants of the study as having behavioral problems: the behaviors of the participants may have become "normalized" as the informants experience them. This finding (absence of maladaptive behaviors as reported by informants) contrasts with the brain injury literature that found the subjective burden of family members – which has been defined as stress experienced by the family that was caused by changes in the injured individual's personality, emotions and behavior – increases over time (Cavallo et al., 1992; Cavallo & Kay, in press). Nevertheless the reports from family and staff, which were based on the "traits" that they experienced in the participants, *predicted* which participants after HRV training would achieve a certain resonance and who would not. In particular, the families knew which individuals had potential for the emotional control and inner calm so integral to achieving the highest scores in HRV biofeedback. The accurate prediction of informants helps explain why the informants' reporting, as reflected in the BRIEF subscales scores, did not change significantly, while the participants' HRV scores changed very significantly in the direction of becoming significantly associated with a strong linear relation to subscales of the BRIEF informant reports. For example, 96% of the variance (r^2 = .955) of the LF/HF ratio and 82% of the variance (r^2 = .821) of the normalized coherence ratio were associated with the participants' capacity for emotional control as reported by the families in the BRIEF. Likewise, 89% of the variance (r^2 = .889) of the LF/HF ratio and 74% of the variance (r^2 = .738) of the normalized coherence ratio were associated with the participants' working memory ability as reported by the staff in the BRIEF.

In addition, the instructions for the BRIEF reports do not specify a reference group. Hence it is possible that both the staff and the family members may have completed the questions of the BRIEF by using the individuals at the day program as the "normative group." If the long-term day program participants served as the norm for these reports, the lack of behavioral problems reported by both family and staff informants becomes more understandable, because the informants are rating the participants' cognitive and behavioral control on a scale of individuals who are functioning with severe disability and not on a scale of individuals from the normal population who are working or going to school, and are independent in the community.

Comparing the family's and the staff's reports, show that different scales of the BRIEF for each informant group predicted which participants would benefit most from HRV training. While it is beyond the scope of this paper to examine in detail why and how the perceptions would differ between family members and program staff, studies do show that the nature of the relationship with the individual with a brain injury influences how that individual is described and evaluated (Cavallo, Kay, & Erazchi, 1992; Fordyce & Roueche, 1986). This finding that the relationship of the informant influences the evaluation of the injured individual would explain why the reports obtained from two different sources differ in their results, since ANOVAs performed to compare the participants in the family-informant group and participants in the staff-informant group showed that these two subgroups were not significantly different at baseline on the BRIEF scores and HRV indices (see Tables 13-14). Category Test scores, which were found to predict which participants would benefit from HRV treatment, were also not significantly different for the participants in either family-informant or staff-informant subgroups. The BRIEF informant scores for the participants did fluctuate somewhat, but the changes were not significant.

An examination of Figures 1-4 clearly show that family members are more atuned to (and affected by) the individual's *emotional control*. There is a significant correlation with large coefficients between measures of HRV resonance and the individual's capacity to regulate and control his or her emotions. The staff's ratings on *emotional control* and HRV measures are not significant. In contrast, the staff's ratings of the individual's *working memory* is significantly and meaningfully correlated with his or her HRV scores. The family member's ratings of the individuals' *working memory* is not significantly associated with his or memory functioning.

Thus, while this study cannot state that HRV training can improve self-regulation, these results that show significant association between the participants' HRV and the informant reports of the participants' behavior and their tested cognition supports theories that explain how psychophysiological resonance is related to self-regulation of behavior. The scatterplots for the HRV and BRIEF subscale variables, for both family and staff as informants as shown in Figures 1- 4 (see Chapter IV) indicate that a strong linear relationship exists between informant ratings of behavior and the HRV indices.

Seven points are critical in understanding the results of the experiment:

1. Although the participants learned how to use the equipment and made dramatic improvements in the biofeedback technique, they never generalized the HRV treatment to their lives; they had difficulty verbalizing the goals of the treatment itself in the session, or even telling me why they were attending the long-term community-based day program at all.

2. The reports from the families and staff on the abilities of the participants to self-regulate their behavior reached significant association with biofeedback scores only at post-treatment testing, Time 3. While the resonance scores changed and improved dramatically, the staff and family reports on the participants' behavior did not change. This finding raises a question about how the *reports* become significantly related

to *resonance* at Time 3. One answer is that the resonance achieved by some participants was present within the individuals in latent form (as a "trait"), and the participants responded to structured practice and teaching so as to activate a "trait-like-resonance" that was already in place.

3. On a treatment level, the participants' self-reports on the BRIEF scale *task monitoring* – defined as the capacity to keep track of and be aware of one's own errors when solving a problem – were significantly associated with the participants' HRV (normalized coherence ratio) at Time 3, post-treatment testing, $r = -.614$, $p = .026$. This relationship was not present at pre-treatment (Time 2).

In order to see how accurate the individuals' self reports were on their ability to monitor their task completion, correlation of their scores to their informants were performed and there was a significant relationship between the self reports and informant reports only at Time 3. For the individuals with family as informants, *task monitoring* self-reports were significantly associated with the family's reports on participants' ability to monitor themselves while working on a task. At pre-treatment (Time 2) there was no association between informant (family) reports and self-reports, $r = -.549$, $p = .20$. But at post-treatment Time 3, a significant relationship between self-reports and informant (family) reports on the individual's task monitoring was attained, both with the family's reports at pre-treatment and with the family's reports at post-treatment: $r = -.860$, $p = .013$ (with family reports at pre-treatment); $r = -.839$, $p = .018$ (with family reports at post-treatment).

This association suggests that the participants were attuned to their body and to their psychophysiology; such attunement has been found to be associated with organized behavior (Damasio, 1994; Thayer et al., 2009). It is also noteworthy that the participants' assessed their functional ability in a way that was consistent with the assessment of others who observed them.

This relationship between HRV and behavioral *self*-ratings could be a result of improved e*mergent* self-awareness. Emergent self-awareness can be defined as the person's ability to recognize his or her difficulties as they are actually occurring in daily life (Ownsworth et al., 2000). Such self-awareness has been identified as a fundamental and preliminary step in treating individuals with brain injuries (Ben Yishay, 2000; Daniels-Zide & Ben Yishay, 2000) and improved awareness is often seen as a first step in improving self-regulation of behavior and cognition (Barco, Crosson, Bolesta, Werts, & Stout, 1991; Diller & Weinberg, 1981; Fleming, Strong, & Ashton, 1996; McGlynn & Schacter, 1987; Prigatano, 1995; Cicerone & Tupper, 1986). Perhaps longer treatment, with more tools to help the participants apply their learning to actual surrounding environments, may have yielded significant functional effects**.**

4. Additional support for the significance of the relationship between HRV and cognition, and thus the utility of including HRV for cognitive remediation, was obtained from the relationship between HRV scores and the Integrated Visual and Auditory Continuous Performance Test (IVA-CPT). At post-treatment testing, a relationship emerged between HRV scores and this continuous performance test. Individual HRV recordings were done for 10 minutes at a time. The signals that were recorded were then examined in two ways: 1) as a full 10-minute segment; and 2) as two segments of five minutes each, the first 1-5 minutes, and the second 6-10 minutes. We found that participants who improved their HRV scores (LF/HF) in the second 6-10

minute segment were most successful in the IVA-CPT *Attention Quotient*. The subject's *Attention Quotient* was significantly associated with the ability to improve resonance in the last 5-minute segment of his or her HRV recording. There was a significant correlation, with a clear linear relationship (r^2 = .597) between IVA scores and improvements in resonance (LF/HF ratio) in the last 5-minute segment of the entire 10-minute HRV recording (see Figures 5 and 6, Chapter IV).

While this study was not able to directly demonstrate that increased resonance in HRV improves measures of problem solving, studies on the relationship between attention and problem solving abilities suggest that HRV training may be useful in training individuals with brain injuries to direct their behavior systematically towards a goal. The importance of HRV training as it relates to improving goal-directed behavior is supported by findings about the need for training in the area of *attentional* deficits for individuals with neurological disorders. For example, Duncan et al. (1996) identified lapses in attention in individuals with brain injury as fundamental to disorganized behavior and a failure to achieve goals. Levine et al. (2000) developed the Goal Management-Training Program, which focuses primarily on sharpening the individual's attention. Research on autism also shows that attentional deficits are associated with poor self-regulation, specifically poor social pragmatics, and cognition (Goldstein et al., 2001).

