The Coherent Heart
Heart–Brain Interactions, Psychophysiological Coherence, and the Emergence of System-Wide Order

Rollin McCraty, Ph.D., Mike Atkinson, Dana Tomasino, B.A.,
and Raymond Trevor Bradley, Ph.D.[1]

Abstract: This article presents theory and research on the scientific study of emotion that emphasizes the importance of coherence as an optimal psychophysiological state. A dynamic systems view of the interrelations between psychological, cognitive and emotional systems and neural communication networks in the human organism provides a foundation for the view presented. These communication networks are examined from an information processing perspective and reveal a fundamental order in heart-brain interactions and a harmonious synchronization of physiological systems associated with positive emotions. The concept of coherence is drawn on to understand optimal functioning which is naturally reflected in the heart's rhythmic patterns. Research is presented identifying various psychophysiological states linked to these patterns, with neurocardiological coherence emerging as having significant impacts on well being. These include psychophysiological as well as improved cognitive performance. From this, the central role of the heart is explored in terms of biochemical, biophysical and energetic interactions. Appendices provide further details and research on; psychophysiological functioning, reference previous research in this area, details on research linking coherence with optimal cognitive performance, heart brain synchronization and the energetic signature of the various psychophysiological modes.

Keywords: Cognitive performance, coherence, emotion, heart rate variability, heart-brain interactions, neurocardiology, psychophysiological coherence, quantum holographic principles.

---

[1] This volume draws on the basic research conducted over the last decade at the Institute of HeartMath by Dr. Rollin McCraty and Mike Atkinson. The original manuscript for this article was drafted between 1998 and 2003 by Rollin McCraty and Dana Tomasino. Mike Atkinson conducted the analysis of the research reported here and also constructed the figures and graphs displaying the statistical information. Dr. Raymond Bradley joined the project in 2004 to work on a major revision and expansion of the manuscript to help bring the article to its present form.

Correspondence should be directed to Dr. Rollin McCraty, Director of Research, HeartMath Research Center.
14700 West Park Avenue
Boulder Creek, California 95006
Office: 831-338-8727
rollin@heartmath.org

SOME RIGHTS RESERVED

Table of Contents

> *…there are organism states in which the regulation of life processes becomes efficient, or even optimal, free-flowing and easy. This is a well established physiological fact. It is not a hypothesis. The feelings that usually accompany such physiologically conducive states are deemed "positive," characterized not just by absence of pain but by varieties of pleasure. There also are organism states in which life processes struggle for balance and can even be chaotically out of control. The feelings that usually accompany such states are deemed "negative," characterized not just by absence of pleasure but by varieties of pain. … The fact that we, sentient and sophisticated creatures, call certain feelings positive and other feelings negative is directly related to the fluidity or strain of the life process.*
> (Damasio, 2003, p. 131)

Prologue[2]

> *Chris, a 45-year-old business executive, had a family history of heart disease, and was feeling extremely stressed, fatigued, and generally in poor emotional health. A 24-hour heart rate variability analysis[3] revealed abnormally depressed activity in both branches of his autonomic nervous system, suggesting autonomic exhaustion ensuing from maladaptation to high stress levels. His heart rate variability was far lower then would be expected for his age, and was below the clinical cut-off level for significantly increased risk of sudden cardiac death. In addition, Chris's average heart rate was abnormally high at 102 beats per minute, and his heart rate did not drop at night as it should.*
>
> *Upon reviewing these results, his physician concluded that it was imperative that Chris take measures to reduce his stress. He recommended that Chris begin practicing a system of emotional restructuring techniques that had been developed by the Institute of HeartMath. These positive emotion-focused techniques help individuals learn to self-generate and sustain a beneficial functional mode known as psychophysiological coherence, characterized by increased emotional stability and by increased synchronization and harmony in the functioning of physiological systems.*
>
> *Concerned about his deteriorating health, Chris complied with his physician's recommendation. Each morning during his daily train commute to work, he practiced the Heart Lock-In technique, and he would use the Freeze-Frame technique in situations when he felt his stress levels rise.*[4]

---

[2] Excerpted from McCraty & Tomasino (2006), pp. 360-361.

[3] The analysis of heart rate variability (HRV), a measure of the naturally occurring beat-to-beat changes in heart rate, provides an indicator of neurocardiac fitness and autonomic nervous system function. Abnormally low 24-hour HRV is predictive of increased risk of heart disease and premature mortality. HRV is also highly reflective of stress and emotions.

[4] The Heart Lock-In tool is an emotional restructuring technique, generally practiced for 5 to 15 minutes, that helps build the capacity to sustain the psychophysiological coherence mode for extended periods of time. The Freeze-Frame technique is a one-minute positive emotion refocusing exercise used in the moment that stress is experienced to change perception and modify the psychophysiological stress response. For in-depth descriptions of these techniques, see Childre & Martin (1999) and Childre & Rozman (2005).

> *At first Chris was not aware of the transformation that was occurring. His wife was the first to notice the change and to remark about how differently he was behaving and how much better he looked. Then his co-workers, staff, and other friends began to comment on how much less stressed he appeared in responding to situations at work and how much more poise and emotional balance he had. A second autonomic nervous system assessment, performed six weeks after the initial one, showed that Chris's average heart rate had decreased to 85 beats per minute and it now lowered at night, as it should. Significant increases were also apparent in his heart rate variability, which had more than doubled! These results surprised Chris' physician, as 24-hour heart rate variability is typically very stable from week to week, and it is generally quite difficult to recover from autonomic nervous system depletion, usually requiring much longer than six weeks.*
>
> *In reflecting on his experience, Chris started to see how profoundly his health and his life had been transformed. He was getting along with his family, colleagues, and staff better than he could remember ever having enjoyed before, and he felt much more clearheaded and in command of his life. His life seemed more harmonious, and the difficulties that came up at work and in his personal relationships no longer created the same level of distress; he now found himself able approach them more smoothly and proactively, and often with a broadened perspective.*

The true story of Chris's transformation is not an isolated example, but rather is only one of many similar case histories that people like Chris have shared with HeartMath, illustrating the amazing transformations that can occur when one learns how to increase psychophysiological coherence.

Introduction

Many contemporary scientists believe that the quality of feeling and emotion we experience in each moment is rooted in the underlying state of our physiological processes. This view is well expressed by neuroscientist Antonio Damasio in the epigram that opened this article. The essence of his idea is that we call certain emotional feelings "positive" and others "negative" because these experiences directly reflect the impact of the "fluidity or strain of the life process" on the body, as is clearly evident in Chris' case, above. The feelings we experience as "negative" are indicative of body states in which "life processes struggle for balance and can even be chaotically out of control" (Damasio, 2003, p. 131). By contrast, the feelings we experience as "positive" actually reflect body states in which "the regulation of life processes becomes efficient, or even optimal, free-flowing and easy" (Damasio, p. 131).

While there is a growing appreciation of this general understanding in the scientific study of emotion, here we seek to deepen this understanding in three primary ways. First, our approach is based on the premise that the physiological, cognitive, and emotional systems are intimately interrelated through ongoing reciprocal communication. To obtain a deeper understanding of the operation of any of these systems, we believe it is necessary to view their activity as emergent from the dynamic, communicative network of interacting functions that comprise the human organism. Second, we adopt an information processing perspective, which views communication within and among the body's systems as occurring through the generation and transmission of *rhythms and patterns* of psychophysiological activity. This points to a fundamental order of information communication—one that both signifies different emotional states, operates to integrate and coordinate the body's functioning as a whole, and also connects the body to the external world. And third, we draw on the concept of *coherence* from the physics of signal processing to understand how different patterns of psychophysiological activity influence bodily function. Efficient or optimal function is known to result from a harmonious organization of the interaction among the elements of a system. Thus, a harmonious order in the rhythm or pattern of psychophysiological activity signifies a coherent system, whose efficient or optimal function is directly related, in Damasio's terms, to the ease and "fluidity" of life processes. By contrast, an erratic, discordant pattern of activity denotes an incoherent system, whose function reflects the difficulty and "strain" of life processes.

In this article we explore the concept and meaning of coherence in various psychophysiological contexts and describe how coherence within and among the physiological, cognitive, and emotional systems is critical in the creation and maintenance of health, emotional stability, and optimal performance. It is our thesis that what we call emotional coherence—a harmonious state of sustained, self-modulated positive emotion—is a primary driver of the beneficial changes in physiological function that produce improved performance and overall well-being. We also propose that the heart, as the most powerful generator of rhythmic information patterns in the body, acts effectively as the global conductor in the body's symphony to bind and synchronize the entire system. The consistent and pervasive influence of the heart's rhythmic patterns on the brain and body not only affects our physical health, but also significantly influences perceptual processing, emotional experience, and intentional behavior.

There is abundant evidence that emotions alter the activity of the body's physiological systems. Yet the vast majority of this scientific evidence concerns the effects of negative emotions. More recently, researchers have begun to investigate the functions and effects of positive emotions. This research has shown that, beyond their pleasant subjective feeling, positive emotions and attitudes have a number of objective, interrelated benefits for physiological, psychological, and social functioning (Fredrickson, 2002; Isen, 1999).

In contributing to this work, we discuss how sustained positive emotions facilitate an emergent global shift in psychophysiological functioning, which is marked by a distinct change in the rhythm of heart activity. This global shift generates a state of optimal function, characterized by increased synchronization, harmony, and efficiency in the interactions within and among the physiological, cognitive, and emotional systems. We call this state *psychophysiological coherence*. We describe how the coherence state can be objectively measured and explore the nature and implications of its physiological and psychological correlates. It is proposed that the global synchronization and harmony generated in the coherence state may explain many of the reported psychological and physiological health benefits associated with positive emotions.

Our discussion of the major pathways by which the heart communicates with the brain and body shows how signals generated by the heart continually inform emotional experience and influence cognitive function. This account includes a review of previous research on heart–brain interactions and theories regarding how the activity of the heart affects brain function and cognitive performance. We then present research conducted in our laboratory, which brings a new perspective, focusing on the *pattern* of the rhythm of heart activity and its relationship to emotional experience. From this vantage point, we derive a new hypothesis—that sustained, self-induced positive emotions generate a shift to a state of system-wide coherence in bodily processes, in which the coherent pattern of the heart's rhythm plays a key role in facilitating higher cognitive functions.

In short, the science reviewed in this article shows that through regular heart-based practice, it is possible to use positive emotions to shift one's whole psychophysiological system into a state of global coherence. When sustained, the harmonious order of coherence generates vital benefits on all levels and can even transform an individual's life, as we saw in the prologue describing Chris's story.

Theoretical Considerations

We begin by introducing the basic concepts and theoretical ideas that inform the material presented in this article.

Conceptual Framework

Integral to the understanding of psychophysiological interaction developed in this work are the concepts of information and communication. As we will see next, coherence is a particular quality that emerges from the relations among the parts of a system or from the relations among multiple systems. And since relations are constitutive of systems, the communication of information plays a fundamental constructive role in the generation and emergence of coherence. Although the communication of information is largely implicit in the interactional basis of the three basic concepts of coherence we begin with in this conceptual framework, we go onto develop a detailed account of the nature, substance, and dynamics of the psychophysiological interactions between the heart, the brain, and the body as a whole.

Information and Communication

The most basic definition of *information* is data which *in-form*, or give shape to, action or behavior, such as a message that conveys "meaning" to the recipient of a signal (Bradley & Pribram, 1998). In human language, abstract symbols like words, numbers, graphical figures, and even gestures and vocal intonations are used to encode the meaning conveyed in a message. In physiological systems, changes in chemical concentrations, the amount of biological activity, or the pattern of rhythmic activity are common means by which information is encoded in the movement of energy to inform system behavior.

But in order to be used to shape or regulate system behavior, the information must be distributed to and "understood" by the system elements involved. Thus, by *communication* we mean a process by which meaning is encoded as a message and transmitted in a signal to be received, processed, and comprehended by the various elements of a system.

The Concept of Coherence

In this article we describe the relationship between different patterns of psychophysiological activity and physiological, emotional and cognitive functions by drawing on three distinct but related concepts of coherence used in physics; *global coherence, cross coherence* and *auto-coherence*. The most common definition of coherence is "the quality of being logically integrated, consistent and intelligible," as in a coherent argument. A related meaning is "a logical, orderly and aesthetically consistent relationship of parts" (McCraty & Tomasino, 2006, p. 4). In the following discussion we delve deeper into the meaning of coherence.

Coherence in ordinary language means correlation, a sticking together, or connectedness; also, a consistency in the system. So we refer to people's speech or thought as coherent, if the parts fit together well, and incoherent if they are uttering meaningless nonsense, or presenting ideas that don't make sense as a whole (Ho, 1998). Thus, coherence in this context refers to wholeness and a global order: This is coherence as a distinctive organization of parts, the relations among which generate an emergent whole that is greater than the sum of the individual parts. In the example of organizing words in a coherent sentence, the meaning and purpose conveyed by the arrangement of the words is greater than the individual meaning of each word.

It is important to note that all systems, to produce any function or action, must have the property of *global coherence*. The efficiency and effectiveness of the function or action can vary widely, however, and therefore does not necessarily result in a coherent flow of behavior. Global coherence does not mean that everybody or all the parts are doing the same thing at the same time. Think of a jazz band for example, where the individual players are each doing his or her own thing, yet keeping in tune and step with the whole band. Coherence in this sense maximizes local freedom and global cohesion and resonance with the musical theme (Ho, 1998).

In a living system global order or coherence must be sustained and maintained over time. For example, biochemist and geneticist Mae-Wan Ho (1998) has suggested that a whole living system is a domain of coherent, autonomous activity that is coordinated across a continuum from the molecular to macroscopic to social levels.

In physics, the concept of coherence is also used to describe the interaction or coupling among different oscillating systems in which synchronization is the key idea in this concept. Synchronization describes the degree to which two or more waves are either phase or frequency-locked together, or when communication occurs between systems or modes without obstruction.

Returning to the music example, a chord is composed of notes of different frequencies yet resonate as a harmonious order of sound waves. In physiology, coherence is similarly used to describe the degree of coupling and harmonious interaction between two or more of the body's oscillatory systems such as respiration and heart rhythms. There are modes where they are operating at different frequencies, and modes when they become entrained and oscillate at the same frequency. This is also true for brain states in which the brainwaves can be momentarily in phase at different locations across the brain. The term *cross-coherence* is used to specify this type aspect of coherence.

Another example, from a physiological systems perspective, is that people's thoughts, emotions and attitudes can either be aligned and coherent or incoherent. When individuals think one way, feel another, and behave inconsistently, they are in an inefficient and ineffective state-that's non-coherence. A situation adults commonly face illustrates another kind of incoherence. For example, if a child has hit another child and must be taught to be kind to others and that hitting is not acceptable, consider the internal state of an adult in the following two scenarios:

1. The adult who punishes the child with a spanking for hitting another child.
2. The adult who takes time to teach and encourage the child to apologize and render an act of service or kindness to the other child. In this instance, the thoughts, feelings and actions of the adult are in coherent alignment with the message being taught. Then the child is more likely to have a coherent understanding of the lesson being taught.

Another aspect of coherence relates to the dynamics of the flow of action produced by a single system (McCraty & Tomasino, 2006). This is *coherence as a uniform pattern of cyclical behavior*. Because this pattern of action is generated by a single system, the term *auto-coherence* is used to denote this type of coherence. This concept is commonly used in physics to describe the generation of an ordered distribution of energy in a waveform. An example is a sine wave, which is a perfectly coherent wave. The more stable the frequency, amplitude, and shape of the waveform, the higher the degree of coherence. In physiological systems, this type of coherence describes the degree of order and stability in the rhythmic activity generated by a single oscillatory such as the hearts rhythmic activity. When coherence is increased in a single system that is coupled to other systems, it can pull the other systems into coherence or *entrainment*, resulting in increased cross-coherence in the activity of the other systems, even across different time scales of activity. An example of this is in the increased heart-brain synchronization that occurs in a heart coherent mode.

Theory

The material presented in this article is informed by the following theoretical considerations. Our psychophysiological systems process an enormous amount of information, which must be continuously communicated from one part of the brain or body to another and often stored as a memory of one type or another. The traditional approach to understanding how the body’s systems interact adopts an activation perspective, in which variation in the *amount* of a substance or the *amount* of a given physiological activity is viewed as the basis of communication. Although the amount of activity is clearly an important aspect of communication, the generation and transmission of *rhythms and patterns* of physiological activity appear reflective of a more fundamental order of information communication—one that signifies different emotional states and operates to integrate and coordinate the body’s functioning as a whole.

Throughout the body, information is encoded in waveforms of energy as patterns of physiological activity. Neural, chemical, electromagnetic, and oscillatory pressure wave patterns are among those used to encode and communicate biologically relevant information. By these means, the body’s organs continually transmit information to the brain as patterns of afferent (ascending) input. In turn, as we will see below, changes in the patterns of afferent input to the brain cause significant changes in physiological function, perception, cognition, emotion, and intentional behavior.

A primary proposition explored in this article is that different emotions are associated with distinct patterns of physiological activity. This is the result of a two-way process by which, in one direction, emotions trigger changes in the autonomic nervous system and hormonal system, and in the other direction, specific changes in the physiological substratum are involved in the generation of emotional experience. Research at the Institute of HeartMath has identified six distinct patterns of physiological activity generated during different emotional states. We call these *psychophysiological modes*. Each of these is described in detail in Appendix A. Of particular significance is the *psychophysiological coherence* mode, which is characterized by ordered, harmonious patterns of physiological activity. This mode has been found to be generated during the experience of sustained positive emotions. The psychophysiological coherence mode has numerous physiological and psychological benefits, which can profoundly impact health, performance, and quality of life.

A second proposition is that the heart plays a central role in the generation and transmission of system-wide information essential to the body's function as a coherent whole. There are multiple lines of evidence to support this proposition: The heart is the most consistent and dynamic generator of rhythmic information patterns in the body; its intrinsic nervous system is a sophisticated information encoding and processing center that operates independently of the brain; the heart functions in multiple body systems and is thus uniquely positioned to integrate and communicate information across systems and throughout the body; and, of all the bodily organs, the heart possesses by far the most extensive communication network with the brain. As described subsequently, afferent input from the heart not only affects the homeostatic regulatory centers in the brain, but also influences the activity of higher brain centers involved in perceptual, cognitive, and emotional processing, thus in turn affecting many and diverse aspects of our experience and behavior. These are the central ideas that guide what follows.

The Psychophysiological Network: A Systems Perspective

As science has increasingly adopted a systems perspective in investigation and analysis, the understanding has emerged that our mental and emotional functions stem from the activity of *systems*—organized pathways interconnecting different organs and areas of the brain and body—just as do any of our physiological functions. Moreover, our mental and emotional systems cannot be considered in isolation from our physiology. Instead, they must be viewed as an integral part of the dynamic, communicative network of interacting functions that comprise the human organism.

These understandings have led to the emergence and growth of new scientific fields of study, such as psychophysiology. Psychophysiology is concerned with the interrelations among the physiological, cognitive, and emotional systems and human behavior. It is now evident that every thought, attitude, and emotion has a physiological consequence, and that patterns of physiological activity continually influence our emotional experience, thought processes, and behavior. As we will see shortly, the efficacy of this perspective has been substantiated by our own research, as well as that of many others, examining how patterns of psychophysiological activity change during stress and different emotional states.

Heart Rate Variability and Measurement of Psychophysiological Modes

In the early stages of our work at the Institute of HeartMath, we sought to determine which physiological variables were most sensitive to and correlated with changes in emotional states. In analyzing many different physiological measures (such as heart rate, electroencephalographic and electromyographic activity, respiration, skin conductance, etc.), we discovered that the *rhythmic pattern of heart activity* was directly associated with the subjective activation of distinct emotional states, and that the heart rhythm pattern also reflected changes in emotional states, in that it covaried with emotions in real time. We found strong differences between quite distinct rhythmic beating patterns that were readily apparent in the heart rhythm trace and that directly matched the subjective experience of different emotions. In short, we found that the pattern of the heart's activity was a valid physiological indicator of emotional experience and that this indicator was reliable when repeated at different times and in different populations.

In more specific terms, we examined the natural fluctuations in heart rate, known as *heart rate variability* (HRV). HRV is a product of the dynamic interplay of many of the body's systems. Short-term (beat-to-beat) changes in heart rate are largely generated and amplified by the interaction between the heart and brain. This interaction is mediated by the flow of neural signals through the efferent and afferent pathways of the sympathetic and parasympathetic branches of the autonomic nervous system (ANS). HRV is thus considered a measure of neurocardiac function that reflects heart–brain interactions and ANS dynamics.

From an activation theory perspective, the focus is on changes in heart *rate* or in the *amount* of variability that are expected to be associated with different emotional states. However, while these factors can and often do covary with emotions, we have found that it is the *pattern* of the heart's rhythm that is primarily reflective of the emotional state. Furthermore, we have found that changes in the heart rhythm pattern are independent of heart *rate*: one can have a coherent or incoherent pattern at high or low heart rates. Thus, it is the rhythm, rather than the rate, that is most directly related to emotional dynamics and physiological synchronization.

Emotions and Heart Rhythm Patterns

As mentioned at the outset, researchers have spent much time and effort investigating how emotions change the state and functioning of the body's systems. While the vast majority of this body of work has focused on understanding the pathological effects of negative emotions, recent research has begun to balance this picture by investigating the functions and effects of positive emotions.

A synthesis of the voluminous work in developmental neurobiology has shown that the modulation of positive emotions plays a critical role in infant growth and neurological development, which has enormous consequences for later life (Schore, 1994). Other research on adults has documented a wide array of effects of positive emotions on cognitive processing, behavior, and health and well-being. Positive emotions have been found to broaden the scope of perception, cognition, and behavior (Fredrickson, 2001, 2005; Isen, 1999), thus enhancing faculties such as creativity (Isen, 1998) and intuition (Bolte, Goschke, & Kuhl, 2003). Moreover, the experience of frequent positive emotions has been shown to predict resilience and psychological growth, (Fredrickson, Tugade, Waugh, & Larkin, 2003) while an impressive body of research has documented clear links between positive emotions, health status, and longevity (Blakeslee & Grossarth-Maticek, 1996; Danner, Snowdon, & Friesen, 2001; Medalie & Goldbourt, 1976; Moskowitz, 2003; Ostir, Markides, Black, & Goodwin, 2000; Ostir, Markides, Peek, & Goodwin, 2001; Russek & Schwartz, 1997; Seeman & Syme, 1987). In addition, there is abundant evidence that positive emotions affect the activity of the body's physiological systems in profound ways. For instance, studies have shown that positive emotional states speed the recovery of the cardiovascular system from the after-effects of negative emotions (Fredrickson et al., 2000), alter frontal brain asymmetry (Davidson et al., 2003), and increase immunity (Davidson et al.; McCraty, Atkinson, Rein, & Watkins, 1996; Rein, Atkinson, & McCraty, 1995). Finally, the use of practical techniques that teach people how to self-induce and sustain positive emotions and attitudes for longer periods has been shown to produce positive health outcomes. These include reduced blood pressure in both hypertensive and normal populations, (McCraty, Atkinson, Lipsenthal, et al., 2003; McCraty, Atkinson, & Tomasino, 2003) improved functional capacity in patients with heart failure (Luskin, Reitz, Newell, Quinn, & Haskell, 2002), improved hormonal balance, (McCraty, Barrios-Choplin, Rozman, Atkinson, & Watkins, 1998) and lower lipid levels (McCraty, Atkinson, Lipsenthal, et al., 2003).