5. If the above suggestions about ways to use HRV in cognitive training are accurate, then HRV recordings, which take 5-10 minutes to complete, could be an effective way to measure real-life behaviors of individuals with brain injuries as these individuals function in the community. Such a tool would have ecological validity

because it can supply measures of these individuals' real-life behavior beyond laboratory-based neuropsychological testing. Currently in the profession, changes in the behavior of an individual with brain injuries, specifically frontal lobe damage, as reported by the individual and his or her relatives are significant but difficult to quantify. Standard neuropsychological test scores typically show little relation to the behaviors individuals with brain injuries manifest in their daily routine and lives (Tate (1987).

6. This study provided additional evidence that demonstrates the association between psychophysiological methods and neuropsychology. Despite the Task Force that met in1996 to standardize the nomenclature of HRV, disagreement persists on how to quantify improvements in HRV and in particular what particular HRV "score" reflects optimal cognitive functioning. This experiment provides evidence that two particular HRV indices – LF/HF (the higher the score, the better) and normalized coherence ratio (score of 1 is maximal coherence) – were meaningfully associated with standardized neuropsychological tests and behavioral reports in individuals with severe brain injury.

7. Finally, the analyses that were performed using these forms of assessments – neuropsychological test scores, behavioral reports completed by the informants, and reports completed by the participants – revealed significant and meaningful associations among all three forms of assessments. These results are contrary to other studies of individuals with brain injuries. For example, Rath et al. (2000; 2003; 2004), demonstrated that neuropsychological test results do not have associations with functioning in real-life situations. Other studies have found the same discrepancy among objective tests, informant reports, and self-reports of behavior (Hart & Hayden, 1986; Miller & Donders, 2001; Prigatano, 1991).

Limitations of the Study

There are seven limitations to this experiment. First, the sample size was small and the experiment was a prospective cohort pilot study. Thus any conclusions made are preliminary. And because the sample was so small, in the analysis no demographic variables such as age of onset, gender, and education, were included when performing regression analyses to identify predictors of treatment effects. In addition, because of the small sample size, no statistical controls were performed to control for the probability of type I errors.

Second, a significant problem was not being able to precisely quantify and measure what happened in the treatment with the biofeedback games and paced breathing exercises. This measurement was not possible because the proprietors of the HRV equipment that was used do not publish the algorithm used in their equipment. Perhaps if the means were available to quantify or know the thresholds of exactly when the participants got positive feedback from the HeartMath equipment, more definitive conclusions could have been drawn, and statements on how effective HeartMath treatment is for individuals with severe brain injuries could be offered with more certitude.

Third, the sampling rate of HeartMath just met the minimal requirements set by the Task Force (1996). Given individual variability, it is possible that the frequency obtained for some recordings were above 0.4 total powers. HeartMath uses a digital Butterworth low pass filter with a cutoff at 0.4 Hz and stopband edge at 0.5 Hz which would reduce any aliasing effects, if any. Despite these measures, aliasing frequencies cannot be fully eliminated. Under sampling can alias the frequencies so that the high frequency band of the HRV might leak into the power measured by the lower frequency thus distorting the data and the consequent HRV indices obtained.

Fourth, many of the files on the study participants were missing medical information, so that it was impossible to see if initial injury influenced treatment outcome or to see if individuals who made the most gains after treatment were less severely injured at the onset of their trauma. Fifth, the informants were a mix of family members, and staff members and while these two groups were not significantly different demographically or cognitively, separating the participants into two groups – those with family as informants and those with staff as informants – made the study sample even smaller; and so the conclusions drawn can only be very tentative. It would also have been useful if we were able to compare qualitative differences between the evaluations of the study individuals completed by the staff and those completed by the individuals' families. We chose not to do this analysis because the subgroups were so small.

Sixth, treatment was of relatively very short duration for this population. Longer treatment duration and efforts to incorporate the HRV into the lives of the participants in a meaningful way, such as visits to their homes and the training of program staff and family to help encourage more practice by the participants, may have yielded functional changes in the individuals as part of the treatment effects.

Seventh, and most critical, the participants usually could not verbalize experiences of stress or any problems with emotional regulation. So while the participants were motivated to partake in this experiment because of the one-on-one attention provided during individual treatment, they had no idea how or if they needed to incorporate the HRV techniques into their everyday life.

Future Directions

This study provides one of the first empirical demonstrations of psychophysiological self-regulation training applied to individuals with severe brain injuries who were on the average 24 years post-injury. The findings contribute to the profession's understanding of the relationship between psychophysiology and neuropsychology. Because this study provides empirical evidence that the brain and emotions are connected in the body, it also presents the possibility that this connection could be used to train individuals with brain injury to better self-regulate their behavior and control disinhibition and impulsivity. Evidence is also presented that even individuals with severe brain injuries – those who are past the post-acute phase of rehabilitation and were enrolled in a long-term community-based rehabilitation program – can learn new techniques, respond to biofeedback, and greatly increase coherence in heart rate variability.

Future work on HRV biofeedback for individuals with brain injuries should draw upon a larger sample, using a randomized clinical trial to test the functional effects of HRV treatments given to higher functioning individuals for a longer time period. In addition, such larger scale research could yield information on if and how biofeedback HRV can be incorporated within a comprehensive rehabilitation program with higher functioning individuals. Testing this experiment on a larger sample size may also provide an opportunity to identify predictors of those individuals who would and would not benefit from this kind of intervention. Given a larger sample size of higher functioning individuals may also provide an opportunity to identify cut-offs or a range of

HRV scores that would correlate to impaired and not impaired cognition and emotional control.

Research could also test if certain levels of HRV resonance measures are useful as <u>indicators</u> of intact cognitive abilities, based on whether elevation of resonance (or coherence) is achievable by the individual who is given biofeedback treatment.

Related to the possibilities of future research is the possibility that if the Halstead Reitan Impairment index was given at pre-treatment, then we could see if the biofeedback actually improves the individual's impairment index. Also useful would be research on the differences between coherence ratio and LF/HF – the two HRV indices that were used in this experiment – to determine if and how each HRV index can uniquely quantify neuropsychological and functional behavior. In this study, greater effect sizes were obtained from pre-to-post-treatment testing for the LF/HF index as compared to the normalized coherence index. Future research could also be done to discover why the effect sizes for the two HRV indices varied. Because time domain measures of HRV were not used in this study, it would also be useful to see what unique contributions time domain HRV indices, as opposed to the frequency domain indices, may provide to quantify neuropsychological behavior. Research of this kind would add to the literature on better understanding psychophysiology in the context of neuropsychological behavior.

Finally, given the emphasis HRV biofeedback places on slow paced breathing, it would be useful to test if HRV biofeedback provides any additional therapeutic effects (and specifically what those benefits are) that are not available with other practices such as meditation and slow breathing exercises.

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Appendix A

Sample Consent Form

Institutional Review Board
APPROVED
3/4/2009 through 3/3/2010
Protocol #: 2009-253

ALBERT EINSTEIN COLLEGE OF MEDICINE OF YESHIVA UNIVERSITY
FERKAUF GRADUATE SCHOOL OF PSYCHOLOGY

Individual Information and Consent Form

You are being asked to join this research study.
The title of the study is: Using Heartrate Variability Biofeedback Methods with Training in Problem-Solving Skills to Improve Executive Functioning in Individuals with Chronic TBI

The study is being done under the supervision of:

Principal Investigator (Research Study Doctor): Fred Foley, PhD, Professor Psychology
Ferkauf Graduate School of Psychology
Office Address: 1165 Morris Park Ave, Rousso Rm. 107
Telephone #: 718-430-3937
Protocol #: 2009-253-000

DO I HAVE TO TAKE PART IN THIS RESEARCH STUDY?

- Your participation is voluntary. This means that you decide whether or not you want to join the study after speaking with the researcher, or other member of the research team.
- If you decide to take part you will be asked to sign this consent form. Your signature means that you agree to be a subject in this research.
- After reading this form and having a discussion about what it says, you should ask all the questions you want to ask. You should take as much time as you need to make a decision.
- If you do not understand some of the terms used in this form, ask the person who is discussing the study with you to give any additional information that may make this easier to understand.
- You do not have to consent to participate in the study immediately, or ever. Take time to decide whether or not you wish to join. You may take home a copy of this consent form to think about it or discuss the information with family or friends before you decide.
- If you decide not to participate the care providers at this facility will give you all of the standard care that is appropriate for you.
- You will be given a copy of this form whether or not you agree to participate in this study. Do not sign the form unless you have had all your questions answered and understand exactly what is involved.
- If you decide to take part you are still free to withdraw at any time without giving a reason. This will not affect your care and you will continue to be treated at this facility.