In investigating the physiological foundation of this important work, we have utilized HRV analysis to show how distinct heart rhythm patterns characterize different emotional states. In more specific terms, we found that underlying the experience of different emotional states there is a distinct physiology directly involved. Thus we have found that sustained positive emotions such as appreciation, care, compassion, and love generate a smooth, sine-wave-like pattern in the heart's rhythms. This reflects increased order in higher-level control systems in the brain, increased synchronization between the two branches of the ANS, and a general shift in autonomic balance towards increased parasympathetic activity. As is visually evident (Figure 1) and also demonstrable by quantitative methods, heart rhythms associated with positive emotions, such as appreciation, are clearly more *coherent*—organized as a stable pattern of repeating sine waves—than those generated during a negative emotional experience such as frustration. We observed that this association between positive emotional experience and this distinctive physiological pattern was evident in studies conducted in both laboratory and natural settings, and for both spontaneous emotions and intentionally generated feelings (McCraty, Atkinson, Tiller, Rein, & Watkins, 1995; Tiller, McCraty, & Atkinson, 1996).

By contrast, our research has shown that negative emotions such as frustration, anger, anxiety, and worry lead to heart rhythm patterns that appear *incoherent*—highly variable and erratic. Overall, this means that there is less synchronization in the reciprocal action of the parasympathetic and sympathetic branches of the ANS (McCraty et al., 1995; Tiller et al., 1996). This desynchronization in the ANS, if sustained, taxes the nervous system and bodily organs, impeding the efficient synchronization and flow of information throughout the psychophysiological systems. Furthermore, as studies have also shown that prefrontal cortex activity is reflected in HRV via modulation of the parasympathetic branch of the ANS (Lane, Reiman, Ahern, & Thayer, 2001), this increased disorder in heart rhythm patterns is also likely indicative of disorder in higher brain systems.

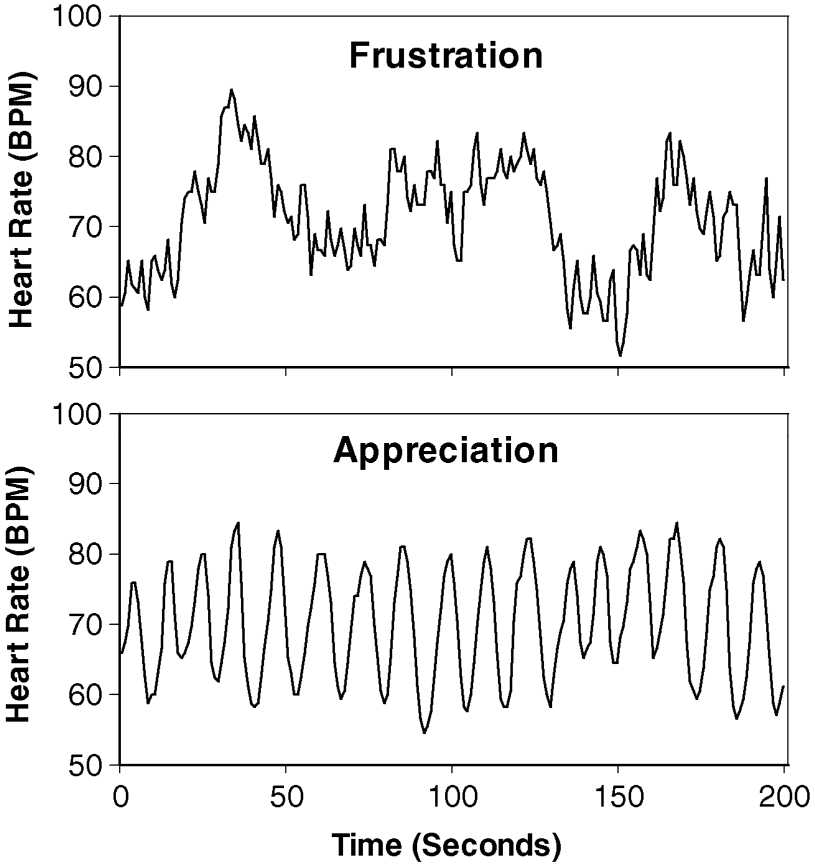


Figure 1. Emotions are reflected in heart rhythm patterns. The heart rhythm pattern shown in the top graph, characterized by its erratic irregular pattern (incoherence), is typical of negative emotions such as anger or frustration. The bottom graph shows an example of the coherent heart rhythm pattern that is typically observed when an individual is experiencing sustained, modulated positive emotions, in this case appreciation.

Psychophysiological Coherence

In our research on the physiological correlates of positive emotions we have found that when certain positive emotional states, such as appreciation, compassion, or love, are intentionally maintained, coherent heart rhythm patterns can be sustained for longer periods, which also leads to increased synchronization and entrainment between multiple bodily systems. Because it is characterized by distinctive psychological and behavioral correlates as well as by specific patterns of physiological activity throughout the body, we introduced the term *psychophysiological coherence*[5] to describe this mode of functioning.

---

[5] In earlier publications (Tiller et al., 1996), the psychophysiological coherence mode was referred to as the “entrainment mode” because a number of physiological systems entrain with the heart rhythm in this mode.

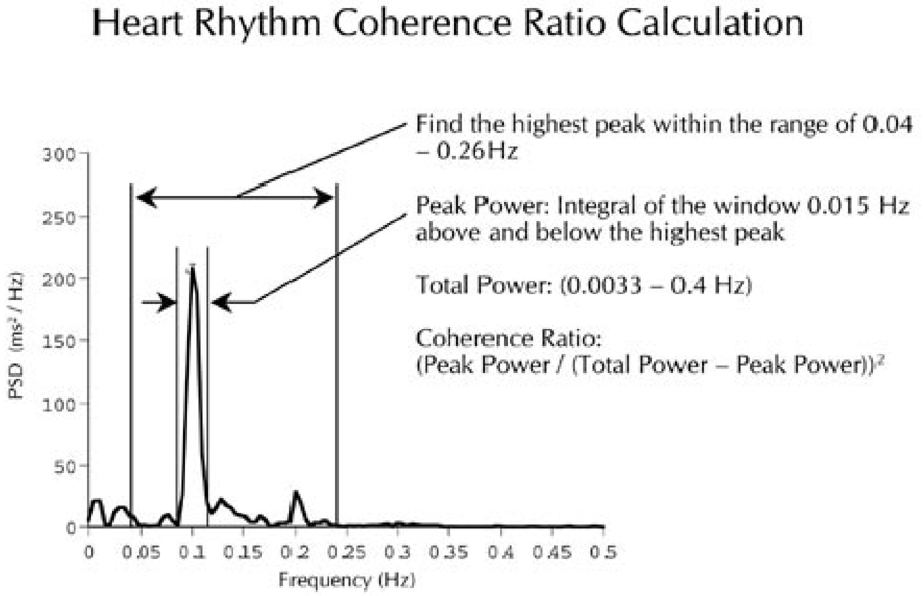
Heart Rhythm Coherence

The development of *heart rhythm coherence*—a stable, sine-wave-like pattern in the heart rate variability waveform—is the key marker of the psychophysiological coherence mode. Heart rhythm coherence is reflected in the HRV power spectrum as a large increase in power in the low frequency (LF) band (typically around 0.1 Hz) and a decrease in the power in the very low frequency (VLF) and high frequency (HF) bands. A coherent heart rhythm can therefore be defined as a relatively harmonic (sine-wave-like) signal with a very narrow, high-amplitude peak in the LF region of the HRV power spectrum and no major peaks in the VLF or HF regions. Coherence thus approximates the LF/(VLF + HF) ratio. (See Appendix A for an explanation of the HRV power spectrum and a description of the physiological significance of the different frequency bands.)

A method of quantifying heart rhythm coherence is shown in Figure 2. First, the maximum peak is identified in the 0.04–0.26 Hz range (the frequency range within which coherence and entrainment can occur). The peak power is then determined by calculating the integral in a window 0.030 Hz wide, centered on the highest peak in that region. The total power of the entire spectrum is then calculated. The coherence ratio is formulated as:

(Peak Power / (Total Power − Peak Power)) (Childre & Martin, 1999)

This method provides an accurate measure of coherence that allows for the nonlinear nature of the HRV waveform over time.


Heart Rhythm Coherence Ratio Calculation

Find the highest peak within the range of 0.04 – 0.26Hz

Peak Power: Integral of the window 0.015 Hz above and below the highest peak

Total Power: (0.0033 – 0.4 Hz)

Coherence Ratio:
(Peak Power / (Total Power – Peak Power))^2

Figure 2. Heart rhythm coherence ratio calculation.

Physiological Correlates

At the physiological level, psychophysiological coherence embraces several related phenomena—autocoherence, entrainment, synchronization, and resonance—which are associated with increased order, efficiency, and harmony in the functioning of the body's systems. As described above, this mode is associated with increased coherence in the heart's rhythmic activity (autocoherence), which reflects increased ANS synchronization and manifests as a sine-wave-like heart rhythm pattern oscillating at a frequency of approximately 0.1 Hz. Thus, in this mode the HRV power spectrum[6] is dominated by a narrow-band, high-amplitude peak near the center of the low frequency band (see Figures 3 below and 8 in Appendix A) (McCraty et al., 1995; Tiller et al., 1996).

Another physiological correlate of the coherence mode is the phenomenon of resonance. In physics, resonance refers to a phenomenon whereby an unusually large oscillation is produced in response to a stimulus whose frequency is the same as, or nearly the same as, the natural vibratory frequency of the system. The frequency of the vibration produced in such a state is defined as the resonant frequency of the system. When the cardiovascular system is operating in the coherence mode, it is essentially oscillating at its resonant frequency; this is reflected in the distinctive high-amplitude peak in the HRV power spectrum around 0.1 Hz. Most mathematical models show that the resonant frequency of the human cardiovascular system is determined by the feedback loops between the heart and brain (Baselli et al., 1994; DeBoer, Karemaker, & Strackee, 1987). In humans and in many animals, the resonant frequency of the system is approximately 0.1 Hz, which is equivalent to a 10-second rhythm. The system naturally oscillates at its resonant frequency when an individual is actively feeling a sustained positive emotion such as appreciation, compassion, or love, (McCraty et al., 1995) although resonance can also emerge during states of deep sleep.

Furthermore, increased heart–brain synchronization is observed during coherence; specifically, the brain's alpha rhythms exhibit increased synchronization with the heartbeat in this mode. This finding is discussed in greater depth in Appendix D.

Finally, there tends to be increased cross-coherence or entrainment among the rhythmic patterns of activity generated by different physiological oscillatory systems. Entrainment occurs when the frequency difference between the oscillations of two or more nonlinear systems drops to zero by being "frequency pulled" to the frequency of the dominant system. As the body's most powerful rhythmic oscillator, the heart can pull other resonant physiological systems into entrainment with it. During the psychophysiological coherence mode, entrainment is typically observed between heart rhythms, respiratory rhythms, and blood pressure oscillations; however, other biological oscillators, including very low frequency brain rhythms, craniosacral rhythms, and electrical potentials measured across the skin, can also become entrained (Bradley & Pribram, 1998; Tiller et al., 1996).

Figure 3 shows an example of entrainment occurring during psychophysiological coherence. The graphs plot an individual's heart rhythm, arterial pulse transit time (a measure of beat-to-beat blood pressure) (Bradley & Pribram, 1998), and respiration rate over a 10-minute period. In this example, after a 300-second normal resting baseline period the subject used a heart-based positive emotion refocusing technique known as Freeze-Frame, (Childre & Martin, 1999) which

---

[6] Spectral analysis decomposes the HRV waveform into its individual frequency components and quantifies them in terms of their relative intensity using power spectral density (PSD) analysis. Spectral analysis thus provides a means to quantify the relative activity of the different physiological influences on HRV, which are represented by the individual oscillatory components that make up the heart rhythm.

involves focusing attention in the area of the heart while self-generating a sincere positive emotion, such as appreciation. After the subject used the Freeze-Frame technique, the three rhythms shifted from an erratic to a sine-wave-like pattern (indicative of the coherence mode) and all entrained at a frequency of 0.12 Hz. (Tiller et al., 1996). The entrainment phenomenon is thus an example of a psychophysiological state in which there is increased coherence within each system (autocoherence) *and* among multiple oscillating systems (cross-coherence) as well. This example also illustrates how the intentional generation of a self-regulated positive emotional state can bring about a phase-shift in physiological activity, driving the physiological systems into a globally coherent mode of function.