STUDY SPECIFICS

WHY HAVE I BEEN ASKED TO TAKE PART IN THIS RESEARCH STUDY? Because you have a diagnosis of TBI, you are being asked to participate in the study.

If you agree to take part in this study you will have tests and examinations to be sure that you qualify for the study.

WHY IS THIS RESEARCH STUDY BEING DONE?

- The purpose of this research study is to propose a treatment method that will address problem-solving deficits in individuals with chronic TBI.
- This study seeks to test that a two-pronged approach to training individuals with TBI-1) to improve regulation of emotion and 2) to implement a strategic approach to solve problems will be most effective in helping them to solve problems that arise in daily living.
- The more specific aims of this study are: 1) to compare the problem-solving skills of the treatment group vs. the non-treatment group, after a 12-week period of intensive training in POWS [a specific problem sovling technique] and HeartMath heart rate variability (HRV) biofeedback methods; and 2) to evaluate predictors of treatment effects in the treatment group.

WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

- In this study, information that is contained in your medial chart at the AHRC will be entered into a research database. Specifically, demographic information, current and past medical/psychiatric treatment, as well as information about your TBI and treatment will be retrieved from your file.
- You will also be scheduled to come to AHRC to take standardized cognitive tests. Some of them will be on a computer while others will be administered by a trained examiner. All testing will be conducted by a trained PhD student. The testing will take place at the AHRC Brooklyn TBI day program.
- Participating in this study will require one session of approximately 2 hours of testing (screening phase) to see if you meet the inclusion criteria. If you meet the criteria, you will
- Participate in one session of 2 to 3 hour pre-treatment testing.
- After the pre-treatment testing, some of the individuals will be assigned to partake in the treatment protocol (the experimental group). The assignment to the treatment group is strictly on a random basis.
- As a subject enrolled in the experimental group, you are expected to attend treatment groups and individual sessions, a total of 1.5 to 2 hours a week for 12 weeks. The sessions will span 2 days a week, though it will be modified to meet your schedule needs,. Some outside homework related to the groups may also be assigned for you to complete. All treatment sessions will take place at the AHRC Brooklyn TBI day program.
- Finally, you will participate in one session of approximately 2 to3 hours of testing after the treatment ends 12 weeks later.

WHAT ARE THE POSSIBLE SIDE EFFECTS, DISCOMFORTS, RISKS OR INCONVENIENCES I CAN EXPECT FROM BEING IN THIS RESEARCH STUDY?

There are minimal risks to participating in this study. The HeartMath emWave PC sensors used for the HRV treatment component of this study are infrared plethysmographs so there is no electrical contact between the sensor and the user. This is different than GSR biofeedback devices where there is an electrical connection between the sensor and the user, and care must be taken in the design of the GSR equipment to avoid the possibility of a shock occurring.

Here is a list of the known risks associated with this research:

- Whenever data about a person is entered into a research database, there is some risk to confidentiality.
- The following procedures will be employed to minimize this risk:
  Your name and other identifying information will not be entered into the database. Each participating individual will be assigned a code number. A separate key will contain the code numbers, and the participants' names will be kept in a confidential file. Only the investigators will have the knowledge that links the key file with the database.
- In addition to the potential risk to confidentiality (see above), another risk is that most people will be tired after 2-4 hour-sessions of cognitive tests and will experience temporary distress. In order to avoid fatigue and emotional distress as much as possible, testing sessions can be divided into different subsections at the request of the participant. Breaks will also be provided upon request.

ARE THERE LIKELY TO BE ANY BENEFITS TO TAKING PART IN THIS RESEARCH STUDY?

There may or may not be a direct benefits to participating in this study.

- As a subject randomly selected to participate in the treatment group, you may benefit from the problem-solving protocol that is being researched. But benefits from this experiment are not guaranteed.
- Indirect benefits include advancing scientific knowledge about understanding the nature of problem solving deficits in individuals with TBI and possible effective treatments.

WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS RESEARCH STUDY?

- You may choose not to participate in this study.

WILL I BE PAID FOR BEING IN THE STUDY?

All subjects who choose to participate will be compensated:

1) 5.00 to participate in approximately a 2-hour testing session to see if you meet the study's inclusion criteria. *If you meet the study's inclusion criteria, you will be asked to:*

2) undergo another 2-2 ½ hour testing session. *At this point, some of you will be randomly selected to join the Problem-solving Treatment. But there is no guarantee of who will be selected because there will be a blind draw. You will compensated $5.00*

Those selected to participate in the treatment will:

3) be compensated $2.50/weekly to attend sessions for 12 weeks. The problem solving skills training (group problem-solving classes and individual biofeedback training totally 1½ - 2 hours/wkly). Homework may be assigned.

12 weeks later when the training concludes,

4) you will asked to participate in a final 2-3 hour testing session. You will be compensate $5.00

WHO MAY SEE MY RECORDS?

- The research records will be kept private and your name will not be used in any written or verbal reports.
- The researcher and research staff will review your medical records and will keep the *everyone who was enrolled in the study, **both those who got the treatment and those who did not** will* information private.
- The research records will be kept in a secured manner and computer records will be password protected.
- The medical and reseaerch information recorderd about you will be used or disclosed by the research investigators only as part of this research project
- Support for this study is provided by: HeartMath Institute, Boulder Colarado, Brain Train, Richmond, VA, and AHRC, Traumatic Brain Injury Services, New York City.

WILL THERE BE ANY COSTS TO ME?

- There will be no costs to you for participating in this study.

WHO CAN ANSWER MY QUESTIONS ABOUT THE STUDY?

Researcher's Name: Sonya Kim, Study Delegate
Office Address: Ferkauf School of Psychology Yeshiva University, Clinical Psychology [Health] 1165 Morris Park Ave; Bronx NY 10461
Office Phone: 718-430-3937 [Fred Foley, PhD, PI]

- If any questions arise related to this research project, or you believe you have any injury related to this study, you can call the researcher above.
- You may also call Marie Cavallo, PhD, Assistant Director of Adult Day Services at AHRC at 212-780-2504, Monday through Friday between 9 AM and 5 PM.
- If you have questions regarding your rights as a research subject, you may also call the Manager of The Albert Einstein College of Medicine Committee on Clinical Investigations at (718) 430-2253, Monday through Friday between 9 AM and 5 PM.

Informed Consent Signature Page

The following is a list of items we discussed about this research study. If you have any questions about any of these items, please ask the person who is discussing the study with you for more information before agreeing to participate.

- What the study is about.
- What I must do when I am in the study.
- The possible risks and benefits to me.
- Who to contact if I have questions or if there is a research related injury.
- Any costs and payments.
- I can discontinue participating in the study at any time without penalty.
- Other choices.

- All written and published information will be reported as groups data with no reference to my name.
- I have been given the name of the researcher and others to contact.
- I have the right to ask any questions.

May I STOP THE STUDY AT ANY TIME?

- Your participation in this study is voluntary and you may withdraw from the study at any time without giving a reason.
- If you agree to participate and withdraw at a later time, some of your information may have already been entered into the study and that will not be removed.
- Your treatment by doctors and staff at the institution(s) involved in this study, now and in the future, will not be affected in any way if you agree to participate and withdraw later.
- Your decision not to be in this research study will not result in any loss of benefits to which you are otherwise entitled.

WHAT ARE MY RIGHTS IF I TAKE PART IN THIS RESEARCH STUDY?

- Your participation in this study is voluntary.
- You do not waive any of your legal rights by participating in this research study.
- Your treatment by doctors and staff at the institution(s) involved in this study, now and in the future, will not be affected in any way if you refuse to participate or if you enter the study and withdraw later.
- What I must do when I am in the study.
- The possible risks and benefits to me.
- Who to contact if I have questions or if there is a research related injury.
- Any costs and payments.
- I can discontinue participating in the study at any time without penalty.
- Other choices.
- All written and published information will be reported as group data with no reference to my name.
- I have been given the name of the researcher and others to contact.
- I have the right to ask any questions.

Printed Name of Participant	Signature of Participant	Date
Name of Person conducting the the Informed consent Process	Signature of Person conducting the Informed consent Process	Printed Date

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Appendix B

Sample HIPAA Form

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Institutional Review Board; ACKNOWLEDGED 3/4/2009

MONTEFIORE MEDICAL CENTER | **ALBERT EINSTEIN COLLEGE OF MEDICINE OF YESHIVA UNIVERSITY**

AUTHORIZATION TO USE OR DISCLOSE PROTECTED HEALTH INFORMATION FOR A RESEARCH STUDY

You have agreed to participate in the research study titled:
Using Heartrate Variability Biofeedback Methods with Training in Problem-Solving Skills to Improve Executive Functioning in Individuals with Chronic TBI

AECOM CCI #: 2009-253-000   MMC IRB#

Principal Investigator Name: Fred Foley

You authorize use or disclosure of the information described below.

The information may be disclosed, as applicable, by:

- The research team (investigators, nurses, data managers, etc.)
- Montefiore Medical Center
- Albert Einstein College of Medicine (Yeshiva University)
- Jacobi Medical Center and North Central Bronx Hospital (New York City Health and Hospitals Corporation)

The information may be disclosed, as applicable, to:

- Montefiore Medical Center
- Albert Einstein College of Medicine (Yeshiva University)
- The sponsor(s) of this research and any company with which the sponsor has contracted to oversee the research
- U.S. Food and Drug Administration, the U.S. Office of Human Research Protection, other federal agencies involved with research
- Jacobi Medical Center and North Central Bronx Hospital (New York City Health and Hospitals Corporation)

The following information is to be disclosed: The specific health information about you to be used or disclosed in the research includes all personally identifiable health information concerning you collected or generated as a result of this research. The purpose of the use and/or disclosure of Protected Health Information is to be able to use the information collected about you in the results of the research.

Right to Revoke: You have the right to revoke (or cancel) this authorization at any time. If you revoke this authorization, you must do so in writing to the Principal Investigator at the address shown on the first page of the research consent form. The revocation will not apply to information that has already been disclosed based on this authorization.

Expiration: This Authorization does not have an automatic end date.

Redisclosure: Your information may be re-disclosed by the organization that receives it, and the information may no longer be protected by HIPAA rules. Please refer to the Confidentiality Section of your Research Subject and Information Consent Form for additional information regarding confidentiality outside the Research Study.

Other Rights: Authorizing the disclosure of this health information is voluntary. You can refuse to sign this authorization. You do not need to sign this form to assure treatment. However, since this authorization is needed for participation in a research study, your enrollment in the research study may be denied. You will receive a signed copy of this form.

Signature of Research Participant/Authorized Representative | **Date** | **Printed Name of Individual Signing Form**

Printed Name of Research Participant
(If different from the individual signing the form.)

Relationship of Individual Signing Form

Appendix C

Heart Rate Variability Indices: Matlab Implementation

```
function out = sonya2(filename,be,display)
%loading the file
RR = load(filename);
out.filename = filename;
out.SDNN = std(RR);
out.RMSSD = sqrt(mean(diff(RR).^2));
out.IBI = mean(RR);
out.BPM = 60./mean(RR).*1000;
while length(RR)<1024
   RR = [RR;RR(end:-1:1)];
end;
%put data in variable RR and compute BPM
RR(RR>median(RR)+200|RR<median(RR)-200) = median(RR);
% RR = medfilt1(RR,3);
% if be,
%     RR = RR(1:512);
% else
%     RR = RR(end-513:end);
% end;
% RR = [RR(1:600)',zeros(1,1024-600)]';
if be == 1
   RR = RR(1:300);
elseif be == 2
   RR = RR(301:600);
elseif be == 3
   RR = RR(1:600);
elseif be == 4
   RR = RR(151:450);
end;
%Remove average of signal
RR = RR-mean(RR);
%Compute the PSD (power spectral density)
Fs = 1;
Pxx=pwelch(RR,64,[],[],Fs,'onesided');
freq = linspace(0,Fs/2,length(Pxx));
%Interpolate using splines
Pspl = spline(freq,Pxx);
```

```
Pfp = spline(freq,freq.*Pxx');
Pfpint = fnint(Pfp);
Pint = fnint(Pspl);
Psplneg = fncmb(Pspl,-1);
%Compute values

VLF = fnval(Pint,0.04)-fnval(Pint,0);
meanFvlf = (fnval(Pfpint,0.04)-fnval(Pfpint,0))./VLF;
LF = fnval(Pint,0.15)-fnval(Pint,0.04);
meanFlf = (fnval(Pfpint,0.15)-fnval(Pfpint,0.04))/LF;
HF = fnval(Pint,0.4)-fnval(Pint,0.15);
meanFhf = (fnval(Pfpint,0.4)-fnval(Pfpint,0.15))./HF;
%find max in 0.04-0.26 interval
[val, ind] = fnmin(Psplneg,[0.04,0.26]);
Peak = (fnval(Pint,ind+0.015)-fnval(Pint,ind-0.015));
Total = fnval(Pint,freq(end));
HmathCR = Peak./(Total-Peak);
% Display
if display
scrsz = get(0,'ScreenSize');
figure('Position',scrsz)
fnplt(Pspl);hold on;
title(filename,'interpreter','none');
xlabel('Frequency (Hz)');
ylabel('Power Density (ms^2/Hz)');
vec = [ind-0.015,ind+0.015];
line([vec;vec],[min(fnval(Pspl,vec));min(fnval(Pspl,vec))+max(fnval(Pspl,vec))],'linewid
th',1,'color','k','linewidth',3,'linestyle','--')
text(vec(1),(min(fnval(Pspl,vec))+max(fnval(Pspl,vec))+200),['Peak = ',
num2str(Peak,'%6.1f'), 'ms^2'],'color','k','fontweight','bold');
line([0.04:0.001:0.16;0.04:0.001:0.16],[zeros(size(0.04:0.001:0.16));fnval(Pspl,0.04:0.00
1:0.16)],'linewidth',1,'color','b')
text(0.05,1000,['LF = ', num2str(LF,'%6.1f'), 'ms^2'],'color','k','fontweight','bold');
line([0.15:0.001:0.4;0.15:0.001:0.4],[zeros(size(0.15:0.001:0.4));fnval(Pspl,0.15:0.001:0.
4)],'linewidth',1,'color','r')
text(0.3,1000,['HF = ', num2str(HF,'%6.1f'), 'ms^2'],'color','k','fontweight','bold');
end;

%    disp(['LF = ', num2str(LF,'%6.1f'), ' ms^2'])
%    disp(['HF = ', num2str(HF,'%6.1f'), ' ms^2'])
%    disp(['LF/HF = ', num2str(LF/HF,'%6.1f')])
%    disp(['Peak = ', num2str(Peak,'%6.1f'), ' ms^2'])
%    disp(['Total = ', num2str(Total,'%6.1f'), ' ms^2'])
%    disp(['SDNN =', num2str(std(RR),'%6.1f'), ' ms']);
out.VLF = VLF;
```

```
out.LF = LF;
out.HF = HF;
out.Peak = Peak;
out.Total = Total;
out.cohratio = Peak./(Total-Peak);
out.LFoverHF = LF/HF;

out.LFnorm = LF./(Total-VLF)*100;
out.HFnorm = HF./(Total-VLF)*100;
out.meanFvlf = meanFvlf;
out.meanFlf = meanFlf;
out.meanFhf = meanFhf;
```

Appendix D

Problem Solving Inventory, Adolescent Version

Instructions: Here are a list of items. These items ask you how you deal with everyday problems. Some examples of problems might be feeling sad, or not getting along with friends. There are no right or wrong answers. Please answer the items as honestly as you can. *Your answers should be how you really deal with problems. Don't answer how you think you should deal with them.* **Please answer each item.**

Read each item. Answer if you agree or disagree, using the numbers below. Put your

answers on the green scan sheet.

0 Really agree	**1 Mostly agree**	**2 Agree, a little**	**3 Disagree, a little**	**4 Mostly disagree**	**5 Really disagree**

1. When I can't solve a problem, I don't try to find out why.

2. When I have a big problem, I don't get information to help me understand the problem.

3. When I can't solve a problem, I question if I can solve it at all.

4. After I solve a problem, I don't think about what went right or what went wrong.

5. Usually, I can think up new and useful ways to solve a problem.

6. Sometimes, I solve a problem in one way. Then I compare what really happened to what I thought should have happened.

7. I think of as many possible ways to handle a problem until I can't come up with any more ideas.

8. When I have a problem, I always look at my feelings. That helps me to learn what's going on.

9.