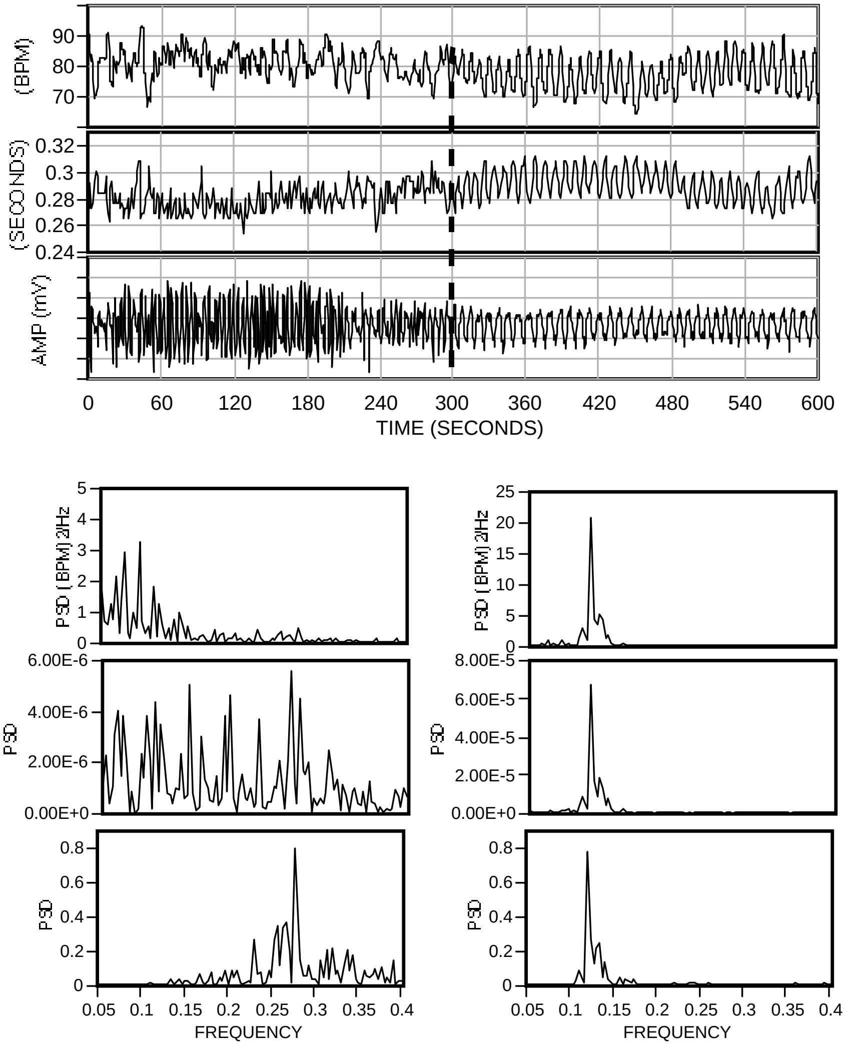


Figure 3. Entrainment. The top graphs show an individual's heart rate variability, pulse transit time, and respiration rhythms over a 10-minute period. At the 300-second mark, the individual used the Freeze-Frame positive emotion refocusing technique, causing these three systems to come into entrainment. The bottom graphs show the frequency spectra of the same data on each side of the dotted line in the center of the top graph. Notice the graphs on the right show that all three systems have entrained to the same frequency.

Psychological and Behavioral Correlates

The experience of the coherence mode is also qualitatively distinct at the psychological level. This mode is associated with reduced perceptions of stress, sustained positive affect, and a high degree of mental clarity and emotional stability. In Appendix C we also present data indicating that coherence is associated with improved sensory-motor integration, cognition, and task performance. In addition, individuals frequently report experiencing a notable reduction in internal mental dialogue, increased feelings of inner peace and security, more effective decision making, enhanced creativity, and increased intuitive discernment when engaging this mode.

In summary, psychophysiological coherence is a distinctive mode of function driven by sustained, modulated positive emotions. At the psychological level, the term "coherence" is used to denote the high degree of order, harmony, and stability in mental and emotional processes that is experienced during this mode. Physiologically speaking, "coherence" is used here as a general term that encompasses entrainment, resonance, and synchronization—distinct but related phenomena, all of which emerge from the harmonious activity and interactions of the body's subsystems. Physiological correlates of the coherence mode include: increased synchronization between the two branches of the ANS, a shift in autonomic balance toward increased parasympathetic activity, increased heart–brain synchronization, increased vascular resonance, and entrainment between diverse physiological oscillatory systems.

Drivers of Coherence

Although the physiological phenomena associated with coherence can occur spontaneously, sustained episodes are generally rare. While specific rhythmic breathing methods may induce heart rhythm coherence and physiological entrainment for brief periods, cognitively directed paced breathing is difficult for many people to maintain for more than about one minute (discussed in detail later). On the other hand, we have found that individuals can intentionally maintain coherence for extended periods by self-generating, modulating, and sustaining a "heart-focused" positive emotional state. Using a positive emotion to drive the coherence mode appears to excite the system at its resonant frequency, and coherence emerges naturally, making it easy to sustain for long periods.

Self-regulation of emotional experience is a key requisite to the intentional generation of sustained positive emotions—the driver of a shift to coherent patterns of physiological activity. Emotional self-regulation involves moment-to-moment management of distinct aspects of emotional experience. One aspect involves the neutralization of inappropriate or dysfunctional negative emotions. The other requires that self-activated positive emotions are modulated to remain within the resonant frequency range of such emotions as appreciation, compassion, and love, rather than escalating into feelings such as excitement, euphoria, and rapture, which are associated with more unstable psychophysiological patterns.

A series of tools and techniques, collectively known as the HeartMath System, provide a systematic process that enables people to self-regulate emotional experience and reliably generate the psychophysiological coherence mode (Childre & Martin, 1999; Childre & Rozman, 2002, 2005). The primary focus of these techniques is on facilitating the intentional generation of a sustained, heart-focused positive emotional state. This is accomplished by a process that combines a shift in attentional focus to the area of the heart (where many people subjectively experience positive emotions) which the self-induction of a positive feeling, such as appreciation. Our work has shown that this shift in focus and feeling experience allows the coherence mode to emerge naturally and helps to reinforce the inherent associations between coherence and positive feelings. Our research also suggests that the intentional application of these coherence-building techniques, on a consistent basis, effectively facilitates a *repatterning process* whereby coherence becomes increasingly familiar to the brain and nervous system, and thus progressively becomes established in the neural architecture as new, stable psychophysiological baseline or set point (McCraty, 2003; McCraty & Childre, 2004; McCraty & Tomasio, 2006). Once the coherence mode is established as the familiar pattern, the system then strives to maintain this mode automatically, thus rendering coherence a more readily accessible state during day-to-day activities, and even in the midst of stressful or challenging situations.

At the physiological level, the occurrence of such a repatterning process is supported by electrophysiological evidence demonstrating a greater frequency of spontaneous (without conscious practice of the interventions) periods of heart rhythm coherence in individuals practiced in the HeartMath coherence-building techniques. Furthermore, a number of studies suggest that this "repatterning" process can produce enduring system-wide benefits that significantly impact overall quality of life (discussed below).

While evidence clearly shows that the HeartMath positive emotion refocusing and emotional restructuring techniques lead to increased psychophysiological coherence, other approaches have also been shown to be associated with increased coherence. For example, in a recent UCLA study, Buddhist monks meditating on generating compassionate love tended to exhibit increased coherence, and another study of Zen monks found that the more advanced monks tended to have coherent heart rhythms, while the novices did not (Lehrer et al., 2003). This does not imply, however, that all meditation approaches lead to coherence; as we and others have observed, approaches that focus attention to the mind (concentrative mediation), and not on a positive emotion, in general do not induce coherence.

Benefits of Psychophysiological Coherence

In terms of physiological functioning, coherence is a highly efficient mode that confers a number of benefits to the system. These include: (1) resetting of baroreceptor sensitivity, which is related to improved short-term blood pressure control and increased respiratory efficiency; (2) increased vagal afferent traffic, which is involved in the inhibition of pain signals and sympathetic outflow; (3) increased cardiac output in conjunction with increased efficiency in fluid exchange, filtration, and absorption between the capillaries and tissues; (4) increased ability of the cardiovascular system to adapt to circulatory requirements; and (5) increased temporal synchronization of cells throughout the body. This results in increased system-wide energy efficiency and metabolic energy savings (Lehrer et al., 2003; Langhorst, Schulz, & Lambertz, 1984; Siegel et al., 1984).

Psychologically, the coherence mode promotes a calm, emotionally balanced, yet alert and responsive state that is conducive to cognitive and task performance, including problem-solving, decision-making, and activities requiring perceptual acuity, attentional focus, coordination, and discrimination. Individuals generally experience a sense of enhanced subjective well-being during coherence due to the reduction in extraneous inner "noise" generated by the mental and emotional processing of daily stress and the positive emotion-driven shift to increased harmony in bodily processes. Many also report increased intuitive clarity and efficacy in addressing troublesome issues in life.

The use of coherence-building interventions has been documented in numerous studies to give rise to significant improvements in key markers of both physical and psychological health. Significant improvements in several objective health-related measures have been observed, including immune system function (McCraty et al., 1996; Rein et al., 1995), ANS function and balance (McCraty et al., 1995; Tiller et al., 1996), and the DHEA/cortisol ratio (McCraty et al., 1998). At the emotional level, significant reductions in depression, anxiety, anger, hostility, burnout, and fatigue and increases in caring, contentment, gratitude, peacefulness, and vitality have been measured across diverse populations (Arguelles, McCraty, & Rees, 2003; Barrios-Choplin, McCraty, & Cryer, 1997; Luskin et al., 2002; McCraty et al., 1998; McCraty, Atkinson, Lipsenthal, et al. 2003; McCraty, Atkinson, & Tomasino, 2001, 2003). Other research has demonstrated significant reductions in key health risk factors (e.g., blood pressure, glucose, cholesterol) (McCraty, Atkinson, Lipsenthal, et al., 2003) and improvements in health status and quality of life in various populations using coherence-building approaches. More specifically, significant blood pressure reductions have been demonstrated in individuals with hypertension (McCraty, Atkinson, & Tomasino); improved functional capacity and reduced depression in patients with congestive heart failure (Luskin et al.); improved glycemic regulation and quality of life in patients with diabetes (McCraty, Atkinson, & Lipsenthal, 2000); and improvements in asthma (Lehrer, Smetankin, & Potapova, 2000). Coherence-building interventions have also been found to yield favorable outcomes in organizational, educational, and mental health settings (Arguelles et al., 2003; Barrios-Choplin et al.; Barrios-Choplin, McCraty, Sundram, & Atkinson, 1999; McCraty et al., 2001; McCraty, Atkinson, Lipsenthal, et al.; McCraty, Atkinson, Tomasino, Goelitz, & Mayrovitz, 1999; McCraty & Childre, 2004; McCraty & Tomasio, 2004).

In short, our findings on psychophysiological coherence essentially substantiate what human beings have known intuitively for thousands of years: namely, that positive emotions not only feel better subjectively, but they also increase the synchronous and harmonious function of the body's systems. This optimizes our health, well-being, and vitality, and enables us to function with greater overall efficiency and effectiveness.

A Typology of Psychophysiological Interaction

In the Appendix A we identify six distinct patterns of HRV, which appear to denote six different modes of psychophysiological interaction. Four of these modes are readily generated in the context of everyday life. We have termed these *Mental Focus*, *Psychophysiological Incoherence*, *Relaxation* and *Psychophysiological Coherence*. Two further modes, *Emotional Quiescence* and *Extreme Negative Emotion*, are generated under more extraordinary life circumstances. This appendix provides empirical data and detailed descriptions for each of these.