10. When I feel mixed-up about a problem, I don't try to understand my ideas or feelings.

11. I can solve most problems even if I don't have a solution at first.

12. Many of my problems are too big and hard for me to solve.

13. When solving a problem, I make decisions that I am happy with later.

14. When I have a problem, I usually do the first thing I think of to solve it.

15. Sometimes, I don't take enough time to solve my problems carefully.

16. I don't take time to think if other solutions to a problem will work.

17. When I have a problem, I stop and think about it before deciding on a next step.

18. When solving problems, I usually use the first good idea that I think of.

19. When solving a problem, I think about the effects of all possible solutions. Then I compare the solutions to each other.

20. I'm almost sure that my plans to solve a problem will work.

21. Sometimes before I carry out a certain plan, I try to guess what might happen.

22. When I try to think of possible ways to solve a problem, I don't come up with very many answers.

23. Circle the number 2 for this item.

24. If I spend enough time and effort, I can solve most of my problems.

25. When faced with a new situation, I can handle any possible problems.

26. While working on a problem, I sometimes get confused. Then I don't concentrate on the real problem.

27. I often make quick decisions and regret them later.

28. I trust my ability to solve new and different problems.

29. I carefully compare different solutions to solve problems.

30. When I think of ways of handling a problem, I don't put different ideas together.

31. When faced with a problem, I don’t usually see the things around me that may make my problem worse.

32. When faced with a problem, I first look at the situation to get all the important pieces of information.

33. Sometimes I get so upset, I can’t think of ways to solve my problem.

34. After choosing a solution to a problem, the results usually match what I expect.

35. When faced with a problem, I am not sure I can handle the situation.

36. When I have a problem, one of the first things I do is try to learn exactly what the problem is.

Appendix E

Clinician Rating Forms (Problem solving [PS] and Self-regulation [SR])

Clinician Version

RUSK INSTITUTE of Rehabilitation Medicine

PS-Clinician Rating Form

Patient name: ________________________ Date: ________________________

Clinician name: ______________________

How long have you known this patient? __________

How long has s/he been receiving treatment for cognitive problems? __________

INSTRUCTIONS: Please use this form to rate your patient's **problem-solving ability** and compensatory strategy use, using your clinical impressions. These impressions may be based on observations made in session or on behavior reported by the patient, a family member, or another observer.

Problem solving requires the ability to recognize that there is a problem, define the problem, seek information as needed, generate options, evaluate feasibility of options and whether or not they will achieve the desired outcome, sequence the steps necessary to carry out plan, successfully carry out the plan, review the outcome, and revise as needed.

Problem solving further requires that the perspectives and feelings of other people involved in the situation be taken into account.

On a scale of 1 to 7, please rate the patient's overall **problem-solving ability**:

For all items, the phrase "**cognitive impairments or effects of brain injury/stroke**" refers to difficulties like emotional flooding, impulsivity, or difficulties with logical thinking, planning, or sequencing.

7 = **Excellent problem-solving ability; for example:** Few, if any, apparent difficulties attributable to cognitive impairments or effects of brain injury/stroke. No assistance needed with daily life decisions.

6 = **Good problem-solving ability; for example:** Very slight or very occasional difficulties attributable to cognitive impairments or effects of brain injury/stroke –OR-- Difficulties apparent only in very complex or stressful situations. Only occasional assistance needed with daily life decisions.

5 = **Fair problem-solving ability; for example:** Mild difficulties attributable to cognitive impairment or effects of brain injury/stroke. Supervision or monitoring of daily life decisions is helpful.

4 = **Unreliable problem-solving ability (sometimes fair/sometimes poor); for example:** Mild difficulties in familiar situations/moderate difficulties in unfamiliar situations, attributable to cognitive impairments or effects of brain injury/stroke. Supervision/monitoring of daily life decisions is helpful in familiar situations. Needs some assistance with decisions in unfamiliar situations.

3 = **Poor problem-solving ability; for example:** Moderate difficulties attributable to cognitive impairments or effects of brain injury/stroke. Needs supervision/monitoring of (and/or some assistance with) daily life decisions.

2 = **Very poor problem-solving ability; for example:** Severe difficulties attributable to cognitive impairments or effects of brain injury/ stroke. Needs major assistance with daily life decisions.

1 = **Extremely poor problem-solving ability; for example:** Little or no ability to solve problems due to cognitive impairments or effects ofbrain injury/stroke. Needs others to make daily life decisions.

On a scale of 1 to 7, please rate how well this patient has adopted **strategies to compensate for difficulties with problem-solving**.

7 = Excellent compensator; for example: Learned a variety of compensatory strategies and uses them effectively when needed. Independently generates new strategies as needed.

6 = Good compensator; for example: Learned some compensatory strategies and typically uses them effectively without prompting, but may not consistently generate new strategies without help.

5 = Fair compensator; for example: Learned some compensatory strategies, but sometimes needs prompting to use them effectively. Usually needs help generating new strategies.

4 = Unreliable compensator; for example: Learned some effective compensatory strategies, but only uses them with major prompting. Even then, strategies are effective only some of the time.

3 = Poor compensator; for example: Rarely, if ever, uses strategies without prompting. Sometimes may not use them even with prompting. When used, strategies tend to be ineffective.

2 = Very poor compensator; for example: Acknowledges the idea of needing strategies, but doesn't use them, even with prompting.

1 = Extremely poor compensator; for example: Considers the use of compensatory strategies unnecessary.

Clinician version

RUSKINSTITUTE of Rehabilitation Medicine

SR-Clinician Rating Form

Patient name: ___________________________ Date: __________________________

Clinician name: _________________________

How long have you known this patient? ___________

How long has s/he been receiving treatment for cognitive problems? ___________

INSTRUCTIONS: Please use this form to rate your patient's **emotional self-regulation skills** and compensatory strategy use, using your clinical impressions. These impressions may be based on observations made in session or on behavior reported by the patient, a family member, or another observer.

Emotional self-regulation difficulties include emotional over-reactions (reactions that are out of proportion to the situation), emotional flooding (becoming overwhelmed), and impulsive responses. They also can include negative, self-deprecating thoughts or statements that disrupt the ability to think clearly, "shutting down," and avoidance/inaction.

On a scale of 1 to 7, please rate the patient's overall **emotional self-regulation skills:**

For all items, the phrase "**emotional self-regulation**" refers to the ability to keep strong emotions from interfering with daily life.

7 **= Excellent emotional self-regulation skills; for example:** Few, if any, emotional self-
regulation difficulties attributable to effects of brain injury/stroke. Strong emotions do not interfere with daily life.

6 **= Good emotional self-regulation skills; for example:** Very slight or very occasional emotional self-regulation difficulties attributable to effects of brain injury/stroke –OR-- Emotional self-regulation difficulties apparent only in very complex or very stressful situations. Only occasional difficulty managing strong emotions.

5 **= Fair emotional self-regulation skills; for example:** Mild emotional self-regulation difficulties attributable to effects of brain injury/stroke. Usually maintains good emotional self-regulation, but may require occasional prompting or redirection.

4 **= Unreliable emotional self-regulation skills (sometimes fair/sometimes poor); for example:** Mild difficulties in familiar situations/moderate difficulties in unfamiliar situations, attributable to effects of brain injury/stroke. Able to maintain good emotional self-regulation in routine, familiar situations, but has difficulty in unfamiliar or stressful situations.

3 **= Poor emotional self-regulation skills; for example:** Moderate emotional self-regulation difficulties attributable to effects of brain injury/stroke. Often has difficulty managing emotions. Redirection or prompting is sometimes helpful.

2 **= Very poor emotional self-regulation skills; for example:** Severe emotional self-regulation difficulties attributable to effects of brain injury/stroke. Great difficulty managing emotions; prompting/redirection usually is not effective.

1 **= Extremely poor emotional self-regulation skills; for example:** Little or no ability to regulate emotions due to effects of brain injury/stroke.

On a scale of 1 to 7, please rate how well this patient has adopted **strategies to compensate for difficulties with emotional-self regulation**.

7 **= Excellent compensator; for example:** Learned a variety of compensatory strategies and uses them effectively when needed. Independently generates new strategies as needed.