Looking more closely at our data, we found a number of empirical clues that point to a more fundamental conceptualization of the relationship between HRV patterns (which include both heart rate and rhythm) and different emotional states. The first clue is that there is a general relationship between coherence and emotional valence, in that positive emotions are associated with physiological coherence and negative emotions with incoherence. The second clue is that, for certain emotions, we found a relationship between the morphology of the HRV waveforms and specific emotional states. The third finding of significance here is that we also found evidence of HRV waveform patterns (namely, those characteristic of the Emotional Quiescence and Extreme Negative Emotion modes) that appear to involve a rapid phase transition into a qualitatively different category of physiological function. In short, the empirical generalization suggested by these findings is that the morphology of HRV waveforms covaries with different emotional experiences.

Following the logic of this general relationship, we can thus use the six psychophysiological modes to construct a typology—a conceptual "map"—showing the expected relationship between different categories of subjective emotional experience and the different patterns of physiological activity associated with them (see Figure 4). This general theoretical scheme applies to normal, healthy individuals experiencing emotions and feelings of relatively short duration (minutes to hours).

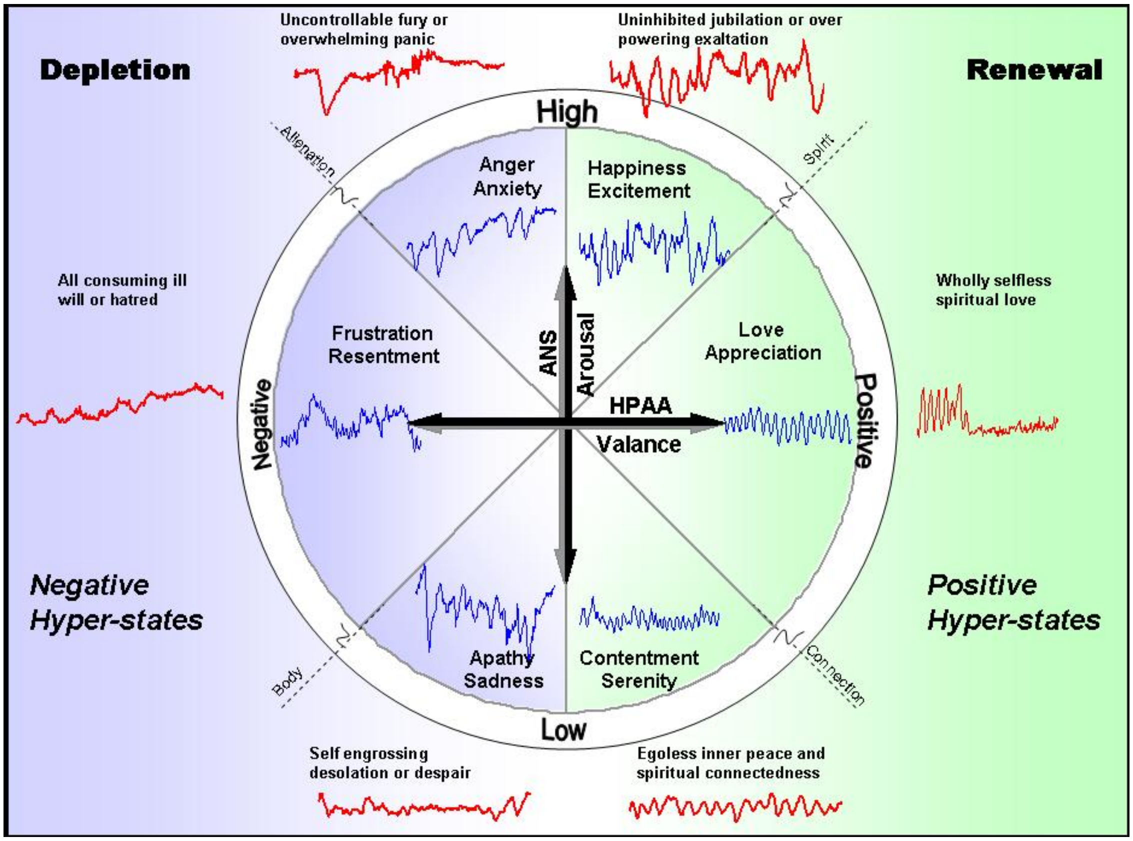


Figure 4. Graphic depiction of everyday states and hyper-states of psychophysiological interaction distinguished by the typology. Two qualitatively different categories of psychophysiological interaction are depicted—the area within the inner circle represents the

range of emotional experience of "normal," everyday life; the area beyond the outer circle represents psychophysiological hyper-states of extreme emotional experience. The psychophysiological transition from one region to another involves an abrupt phase transition, which is depicted graphically by the white space between the two circles. Two dimensions differentiate the varieties of emotional experience shown; for simplification, the relevant psychological and physiological variables are superimposed on the axis for each dimension. One dimension is the degree of *emotional arousal* (vertical axis, high to low)—known to be covariant with ANS balance. The second dimension is the *valence* of the emotion (horizontal axis, positive or negative)—assumed covariant with the degree of activation of the hypothalamic-pituitary-adrenal (HPA) axis. Different patterns of HRV are predicted from the particular combination of arousal and valence values on the two dimensions. Within the inner circle are six segments, each of which demarcates a range of emotion experienced in everyday life. Typical HRV patterns associated with each emotion are shown. The area beyond the outer circle depicts six hyper-states, in which intense emotional experience drives the activity of physiological systems past normal function into extreme modes. The known and predicted HRV waveform patterns associated with these hyper-states are also shown. The labels "Depletion" and "Renewal," on the left and right-hand side of the diagram, respectively, highlight the relationship between the valence of feelings and emotions experienced and the psychophysiological consequences for the individual. Negative emotional states can lead to emotional exhaustion and depletion of physiological reserves. By contrast, positive emotional states are associated with increased psychophysiological efficiency and regeneration.

Although the mapping is not isomorphic between data and concept, the typology provides a compelling and fruitful way of conceptualizing and organizing these phenomena. In addition to offering some understanding of the relationships between different types of emotional experience and their associated physiological processes, this scheme also aims to *predict* the distinguishing physiological correlates of emotional states that, to our knowledge, have yet to be empirically described.

The typology distinguishes between two general classes of psychophysiological interaction. One class reflects "normal" psychophysiological states associated with the variety of subjective experiences of everyday life. This area is represented by the space within the inner circle shown in Figure 4. This area has been divided into six segments, each representing a different basic range of emotion. The second class is a qualitatively different category of psychophysiological interaction associated with extreme emotional experience, represented by the space beyond the outer perimeter of the circle in the figure. Because the patterns of psychophysiological interaction in this space are predicted to show an abrupt movement—a phase shift—from patterns associated with feelings typically experienced in everyday life to qualitatively distinct psychophysiological patterns associated with the experience of extreme positive or extreme negative emotions, well beyond the range of normal feelings, we have labeled them as *hyper*-states. Evidence of such a phase shift can clearly be seen as an abrupt reduction in amplitude and a corresponding increase in frequency in the waveform patterns showing the movement from Psychophysiological Coherence to the Emotional Quiescence, a positive hyper-state (Figure 9, Appendix A) and also in the movement from Psychophysiological Incoherence to Extreme Negative Emotion, a negative hyper-state (Figure 10, Appendix A).

Two dimensions common to the phenomenon of psychophysiological interaction provide the basis for differentiating varieties of emotional experience in the typology. As evident in the term "psychophysiological," there is a psychological element and a physiological element.[7] For purposes of simplification, we have superimposed the relevant psychological and physiological variables on the axis representing each dimension in the figure.[8] One dimension is the degree of *emotional arousal* (high to low), which is known to be covariant with ANS balance. Thus, during short-term emotional experiences, the relative balance between the activity of the sympathetic and parasympathetic branches of the ANS is driven by the degree of emotional arousal. Accordingly, we have mapped emotional arousal and ANS balance together on the vertical axis in Figure 4.

The second dimension is the *valence* (positive or negative) of the emotion, which is represented by the horizontal axis in Figure 4. Again for purposes of simplification, the valence is assumed to be covariant with the degree of activation of the hypothalamic-pituitary-adrenal (HPA) axis, which controls the release of cortisol. For short-term emotional experiences, there is an increase in cortisol during negative emotional states and a decrease in cortisol release during positive emotional states.

HRV patterns can be distinguished on the basis of amplitude, frequency, and degree of coherence. Empirical findings show that the two elements of the psychological dimension in our scheme play a predominant role in determining the characteristics of the HRV pattern. The amplitude of the HRV waveform is modulated by both the degree of emotional arousal (which corresponds to ANS activation) and emotional valence. In general, greater degrees of arousal within normal heart rate ranges produce waveforms of greater amplitude.[9] However, as heart rate increases, the amplitude of the HRV waveform decreases in linear relationship to heart rate until it reaches a point beyond which the amplitude of the HRV waveform is compressed. This is due to a biological constraint known as the cycle-length dependence effect. In terms of emotional valence, the amplitude of the HRV waveform increases during positive emotions, while it decreases during negative emotions. The frequency of the HRV waveform is influenced by the pattern of ANS activation; increased parasympathetic activity leads to higher-frequency (faster) changes in the heart rhythm, while increased sympathetic activity is associated with lower-frequency, higher-amplitude (slower) changes. Finally, the degree of coherence of the HRV waveform is largely determined by the emotional valence, with positive emotion increasing coherence and negative emotion decreasing coherence. Different patterns of HRV can therefore

---

[7] Although the psychological component involves at least three factors for a given emotional experience—emotional arousal, emotional valence, and the degree of cognitive engagement—we have excluded cognitive engagement to avoid the enormous complexity introduced when all three factors are considered simultaneously.

[8] In reality the relationship is much more complicated. While there is a close intra-relationship between each pair of variables on the axis, there are many life circumstances that give rise to a more complex interaction between the emotional and physiological levels.

[9] A secondary modulator of the HRV amplitude is the degree of cognitive engagement. High cognitive engagement tends to reduce HRV, while low cognitive engagement increases HRV. As noted, for purposes of simplification this factor is not considered in this model.

be predicted from the conjunction of the particular combination of arousal and valence values on the two dimensions in our typology.

Following this logic, therefore, each of the six segments within the inner circle in Figure 4 demarcates a range of emotion and its corresponding representative HRV waveform patterns for the variety of emotional experiences that typify everyday life. Organized in terms of degree of arousal and valence, and rotating clockwise around the figure, these are the familiar emotions we experience from day to day. They are labeled: Happiness–Excitement, Love–Appreciation, Contentment–Serenity, Sadness–Apathy, Frustration–Resentment, and Anger–Anxiety. At the center of the circle, in a small area surrounding the intersection of the two axes, is the space of Emotional Impassivity (not labeled in Figure 4). Involving little or no emotional feeling, either positive or negative, emotional impassivity is typically experienced when the individual is mentally engaged in performing a familiar action or routine task. These seven areas within the circle of day-to-day emotional life denote substantively different emotions and feelings subjectively experienced by the individual.

Psychophysiological Hyper-States

Qualitatively distinct from the feelings of daily life are six distinct *psychophysiological hyper-states* reflecting the body's response to extreme emotions. Because these hyper-states involve a phase shift in physiological organization and psychological experience that is discontinuous from the states of normal, everyday emotional life, they are set apart beyond the perimeter of the outer circle in Figure 4.

Generally speaking, the psychophysiological hyper-states are indicative of two quite different directions of movement in bodily processes. As described below, hyper-states involving extreme positive emotions are transcendent states in which the individual's emotional experience involves the feeling of spiritual connectedness to something larger and more enduring beyond themselves. Typically these states are associated with selfless actions and are also generative of bodily renewal. By contrast, hyper-states of extreme negative emotions are all-consuming states of self-absorption and self-focus. These states are usually associated with highly destructive behavior—either directed at the self and/or projected out onto others—and have detrimental, even devastating, consequences. Negative hyper-states lead to a depletion of the body's energy and resources which, in the long term, results in the degeneration of bodily function.

Shown beyond the high end of the arousal axis are two states of hyper-arousal characterized by extreme emotional activation. The extreme emotional activation can result in a loss of self-control, which may lead to unpredictable behavior. It is important to understand that these extreme emotions are associated with the highest level of physiological activation. This drives the heart rate past physiological norms to such a degree that the amplitude of the HRV waveform becomes extremely low.