6 **= Good compensator; for example:** Learned some compensatory strategies and typically uses them effectively without prompting, but may not consistently generate new strategies without help.

5 **= Fair compensator; for example:** Learned some compensatory strategies, but sometimes needs prompting to use them effectively. Usually needs help generating new strategies.

4 **= Unreliable compensator; for example**; Learned some effective compensatory strategies, but only uses them with major prompting. Even then, strategies are effective only some of the time.

3 **= Poor compensator; for example:** Rarely, if ever, uses strategies without prompting. Sometimes may not use them,even with prompting. When used, strategies tend to be ineffective.

2 **= Very poor compensator; for example:** Acknowledges the idea of needing strategies, but doesn't use them, even with prompting.

1 **= Extremely poor compensator; for example:** Considers the use of compensatory strategies unnecessary.

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of Rehabilitation Medicine

PS-CRF (Patient version)

Name: ____ Date: ___________________

INSTRUCTIONS: Please use this form to rate your **problem-solving ability** and your ability to use strategies to compensate for difficulties.

Problem solving requires the ability to recognize that there is a problem, define the problem, seek information as needed, generate options, evaluate feasibility of options and whether or not they will achieve the desired outcome, sequence steps necessary to carry out plan, successfully carry out the plan, review the outcome, and revise as needed.

Problem solving further requires that the perspectives and feelings of other people involved in the situation be taken into account.

On a scale of 1 to 7, please rate the your overall **problem-solving ability**:

For all items, the phrase "**cognitive impairments or effects of brain injury/stroke**" refers to difficulties like emotional flooding, impulsivity, or difficulties with logical thinking, planning, or sequencing.

7 = **Excellent problem-solving ability; for example:** Few, if any, apparent difficulties attributable to cognitive impairments or effects of brain injury/stroke. No assistance needed with daily life decisions.

6 = **Good problem-solving ability; for example:** Very slight or very occasional difficulties attributable to cognitive impairments or effects of brain injury/stroke –OR-- Difficulties apparent only in very complex or stressful situations. Only occasional assistance needed with daily life decisions.

5 = **Fair problem-solving ability; for example:** Mild difficulties attributable to cognitive impairment or effects of brain injury/stroke. Supervision or monitoring of daily life decisions is helpful.

4 = **Unreliable problem-solving ability (sometimes fair/sometimes poor); for example:** Mild difficulties in familiar situations/moderate difficulties in unfamiliar situations, attributable to cognitive impairments or effects of brain injury/stroke. Supervision/monitoring of daily life decisions is helpful in familiar situations. Needs some assistance with decisions in unfamiliar situations.

3 = **Poor problem-solving ability; for example:** Moderate difficulties attributable to cognitive impairments or effects of brain injury/stroke. Needs supervision/monitoring of (and/or some assistance with) daily life decisions.

2 = **Very poor problem-solving ability; for example:** Severe difficulties attributable to cognitive impairments or effects of brain injury/ stroke. Needs major assistance with daily life decisions.

1 = **Extremely poor problem-solving ability; for example:** Little or no ability to solve problems due to cognitive impairments or effects ofbrain injury/stroke. Needs others to make daily life decisions.

On a scale of 1 to 7, please rate how well you have adopted **strategies to compensate for difficulties with problem-solving**.

7 = Excellent compensator; for example: Learned a variety of compensatory strategies and uses them effectively when needed. Independently generates new strategies as needed.

6 = Good compensator; for example: Learned some compensatory strategies and typically uses them effectively without prompting, but may not consistently generate new strategies without help.

5 = Fair compensator; for example: Learned some compensatory strategies, but sometimes needs prompting to use them effectively. Usually needs help generating new strategies.

4 = Unreliable compensator; for example: Learned some effective compensatory strategies, but only uses them with major prompting. Even then, strategies are effective only some of the time.

3 = Poor compensator; for example: Rarely, if ever, uses strategies without prompting. Sometimes may not use them even with prompting. When used, strategies tend to be ineffective.

2 = Very poor compensator; for example: Acknowledges the idea of needing strategies, but doesn't use them, even with prompting.

1 = Extremely poor compensator; for example: Considers the use of compensatory strategies unnecessary.

RUSKINSTITUTE of Rehabilitation Medicine

SR-CRF (Patient version)

Name: ____ Date: __________________

INSTRUCTIONS: Please use this form to rate your **emotional self-regulation skills** and your ability to use strategies to compensate for difficulties.

Emotional self-regulation difficulties include emotional over-reactions (reactions that are out of proportion to the situation), emotional flooding (becoming overwhelmed), and impulsive responses. They also can include negative, self-deprecating thoughts or statements that disrupt your ability to think clearly, "shutting down," and avoidance/inaction.

On a scale of 1 to 7, please rate your overall **emotional self-regulation skills:**

For all items, the phrase "**emotional self-regulation**" refers to the ability to keep strong emotions from interfering with daily life.

7 **= Excellent emotional self-regulation skills; for example:** Few, if any, emotional self-
regulation difficulties attributable to effects of brain injury/stroke. Strong emotions do not interfere with daily life.

6 **= Good emotional self-regulation skills; for example:** Very slight or very occasional emotional self-regulation difficulties attributable to effects of brain injury/stroke –OR-- Emotional self-regulation difficulties apparent only in very complex or very stressful situations. Only occasional difficulty managing strong emotions.

5 **= Fair emotional self-regulation skills; for example:** Mild emotional self-regulation difficulties attributable to effects of brain injury/stroke. Usually maintains good emotional self-regulation, but may require occasional prompting or redirection.

4 **= Unreliable emotional self-regulation skills (sometimes fair/sometimes poor); for example:** Mild difficulties in familiar situations/moderate difficulties in unfamiliar situations, attributable to effects of brain injury/stroke. Able to maintain good emotional self-regulation in routine, familiar situations, but has difficulty in unfamiliar or stressful situations.

3 **= Poor emotional self-regulation skills; for example:** Moderate emotional self-regulation difficulties attributable to effects of brain injury/stroke. Often has difficulty managing emotions. Redirection or prompting is sometimes helpful.

2 **= Very poor emotional self-regulation skills; for example:** Severe emotional self-regulation difficulties attributable to effects of brain injury/stroke. Great difficulty managing emotions; prompting/redirection usually is not effective.

1 **= Extremely poor emotional self-regulation skills; for example:** Little or no ability to regulate emotions due to effects of brain injury/stroke.

On a scale of 1 to 7, please rate how you have adopted **strategies to compensate for difficulties with emotional-self regulation**.

7 **= Excellent compensator; for example:** Learned a variety of compensatory strategies and uses them effectively when needed. Independently generates new strategies as needed.

6 **= Good compensator; for example:** Learned some compensatory strategies and typically uses them effectively without prompting, but may not consistently generate new strategies without help.

5 **= Fair compensator; for example:** Learned some compensatory strategies, but sometimes needs prompting to use them effectively. Usually needs help generating new strategies.

4 **= Unreliable compensator; for example**; Learned some effective compensatory strategies, but only uses them with major prompting. Even then, strategies are effective only some of the time.

3 **= Poor compensator; for example:** Rarely, if ever, uses strategies without prompting. Sometimes may not use them,even with prompting. When used, strategies tend to be ineffective.

2 **= Very poor compensator; for example:** Acknowledges the idea of needing strategies, but doesn't use them, even with prompting.

1 **= Extremely poor compensator; for example:** Considers the use of compensatory strategies unnecessary.

Appendix F

Treatment: Training Protocol To Improve Self-Regulation

Description and Application of Training Equipment

HeartMath emWave PC.

HRV biofeedback training was done with HeartMath emWave PC and Thought Technology's Biograph. HeartMath's emWave PC uses the HRV biofeedback as a measure of emotions and stress. The system seeks to teach individuals to change their heart-rhythm pattern and thereby create physiological coherence in the body. Coherence can be defined as consistency of heartbeat oscillation, which would also reflect a balance between the two branches (sympathetic and parasympathetic) of the autonomic nervous system (ANS). (See definition of terms in Chapter II). The state of being coherent is also described as when multiple physical systems such as respiration, heart rhythm, and blood pressure become "entrained" or "phase locked," and oscillate at the same frequency. An analogy could be drawn to two runners, who are running at the same speed, but one is ahead of the other and this distance stays stable; they are locked and run in phase with each other. Or in music, coherence describes how one chord is made up of many notes of different frequencies that resonant together; the many independent notes or frequencies are locked together to produce one harmonious sound. Visual feedback of coherence is obtained through a smooth sine wave pattern of the heartbeat (heart tracings) that appears on the monitor screen. This *emWave PC* hardware/software system monitors and displays an individual's heart rate variability pattern in real time. Using a fingertip or earlobe sensor to record the pulse wave, this program plots changes in heart rate on a beat-to-beat basis. The emWave PC sensors are infrared plethysmographs, so no electrical contact occurs between the sensor and the user.