On the negative side, violent, uncontrollable anger and rage, or overwhelming fear and anxiety are the hyper-aroused emotions experienced here. As already mentioned, we have empirical data documenting the HRV pattern associated with this state (see the waveform pattern showing the movement to "intense anger" in Figure 10, Appendix A). On the positive side, uninhibited rejoicing and jubilation, or overpowering exaltation and ecstasy are predicted, in the absence of any empirical data documenting this hyper-state. We believe it is this psychophysiological state that is accessed during collective rituals that lead to trance states and spiritual rapture. It also may be possible to enter this state from hyper-aroused, uncontrolled positive emotions that induce a positive hysteria, such as can result from an unexpected, overwhelmingly positive event—for example, reuniting with a loved one who was in a life-threatening situation.

At the low end of the arousal axis are two states of hypo-arousal, the complement to the two states of hyper-arousal we have just described. On the positive side, the individual experiences an ego-less feeling of profound inner peace and deep spiritual connectedness. Typically, this state is accessed by self-disciplined meditative and spiritual practice. Physiologically, the emotional experience of this state of extremely low arousal is characterized by HRV waveform patterns of very low amplitude with some degree of coherence, reflecting the body's state of complete calm and rest.

On the negative side, individuals can enter a state of hypo-arousal when they have been in an enduring negative emotional state (weeks to months). This is a state of self-engrossing desolation and despair and is accompanied by obsessive negative mental and emotional activity, such as that experienced in prolonged grief or long-term depression. However, an episode of severe trauma or negative emotion can rapidly propel an individual into this state. Either way, this can result in a depletion of physiological reserves, which is in turn reflected in a very low-amplitude HRV waveform. Often, individuals in this hypo-state are emotionally numb and socially alienated or withdrawn.

If this state is sustained on a long-term basis, there is further depletion of both the sympathetic and parasympathetic systems. In the first stages of this process, sympathetic activity becomes substantially reduced, resulting in an autonomic imbalance. As the process continues, parasympathetic activity (vagal tone) is correspondingly reduced. The process culminates with a phase-transition into exhaustion and breakdown.

Between the four states of extreme hyper-arousal and extreme hypo-arousal in the mid-range of emotional arousal, are two other states of extraordinary emotional experience. On the positive side, there is the state of wholly self-less spiritual love in which the individual experiences a deep feeling of all-embracing "big love"—*Agape*, as defined by the dictionary: a love that is open to and non-judgmental about all perceptions, cognitions, and intuitions. To enter this hyper-state requires a deep, heart-focused, self-less love, which can be associated with contemplative introspection. This hyper-state is accessed via a phase transition when this deep heart-focused introspection is sustained for a few minutes or more. This state is experienced as a substantial reduction in mental and emotional "chatter" to a point of internal quietness, often associated with a profound feeling of peace and serenity. This is the phase space within which the Emotional Quiescence mode falls. We also expect this hyper-state to be associated with other types of emotional experience that may have a spiritual dimension, such as those accessed by a number of introspective disciplines and practices.

Physiologically, there are two likely mechanisms to explain how this hyper-state occurs. One is that, in this state, the sympathetic and parasympathetic outflow from the brain to the heart is substantially reduced—reduced to such a degree that the amplitude of HRV waveform becomes very low. The other logical possibility is that the heart acts as an antenna to a field of information beyond space and time surrounding the body that directly informs the heart and modulates its rhythmic patterns. As astounding as this may sound, there is compelling evidence from our study of the electrophysiology of intuition that points in this direction (McCraty, Atkinson, & Bradley, 2004a, 2004b).

On the negative side, there is a hyper-state in which the individual is consumed by powerful malevolent feelings of extreme ill-will and hatred. These ego-centric feelings occupy virtually all of the individual's time and energy and engage one's whole attention. Typically, these feelings of evil and harm are not directed inwards against the self, but, instead, are projected outwards to be expressed as an intense pathological desire to cause great pain and suffering to others. Sustained, fanatical feelings of ill-will toward others can propel an individual into this hyper-state. Subjectively, there is a substantial reduction in mental and emotional "chatter" and a correspondingly heightened state of calm, malevolent feelings. The emotional calm reflects the individual's disassociation from the humanity of others and the total acceptance of the all-consuming negative thoughts and emotions experienced in this state. We expect this hyper-state to be one that can be entered by individuals who hold fanatical beliefs based on extreme negative stereotypes or caricatures of others. This is often the case with radical groups on the margins of society who see themselves suffering a great injustice or harm from the hands of those they hate.

Physiologically, this hyper-state likely involves a zombie-like state in which there is such emotional disassociation that the amplitude of HRV waveform becomes very low but with some variability spikes which may reflect the individual's momentary transitions between different emotions.

To conclude, the typology provides a more general conceptual framework from which to view the six modes of psychophysiological interaction we identified in our empirical studies. We have found the typology a useful way of conceptually organizing the broad range and highly variable phenomena in this domain. It will be up to future research to test the degree to which the typology offers a fruitful map of the nature and organization of the different types of emotional–physiological interaction.

Heart Coherence and Psychophysiological Function

So far, we have discussed how changes in the patterns of neural activity can encode and transmit information in the psychophysiological networks independent of changes in the amount of activity and how this level of information processing may well play a more fundamental role in information exchange than changes in the amount and/or intensity of neural activity. In this section we will see that increased coherence is associated with favorable changes in various aspects of physiological function, which in turn are associated with psychological benefits. We introduce this discussion by describing how the amount of information traveling through the afferent nerves increases during coherence, and we then examine the role that cardiac afferent input plays in the neural pathways involved in pain perception, respiratory function, emotional processing, and cognitive performance.

Vagal Afferent Traffic

The vagus nerve is a major conduit though which afferent neurological signals from the heart and other visceral organs are relayed to the brain. Psychophysiologist Paul Lehrer has shown that by using heart rhythm feedback to facilitate a state of physiological coherence (which he calls "resonance"), a lasting increase in baroreflex gain[10] is accomplished independent of respiratory and cardiovascular changes, thus demonstrating neuroplasticity of the baroreflex system (Lehrer et al., 2003). This shift in baroreflex gain indicates that with repeated episodes of coherence, the activation threshold of some of the mechanosensory neurons in the baroreflex system is reset and, as a result, these neurons increase their output accordingly.

In addition, a basic property of mechanosensory neurons is that they generally increase their output in response to an increase in the *rate of change* in the function they are tuned to (heart rate, blood pressure, etc.). During heart rhythm coherence, there is an increase in beat-to-beat variability in both heart rate and blood pressure, which is equivalent to an increase in the rate of change. This results in an increase in the vagal afferent traffic sent from the heart and cardiovascular system to the brain. With regular practice in maintaining the coherence mode, it is likely that increased vagal afferent traffic would also be observed even when one is not in this mode. This is due to the fact that the mechanosensory neurons' threshold is reset as a result of the coherence-building practice, thus establishing a new baseline level of afferent traffic.

Generating an increase in vagal afferent traffic through noninvasive approaches such as heart-based emotion refocusing techniques and heart rhythm coherence feedback has a number of potential benefits. In recent years, a number of clinical applications for increasing vagal afferent traffic have been found; however, the increase in afferent activity is usually generated by implanted or external devices that stimulate the vagal afferent pathways, typically in the left vagus nerve. Vagal stimulation is an FDA-approved treatment for epilepsy and is currently under investigation as a therapy for obesity, depression, anxiety, and Alzheimer's disease (Groves & Brown, 2005; Kosel & Schlaepfer, 2003). It has been established that an increase in the normal intrinsic levels of vagal afferent traffic inhibits the pain pathways traveling from the body to the thalamus at the level of the spinal cord (discussed below) and a recent study has found that stimulation of the afferent vagal pathways significantly reduces cluster and migraine headaches (Mauskop, 2005). Vagal nerve stimulation has also been shown to improve cognitive processing and memory (Hassert, Miyashita, & Williams, 2004)—findings that are consistent with those of several recent studies of individuals using heart rhythm coherence-building techniques (discussed later in this article).

---

[10] Baroreflexes are homeostatic reflexes that regulate blood pressure. Through them, increases in blood pressure produce decreases in heart rate and vasodilation, while decreases in blood pressure produce the opposite. Baroreflex gain is commonly calculated as the beat-to-beat change in heart rate per unit of change in blood pressure. Decreased baroreflex gain is related to impaired regulatory capacity and aging.

Pain Perception

Afferent signals from the heart modulate the neural pathways involved in the perception of pain. Numerous reports from individuals using the HeartMath coherence-building techniques indicate that they are able to greatly reduce their experience of bodily pain, often to a point where they can reduce or eliminate pain medications. This is true of both visceral and cutaneous pain. The HeartMath system is currently employed by numerous clinicians as a pain management aid, and has proven effective in patients with a wide range of conditions, including chronic joint pain, serious burns, and traumatic brain injury. The generation of increased vagal afferent activity during the coherence mode provides a likely mechanism to account for the reduction of pain associated with increased heart rhythm coherence.

Several mechanisms have been identified that explain how increased vagal afferent activity decreases pain sensitivity and increases pain threshold. Nociceptive information (pain signals) from the skin and internal organs is carried to cell bodies located in the dorsal root ganglia of the spinal cord. Axons from neurons in the dorsal root ganglia penetrate the spinal cord and convey afferent pain information to localized regions of the gray matter in the cord. From there, afferent information ascends in pathways to both the lateral and medial thalamus. Cells of the lateral thalamus in turn project to the primary somatosensory cortex, where the location, intensity, and duration of the painful stimulus are analyzed. Information is sent from the medial thalamus to the insular cortex, amygdala, and cingulate gyrus, where motivational-affective components of pain, including autonomic adjustments, occur. This pathway is called the spinothalamic tract (STT) and, although not the only pain pathway, it is the main and most studied system that transmits visceral sympathetic afferent pain information to the brain (Foreman, 1989).

Afferent fibers in the vagus nerve participate in the modulation of pain partly by modulating the flow of pain signals in the STT. An increase in afferent vagal activity causes a general inhibitory effect at most levels of the spinal cord on neurons that transmit nociceptive information to the thalamus and then to areas of the brain involved in pain perception. Vagal afferent fibers terminate primarily in the caudal medulla of the brain stem and nucleus tractus solitarius (NTS), and evidence shows that suppression of spinal neuronal activity is dependent upon the NTS connections. It has been demonstrated that the cardiac branch of the vagus nerve makes up the major contribution for the inhibitory responses on the spinal pain signals and that left vagal stimulation suppresses approximately 60% of the STT cells. Thus, the predominant effect of increased vagal afferent activity, which is associated with increased coherence, is the suppression of somatic and visceral input to STT cells, which provides a mechanism for decreasing pain (Foreman, 1994, 1997).

Respiration

It is well known that the respiratory rhythm modulates the pattern of the heart rhythm. This breath-related modulation of the heart rhythm is called respiratory sinus arrhythmia (RSA) (Hirsh & Bishop, 1981). RSA reflects the complex interaction of central respiratory drive, autonomic afferent signals, efferent outflow from the brain stem, and respiratory mechanics within the thorax. The phenomenon is dependent on the frequency and amplitude of respiration as well as on the underlying autonomic state of the organism.[11]

Since we have conscious control over our breathing, cognitively-directed breathing exercises can be used to *impose* a breathing rhythm on the heart rhythms. Thus, when we breathe at a slow, rhythmic rate (five seconds in and then five seconds out), we can facilitate coherence and entrainment. However, we do not normally think about our breathing. It is automatic; our breathing depth and rate varies without our conscious awareness due to changes in the inputs to the respiratory centers in the brain stem that control respiration.

Among these inputs is the afferent neurological information from the heart and cardiovascular system. Our breathing rate is affected by and often synchronized to the cardiac cycle, which means that changes in our heart rate and rhythm can affect our breathing rate and patterns.[12] During sleep or rest, coupling between the cardiac cycle and respiration is the strongest, and at times of stress, coupling between the heart and respiration becomes disrupted (Langhorst, Schulz, & Lambertz, 1986; Raschke, 1986a, 1986b; Turpin, 1986).