Once the HeartMath program is installed into a computer, referred to as emWave PC, the program provides several screens with different visual and audio options and a number of games that an individual can play to practice instilling "coherence," a state that involves body, brain, and the mind (emotions). For example, the main screen displays the heart pattern or tracing across the center of the computer screen as the PC records the signals from the subject. At the lower right are three rectangular bars in a row, which light up in a particular color – red blue green -- to show how much "coherence" the subject has achieved as the session proceeds. A green bar represents high coherence, blue represents medium, and red, low coherence. These low, medium, and high designations are unique to HMI. Coherence ratio equation to quantify an individual's psychophysiology is uniquely developed by HMI and this qualification of low medium high is also created by HMI. This algorithm is not published in the Task Force on HRV (1996).

Each colored bar comes with a corresponding uniquely pitched tone. The emWave program can be set to many different sounds that represent these colors and range of coherence. For the purposes of this study, we chose the following sounds: The green light comes with a higher bell-tone. The blue light comes with a slightly lower bell-tone. The red light comes with a "gong-like sound. The participants were instructed to try to get the green bar to light up. The more "coherence" they are able to achieve, the bigger the green bar gets, chiming the bell tone as the bar either maintains its level or grows in value.

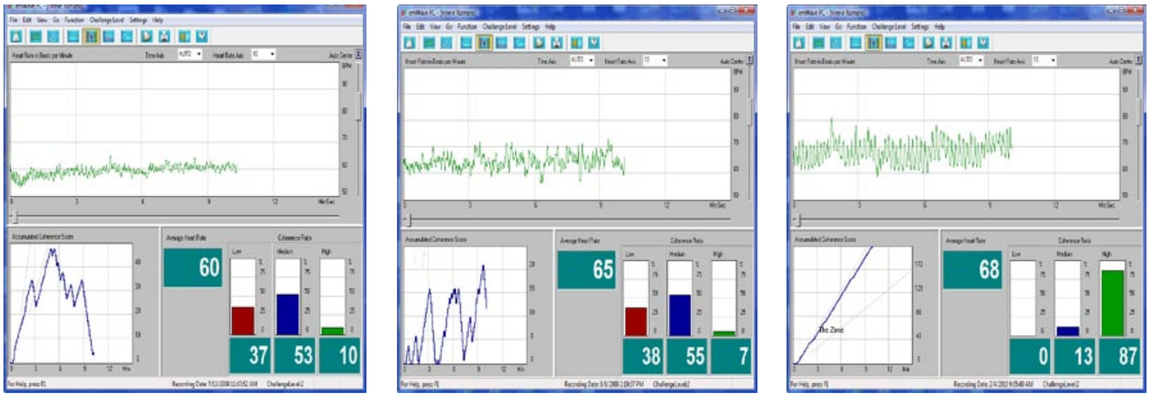

Figure F1. Representative data, heart rate variability recording (Time 1, Time 2, Time 3)

HeartMath emWave PC program is also equipped with interactive games the participants can play. When the participants play these games, they no longer see their heart pattern (tracing) on the screen and the three colored bars in the right lower corner of the screen also disappear; and screen displays only the particular game that has been selected. Each game has its own goal, and when the participants come closer to achieving the goal. They are given different rewards (feedback) depending on the game.

Examples of games.

Balloon game. The screen displays a hot air balloon and the make-believe game that the subject is going to take a trip around the world. The balloon rises, falls, speeds up, and slows down as the “coherence” or resonance in the participant’s autonomic system changes.

*Garden game***.** In this game, achieving resonance/coherence of the ANS transforms a grey garden into a garden that has colors and images; bells chime as the new images appear, such as flowers, gold fish, or a horse.

*Rainbow Game***.** Participants fill the pot of gold at the end of the rainbow by achieving resonance and coherence. The rainbow will slowly descend towards the pot as the participant reaches the threshold of resonance but will retract if he or she is below the threshold.

In the *Emotion Visualizer*, resonance/coherence of the ANS makes the stars that appear in a black screen burst into colors. The more resonant or coherent the participant's ANS becomes, the more the screen becomes a fireworks-like display. For the duration of the game, there is a rhythmic vibrant music plays in the background, but the music does not react to the participant's level of coherence.

Low Coherence High Coherence

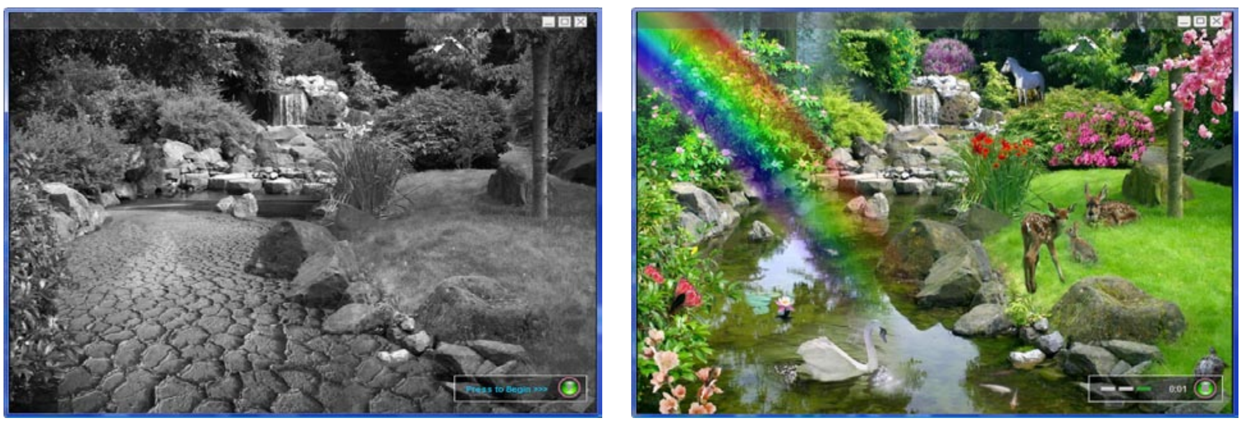

Figure F2. Garden game. The first picture represents the screen that appears at the start of the session. The last picture represents how the screen is transformed once the individual achieves coherence.

Start of session mid-way through session High Coherence

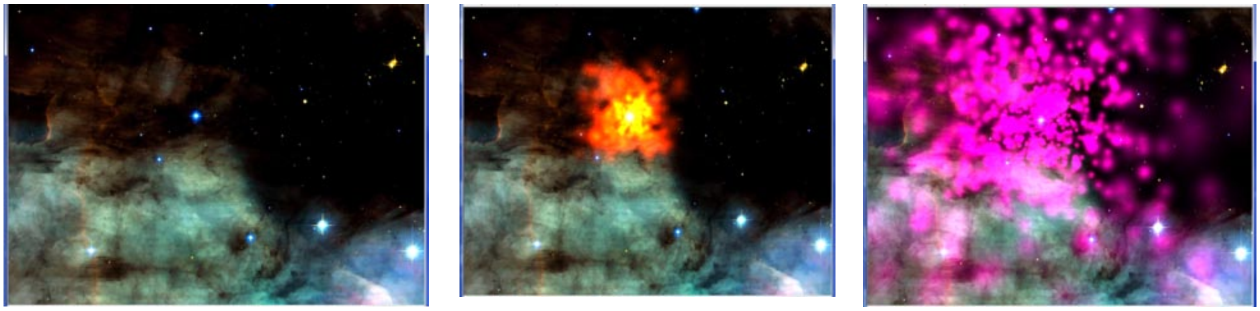

Figure F3. Emotion Visualizer. The first picture represents the screen that appears at the start of the session. The subsequent pictures represent how the screen is transformed once the individual achieves coherence.