It is well established that changes in emotional states also alter breathing rates. Agitated states such as anger and frustration increase the breathing rate and reduce tidal volume (the depth of the breath), while positive emotional states slow the breathing rate and increase tidal volume. These emotion-related changes in breathing are likely to result, at least in part, from changes in input from the cardiovascular centers.

Because respiration modulates the heart rhythm, it can be intentionally used as a powerful intervention that can have quick and profound body-wide effects. As we have conscious control over our breathing rate and depth, we can consciously modulate the heart rhythm and thus change the afferent neural patterns sent to the brain centers that regulate autonomic outflow, emotion, and cognitive processes. Our experience with breathing exercises is that they are effective primarily due to the fact that they modulate the heart's rhythmic patterns.

However, it is important to emphasize that coherence is associated with positive emotions *independent* of conscious alterations in one's breathing rhythm. In our earlier studies, which were focused on the physiological correlates of different emotional states, instructions to subjects purposely made no mention of altering breathing rates or depths. We found that when sustained positive emotional states were maintained, increased heart rhythm coherence and entrainment

---

[11] The effects of lung inflation are mediated by sensory neurons in the lungs that respond to stretch. These neurons increase their firing rate as the lungs expand upon inspiration. The output from these neurons travels to the brain stem and inhibits the parasympathetic outflow from the brain to the heart, resulting in an increase in heart rate. During expiration, the stretch is reduced and the inhibition is removed. The heart rate is quickly reduced. This interaction between the lungs and brain stem is only one source of RSA; however, it provides an easy way to conceptualize RSA.

[12] The influence of afferent information from the heart on respiration was studied in great detail in the 1940s and 1950s. The cardiovascular afferent systems excite the respiratory centers, and if this input is inhibited, so is respiration. For a review of this earlier research, see Chernigovskiy (1967).

between the heart rhythm, blood pressure rhythms, and respiratory rhythms emerged independent of any conscious alterations in breathing pattern (McCraty et al., 1995; Tiller et al., 1996).

Although breathing techniques may sometimes facilitate a feeling shift, coherence that is driven through the use of such techniques alone does not necessarily shift one's emotional state. For example, it is possible to breathe at a rate of six breaths per minute (a 10-second rhythm) and still be feeling anxiety or other feelings of unease. In addition, many people find it difficult to consciously maintain breathing rates at a 10-second rhythm for more than about a minute. On the other hand, by focusing attention on self-generating a positive emotion while pretending to "breathe" this feeling through the area of the heart in a relaxed manner, smooth, coherent heart rhythm patterns occur naturally and are easier to sustain for longer periods of time. This has the added benefit of not only establishing coherence as the familiar pattern, but also strengthening the connection between the constituent physiological patterns of coherence—of which heart rhythm is key—and the positive feeling state.

Emotional Processing

Afferent input from the heart, and, in particular, the pattern of the heart's rhythm, also plays a key role in emotional experience. As described previously, our research suggested a fundamental link between emotions and changes in the *patterns* of both efferent and afferent autonomic activity, as well as changes in ANS activation, which are clearly reflected in changes in the heart rhythm patterns. The experience of negative emotions is reflected in more erratic or disordered heart rhythms, indicating less synchronization in both the activity of brain structures that regulate parasympathetic outflow and in the reciprocal action between the parasympathetic and sympathetic branches of the ANS. In contrast, sustained positive emotions are associated with a highly ordered or *coherent* pattern in the heart rhythms, reflecting greater overall synchronization in these same systems.

It is important to emphasize, however, that the heart's rhythmic beating patterns not only *reflect* the individual's emotional state, but they also play a direct role in *determining* emotional experience. At the physiological level, as shown in Figure 5, afferent input from the heart is conveyed to a number of subcortical regions of the brain that are involved in emotional processing, including the thalamus, hypothalamus, and amygdala. Moreover, cardiac afferent input has a significant influence on the activity of these brain centers (Adair & Manning, 1975; Cameron, 2002; Foreman, 1997; Frysinger & Harper, 1990; Oppenheimer & Hopkins, 1994; Zhang, Harper, & Frysinger, 1986). For example, activity in the amygdala has been found to be synchronized to the cardiac cycle (Frysinger & Harper, 1990; Zhang et al.). These understandings support the proposition that afferent information from the heart is directly involved in emotional processing and emotional experience.

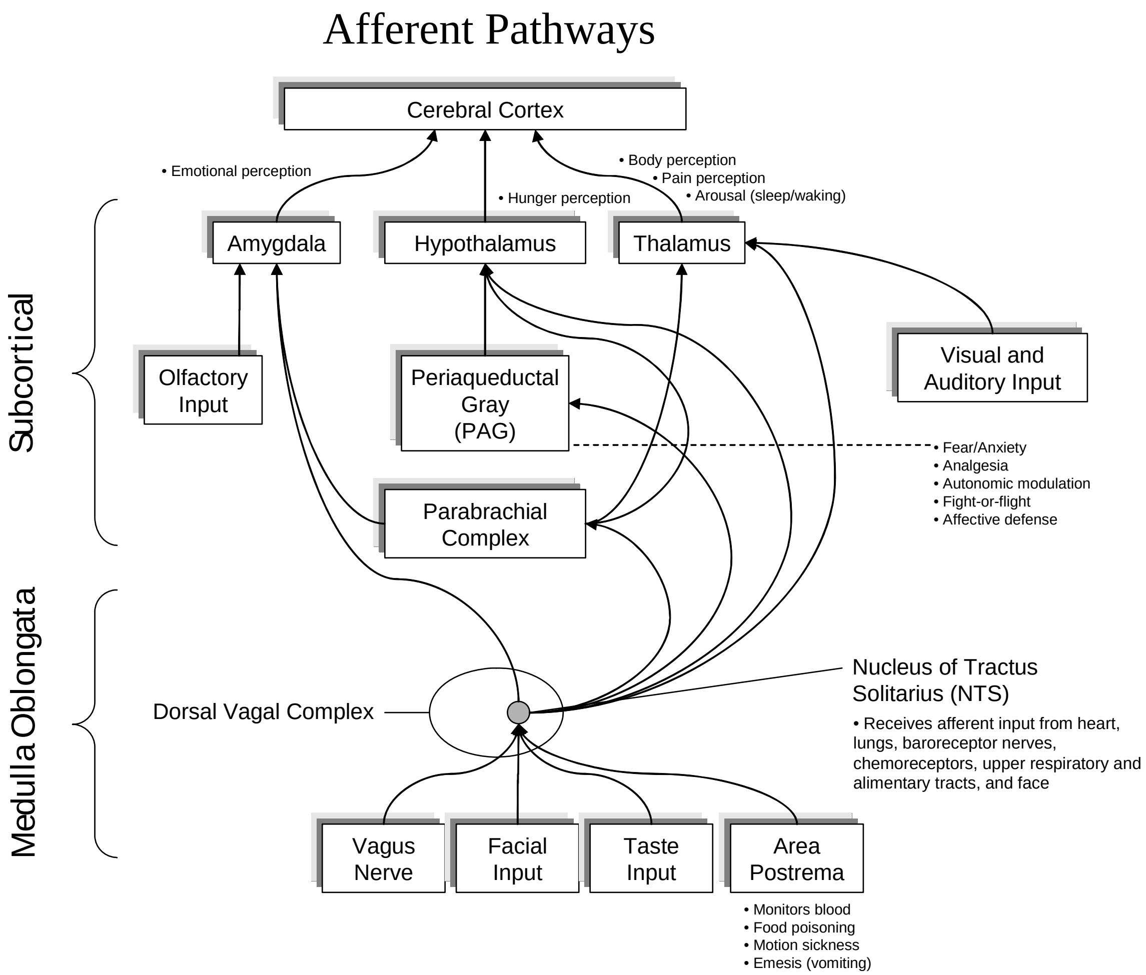


Figure 5. Diagram of the currently known afferent pathways by which information from the heart and cardiovascular system modulates brain activity. Note the direct connections from the NTS to the amygdala, hypothalamus, and thalamus. Although not shown, there is also evidence emerging of a pathway from the dorsal vagal complex that travels directly to the frontal cortex.

These findings and those from our own research led us to ponder the fundamental physiological significance of the covariance between the heart's rhythms and changes in emotion. This question was especially intriguing in light of current views in neuroscience that the contents of feelings are essentially the configurations of body states represented in somatosensory maps (Cameron, 2002; Damasio, 2003). This was of course the essence of the theory of emotion first proposed by William James (1884), which has been refined by many researchers over the years.

A useful way of understanding how the heart is involved in the processing of emotional experience is to draw on Pribram's theory of emotion (Pribram & Melges, 1969). In this theory, the brain is viewed as a complex pattern identification and matching system. Pribram's basic concept is that of a "mismatch" between familiar input patterns and current input patterns that are different or novel. It is this mismatch that provides the mechanism by which feelings and emotions are generated.

According to Pribram's model, past experience builds within us a set of familiar patterns, which are instantiated in the neural architecture. Inputs to the brain from both the external and internal environments contribute to the maintenance of these patterns. Within the body, many processes provide constant rhythmic inputs with which the brain becomes familiar. These include the heart's rhythmic activity; digestive, respiratory and hormonal rhythms; and patterns of muscular tension, particularly facial expressions. These inputs are continuously monitored by the brain and help organize perception, feelings and behavior.

Familiar input patterns form a stable backdrop, or reference pattern, against which new information or experiences are compared. When an input pattern is sufficiently different from the familiar reference pattern, a *"mismatch"* occurs. This mismatch, or *departure from the familiar pattern*, is what underlies the generation of feelings and emotions. In physiological terms, Pribram suggests that the low-frequency oscillations generated by the heart and bodily systems are the carriers of emotional information, and that the higher frequency oscillations found in the EEG reflect the integration, perception, and labeling of these body states along with perception of sensory input from the external environment. The mismatch between a familiar pattern and a pattern that is new or novel in either of these informational inputs is what activates emotional changes (McCraty, 2003; McCraty & Tomasio, 2006).

Although inputs originating from many different bodily organs and systems are involved in the processes that ultimately determine emotional experience, it is now abundantly clear that the heart plays a particularly important role. The heart is the primary and most consistent source of dynamic rhythmic patterns in the body. Furthermore, the afferent networks connecting the heart and cardiovascular system with the brain are far more extensive than the afferent systems associated with other major organs (Cameron, 2002). Additionally, the heart is particularly sensitive and responsive to changes in a number of other psychophysiological systems. For example, heart rhythm patterns are continually and rapidly modulated by changes in the activity of either branch of the ANS, and the heart's extensive intrinsic network of sensory neurons also enables it to detect and respond to variations in hormonal rhythms and patterns (Armour, 1994). In addition to functioning as a sophisticated information processing and encoding center, (Armour & Kember, 2004) the heart is also an endocrine gland that produces and secretes hormones and neurotransmitters (Cantin & Genest, 1985, 1986; Gutkowska, Jankowski, Mukaddam-Daher, & McCann, 2000; Huang et al., 1996; Mukoyama et al., 1991). As we will see later, with each beat, the heart not only pumps blood, but also continually transmits dynamic patterns of neurological, hormonal, pressure, and electromagnetic information to the brain and throughout the body. Therefore, the multiple inputs from the heart and cardiovascular system to the brain are a major contributor in establishing the dynamics of the familiar baseline pattern or set point against which the current input of "now" is compared.

A striking example illustrates the extensiveness of the influence of cardiac afferent input on emotional experience as well as the operation of the mismatch mechanism. Research shows that psychological aspects of panic disorder are actually frequently created by an unrecognized cardiac arrhythmia. One study found that DSM-IV criteria for panic disorder were fulfilled in more than two-thirds of patients with sudden-onset arrhythmias. In the majority of cases, once the arrhythmia was discovered and treated, the symptoms of panic disorder disappeared (Lessmeier et al., 1997). When the heart rate variability patterns of such an arrhythmia are plotted, the erratic, incoherent waveform appears quite similar to the heart rhythm pattern produced during strong feelings of anxiety in a healthy person. Because the sudden, large change in the pattern of afferent information is detected by the brain as a mismatch relative to the stable baseline pattern to which the individual has adapted, it consequently results in feelings of anxiety and panic.