The premise of this HeartMath program is that negative emotions lead to increased disorder in the heart's rhythms and in the autonomic nervous system. In contrast, positive emotions create increased *coherence* in heart rhythms and improve balance in the nervous system (McCraty et al., 1995; 1998; 2003). Teaching the individual to generate positive emotions is the key intervention of HeartMath protocol; but given the severity of the brain injury of this study's population, for the purposes of this experiment, HMI protocol was modified to make the teaching more concrete. An important component of the original HeartMath protocol was that the participants identify stressful experiences. But the study individuals were unable to verbalize examples of feeling stressed, and they denied having any stressful moments at all. Thus a big challenge in this experiment was to try to train individuals to learn new strategies and new behaviors when in fact they could not acknowledge that they needed any training or treatment at all.

Less emphasis was placed on instructing the participants to generate positive emotions. Instead, the training was more based on gaining control and awareness of the body. Using a modified version of Lehrer et al.'s (2000**)** training manual, the investigator of this study instructed the participants to follow a breathing pacer and to observe the changes they could make of the heart rate tracing that appeared on the computer screen. In a departure from Lehrer et al.'s method, the unique resonant frequency for the individuals was not taken and the pacer was not set at that unique breathing pace. All participants were instructed to follow a breathing pacer set at 5.5 to 6.5 breaths per minute based on the "comfort level" that the participants expressed during the activity.

While at first we tried to attain the participants' resonant frequency by using equipment provided by Thought Technology Biograph, the participants could not follow the breathing pacer necessary to determine an individual's resonant frequency. It is unclear as to why this difficulty was experienced and how much it was due to the damage to the brain, specifically the brain stem. But this problem was pervasive in this group. Biograph, which includes visual and auditory feedback (like HeartMath) and also physical feedback (the participants also wear a belt around their abdominal which is hooked up to the computer), served to help the participants increase their RSA by helping them to breathe more slowly and regularly. This practice was usually done for the first five minutes, before the program was changed to HMI. The HMI equipment was more fitted to this group. The reasons for this equipment's adaptability are unclear, but the HMI screen may be more simplified visually.

Thought Technology BioGraph

The Thought Technology Biograph RSA training program was initially brought into the treatment to find the participants' resonant frequency according to Lehrer et al.'s (2000) recommendation. Biograph has the benefit of providing more physical cues to the individual. The individual is hooked up with EKG sensors on both the left and right wrist. The EKG sensor is a pre-amplified electrocardiograph sensor for directly measuring the heart's electrical activity. The participants also wore a respiration sensor, a sensitive girth sensor that is wrapped around the participants' abdominal area with a self-adhering belt. It detects abdominal expansion and contraction and shows the respiration waveform and amplitude. It can be worn over clothing. After the participants were fitted with the equipment, they were presented with a picture of the heart tracing (or heart pattern) that they were going to try to replicate on the computer screen. Then the computer program was turned on, and the investigator of the study provided instructions and feedback when they were able to attain the waveform of the

Self-Regulation Training Sessions Begin

Below is an example of the treatment protocol. The treatment scripts were designed on the basis of multiple sources of published manuals (Thurber et al., 2008, Lehrer et al., 2000; Rath et al., 2003).

At the start of the session, the individuals were seated on a comfortable chair, directly in front of the computer screen. They were introduced to the method, with the following statements read aloud to them by the investigator.

Session 1.

You will be learning skills for stress management because we believe stress management is key to being able to solve problems and feel more independent. The best approach to a problem is to think clearly and calmly about the situation, and emotions can sometimes get in the way.

Today you're going to learn an easy and effective way to reduce the impact of stress on your body, brain, and emotions. First we'll talk a little bit about what stress is and the best way to reduce it. Next you'll learn an easy to use technique that you can practice thoughout the day especially when stress happens. So over the next 10 weeks, you will learn stress management techniques.

At the second session, the computer biofeedback was introduced, and the participants were hooked up with the ear sensor. A review of their baseline HRV recording was done.

Session 2 (introduction).

How your heart beats (heart rate) is affected by different events. It beats slower or faster for many different reasons. When you sleep it slows down. When you climb stairs, it speeds up. How you are feeling also changes heart beat pattern. When we are very sad, we typically say "I'm heart broken" because the sad feeling does something to how the heart operates.

Stress will affect our heart's rhythmic pattern. I am going to show you that stress can be "seen" by watching what happens to the heart rhythm. By learning to regulate our heart rhythms, we can change our feelings of stress.

1) Using this computer you are going to see the rhythm of how your heart beats. [Investigator show them what they should try to get] *You will see how the heart rate tracing should look and how to get the Green bar to light up and sound bells.*
2) Then you are going to be taught techniques to change your heart rhythm (beat pattern) with the aim of learning how to get the heart rhythm to be ***coherent,*** *[point to picture of sine wave of a HRV tracing] The goal is to create a smooth and ordered heart rate patterns, with wide peaks and valleys to the sine waves. When that happens, this green bar will light up and will get a chime-bell-like tone.*

Sessions 3 – 10.

Ten sixty-minute individual sessions were provided during treatment consisting of the following six components

1) Education about the effects that strong emotions and stress have on the body And thinking, and how techniques for managing stress and emotional reactions can help people think more clearly. In this first component, attempts are made to help the

participants see how this HRV technique can be applied to real life situations. A review of any stressful experiences that the participants had during the week, how they reacted to them, and how this HRV can be applied to their reactions;

2) Education on and presenting pictures of what ideal "heart patterns" look like were discussed and how these specific heart patterns are associated with a calmness needed to think clearly;

3) RSA training using Thought Technology Biograph was done, with a belt wrapped around the participants' abdomen and sensors on their wrist; a breathing pacer was set at 6 breaths per minute to train the participants to increase their RSA, or amplitude of waves of their heart rhythm;

4) Training using HeartMath emWave program was done to increase HRV and thereby create the heart pattern model by way of a breathing pacer and the feedback from the computer (at this point the subject is comfortably sitting on a chair in front of the computer, which displays the HeartMath HRV screen. He or she is also hooked up with an ear sensor);

5 minute break (optional)

5) HeartMath HRV interactive game of choice. The participants were set up with HRV biofeedback games. About ten minutes of the session were spent on these games, with and without the coach of a breathing pacer, which helped the participants reach resonance or coherence in his or her bodily system.

After the fourth session, the individuals were given the cell-phone size biofeedback gadget for home practice (handhelds) and from there on, the individual session always ended or began with the participants demonstrating that they knew how to operate their handheld and that they could perform the biofeedback HRV adequately to obtain the “reward cycle.” The handhelds were pre-programmed so that once the individuals reached a certain threshold of “coherence” or “resonance,” the handheld rewarded the individual with sounds of bells. Treatment effects were evaluated with neuropsychological measures, self-report and informant report-inventories.

Appendix G

Table G1

Demographic Data: Comparing Individuals with family as Informants v. Individuals with Staff as Informants

	Mean Square	F	P value
Age	393.64	2.80	.12
Age of onset	472.35	3.74	.08
Time post injury (in years)	.05	0.00	.98
Education	45.72	3.52	.09

Table G2

BRIEF Scores; Comparing Individuals with Family as Informants v. Individuals with Staff as Informants

	Mean Square	F	P value
Pre-Treatment (Time 2)			
Emotional Control	52.93	.57	.47
Self-Monitor	244.00	4.24	.06
Behavioral Regulation Index	52.93	.75	.41
Working Memory	264.47	2.11	.18
Post-Treatment (Time 3)			
Emotional Control	83.88	.94	.36
Self-Monitor	.22	.003	.96

Post-Treatment (Time 3)			
Behavioral Regulation Index	.007	.001	.99
Working Memory	176.01	1.77	.21

Table G3

Category Test Errors: Comparing Individuals with Family as Informants v. Individuals with Staff as Informants

	Mean Square	F	P value
Category Test Errors – Time 1	1694.95	2.74	.13
Category Test Errors – Time 2	1041.24	1.23	.29
Category Test Errors – Time 3	2726.00	3.40	.09

Table G4

HRV Index, LF/HF: Comparing Individuals with Family as Informants v. Individuals with Staff as Informants

	Mean Square	F	P value
LF/HF – Time 1	.005	.01	.91
LF/HF – Time 2	.375	.37	.53
LF/HF – Time 3	9.50	.65	.44

Table G5

HRV Index, Coherence Ratio [normalized]: Comparing Individuals v. Family as Informants v. Individuals with Staff as Informants

	Mean Square	F	P value
Coherence normalized – Time 1	.01	.86	.37
Coherence normalized – Time 2	2.43	.15	.15
Coherence normalized – Time 3	2726.00	.34	.86