The above example illustrates the immediate and profound impact that changes in the heart's rhythmic activity can have on one's emotional experience. In this example—as is usually the case—such changes occur unconsciously. One of the most important findings of our research, however, is that changes in the heart's rhythmic patterns can also be *intentionally generated*. This shift in the heart's rhythmic patterns is one of the physiological correlates of using the HeartMath positive emotion-based coherence-building techniques, which couple an intentional shift in attention to the physical area of the heart with the self-induction of a positive emotional state. We have found that this process rapidly initiates a distinct shift to increased coherence in the heart's rhythms. This, in turn, results in a change in the pattern of afferent cardiac signals sent to the brain, which serves to *reinforce* the self-generated positive emotional shift, making it easier to sustain. Through the consistent use of the coherence-building techniques, the coupling between the psychophysiological coherence mode and positive emotion is further reinforced. This subsequently strengthens the ability of a positive feeling shift to initiate a beneficial physiological shift towards increased coherence, or a physiological shift to facilitate the experience of a positive emotion.

While the process of activating the psychophysiological coherence mode clearly leads to immediate benefits by helping to transform stress in the moment it is experienced, it can also contribute to long-term improvements in emotion regulation abilities and emotional well-being that ultimately affect many aspects of one's life. This is because each time individuals intentionally self-generate a state of psychophysiological coherence, the "new" coherent patterns—and "new" repertoires for responding to challenge—are reinforced in the neural architecture. With consistency of practice, these patterns become increasingly familiar to the brain. Thus, through a feed-forward process, these new, healthy patterns become established as a new baseline or reference, which the system then strives to maintain. It is in this way that HeartMath tools facilitate a *repatterning process*, whereby the maladaptive patterns that underlie the experience of stress are progressively replaced by healthier physiological, emotional, cognitive, and behavioral patterns as the "automatic" or familiar way of being (McCraty & Tomasio, 2006).

Coherence and Cognitive Performance

It is now generally accepted that the afferent neurological signals the heart sends to the brain have a regulatory influence on many of the ANS signals that flow from the brain to the heart, to the blood vessels, and to other glands and organs. However, it is less commonly appreciated that these same cardiovascular afferent signals involved in physiological regulation *also* cascade up into the higher centers of the brain and influence their activity and function. Of particular significance is the influence of the heart's input on the activity of the cortex—that part of the brain that governs thinking and reasoning capacities. As we will see, depending on the nature of the heart's input, it can either inhibit or facilitate working memory and attention, cortical processes, cognitive functions, and performance (Hansen, Johnsen, & Thayer, 2003; Lacey & Lacey, 1974; Rau, Pauli, Brody, Elbert, & Birbaumer, 1993; Sandman, Walker, & Berka, 1982; van der Molen, Somsen, & Orlebeke, 1985).

Our research on psychophysiological coherence has provided new insight into the relationship between heart activity and cognitive performance. The context for this is described in detail in Appendix B. It describes how psychophysiologists John and Beatrice Lacey's baroreceptor hypothesis identified a relationship between the heart's activity and cognitive performance. This work was furthered by Christoph Wölk and Manfred Velden in Germany, who identified the importance of heart rate's *pattern* and *stability* in influencing neurological functioning. Although we agree with Wölk and Velden's conclusions, the primary focus of previous work in this area has been on *micro-scale* temporal patterns of cardiac activity, occurring within a single cardiac cycle, or, at most, across 3–4 heartbeats. However, the interactions between the heart and brain are much more complex and also occur over longer time periods (sequences of heartbeats occurring over seconds to minutes). Based on the evidence we report below, we believe that patterns of the heart's rhythmic activity over a longer time scale are also involved in influencing cognitive performance. Moreover, it appears that these *macro-scale* temporal patterns of cardiovascular afferent activity can have a much greater effect on performance than micro-scale patterns. Therefore, a broader hypothesis is called for.

The Heart Rhythm Coherence Hypothesis: A Macro-Scale Perspective

In the course of conducting our studies, we had received numerous reports from individuals able to maintain the psychophysiological coherence mode that their performance in various activities had noticeably improved. These involved faculties and abilities requiring the processing of external sensory information (e.g., speed and accuracy, coordination, and synchronization, such as in sports and the performing arts) as well as processes requiring primarily internal focus (e.g., problem solving, decision making, creativity, and intuition, such as in business and intellectual activities). This led us to postulate that psychophysiological coherence and the associated *macro-scale* patterns of the temporal organization of the heart's rhythmic activity—heart rhythm patterns occurring over seconds to minutes—also have an important effect on cognitive processes and intentional behavior. Focusing on the nature of the organization of the heart's rhythmic activity, which reflects emotional state, we hypothesize that emotion-driven changes in global psychophysiological function, and the resulting change in the pattern of heart rhythm activity, are also directly related to the facilitation or inhibition of the brain processes involved in cognitive function. In specific terms, sustained positive emotions induce psychophysiological coherence, which, in turn, is reflected in increased heart rhythm coherence. Thus, the greater the degree of emotional stability and system-wide coherence, the greater the facilitation of cognitive and task performance. We call this hypothesis the *heart rhythm coherence hypothesis*.

A number of research projects have been carried out to test this hypothesis. Appendix C describes three studies that show evidence supporting the hypothesis. The first showed that macro-scale patterns of cardiac activity can produce a larger effect on the inhibition/facilitation of cognitive performance than the much smaller inhibition/facilitation fluctuations in performance observed by Wölk and Velden. It found an approximately *six times* greater improvement in performance than previous studies involving similar methods. The second was an independent study conducted in the UK by Dr. Keith Wesnes, who concluded that learning and practicing the HeartMath positive emotion-focused coherence-building techniques appears to enhance an individual's memory capacity and also improves self-reported calmness. The third study was funded by the U.S. Department of Education and carried out with the cooperation of the Claremont Graduate University's School of Educational Studies involving tenth grade students in two large California high schools. It found significant reduction in test anxiety as well as higher test scores for students who learned the positive emotion-focused coherence-building techniques in the TestEdge program.

Overall, the evidence provided by the three studies described in Appendix C indicates that a specific macro-scale pattern of cardiac activity—heart rhythm coherence—is associated with significant improvement in cognitive performance. Not only is this outcome observed in a simple reaction time experiment, but the data suggest that this facilitative effect also extends across more complex domains of cognitive function, including memory and even academic test performance. It also appears that the influence of the coherence mode on cognitive performance is substantially larger in magnitude than that previously documented for changes in cardiac activity patterns on a micro scale.

Assuming these results are validated by other researchers, it is worth considering the likely pathways and mechanisms that could explain these findings. This entails developing an explanation that complements the micro-pattern hypotheses of the Laceys and Wölk and Velden, by identifying other physiological mechanisms that may account for these results. The micro-pattern hypothesis presents a somewhat simplified view of heart–brain interactions, which is not adequate to describe the full range of information communication that takes place between the heart and brain: it only addresses the smaller fluctuations in performance that are associated with physiological changes occurring within a single cardiac cycle or across several heartbeats. As we have seen, however, there are macro-scale temporal patterns that have a significant carry-over effect on cognitive performance. To build an adequate understanding of the physiological mechanisms involved requires developing a deeper understanding of the complexity of heart–brain interactions. This is reflected in the discussion below in three primary ways: first, that the influence of cardiovascular afferent input on the brain is more elaborate than that considered in the micro-pattern hypothesis; second, that afferent input from the heart has effects on brain centers other than the thalamus; and third, that the alpha rhythm is not the only brain rhythm synchronized to the heart.

A More Complex Picture

Complexity of Cardiac Afferent Signals

One of the underlying assumptions of the micro-pattern hypothesis is that there is a one-to-one correspondence between each heartbeat and the burst of neural activity sent to the brain from the cardiac mechanosensory neurites. However, at the level of the macro-scale heart–brain interactions investigated here, the dynamics of the generation and transmission of cardiovascular afferent input involve many types of neurons and a multiplicity of pathways operating over different time scales.

There are approximately 40,000 sensory neurites in the human heart involved in relaying afferent information to the brain. Of these, just 20% are mechanosensory neurons. Of this 20%, only a small proportion actually fire in unison with each heartbeat. Moreover, there are at least five different types of mechanosensory neurons. Almost all mechanosensory neurons are sensitive to rate of change, in that their activity levels increase in a nonlinear manner in response to change in the system. Some increase their firing rate only when blood pressure decreases, while others increase only during pressure increases. Still others are only sensitive to large movements in the rate of change of heart rate or blood pressure (Armour & Kember, 2004). Thus, there is only a minority of sensory neurites whose output activity exhibits a one-to-one relationship to the heartbeat and regional changes in ventricular blood pressure.

To add to the complexity, the heart's intrinsic nervous system has both short-term and long-term memory that affects cardiac function (and thus afferent signals) over two different time scales: (1) variations in activity patterns that occur in response to rapidly occurring alterations in local mechanical status over milliseconds; and (2) variations in activity patterns of a global nature that operate over time scales of seconds to minutes (Armour, 2003; Armour & Kember, 2004). Thus, in addition to the information related to a single cardiac cycle, there is also rhythmic information occurring over longer time scales that may modulate brain activity. The fact that many of the neurons respond primarily to rate of change, and that changes in activity patterns can last for minutes, are important factors in understanding how heart–brain interactions are affected during coherence and can have an extended carry-over effect. This is because in the coherence mode there is an increased rate of change in beat-to-beat variability of both heart rate and blood pressure, in addition to the increased order in the temporal patterns of activity of the cardiovascular system. While it is likely, under normal pressure variations and heart rates, that the overall *amount* of afferent neural activity reaching the brain is the same or nearly the same from one heartbeat to the next, it is our contention that the *macro-scale patterns* of neural activity can be quite different.

In this regard, Wölk and Velden made an important observation in noting that the *frequency* and *stability* of the afferent input were important factors affecting sensory-motor performance (Wölk and Velden, 1989). In this context, however, we suggest that the concept of *activity pattern* is more appropriate than the concept of *frequency*. This is because it is in the interspike interval (the temporal space *between* consecutive spikes of the neural activity) that information is encoded. Thus, it is the overall pattern of activity and *not* merely its frequency that contains the meaning of the information enfolded in the signals. Furthermore, we consider the stability of the pattern over longer time scales, those of seconds to minutes. Therefore, to understand the effects of cardiovascular afferent signals on the brain, the heart's rhythmic pattern over longer time scales must also be considered as an important factor in itself, in addition to those of stimulus intensity, heart rate, and pressure. As we have seen, it is likely that the macro-scale pattern of the heart's activity may have a much greater effect on performance than the within-cardiac cycle effects.

Afferent Input to Brain Centers other than the Thalamus

Another important consideration, in relation to heart–brain interactions, is that while the micro-pattern model focuses solely on cardiovascular input to the thalamus, there are other neural pathways by which the heart's input can modulate cortical activity and thus performance. As shown in Figure 5, cardiovascular inputs from the vagal afferent nerves first reach the nucleus of tractus solitarius (NTS) and from there travel directly to the parabrachial complex, periacqueductal grey, thalamus, hypothalamus, and amygdala. There are then connections by which the afferent inputs move from the amygdala, hypothalamus, and thalamus to the cerebral cortex. There is also evidence to suggest the existence of afferent pathways from the medulla directly to the prefrontal cortex (McCraty et al., 2004b).

Although this diagram primarily shows the afferent pathways—one-way flow of input to the brain—in most cases the regions are reciprocally interconnected such that information flows in both directions. This reciprocally interconnected network allows for continuous positive and negative feedback interactions and the integration of autonomic responses with the processing of perceptual and sensory information. In addition, the numerous distributed parallel pathways permit multiple avenues to process a given response.

Heart–Brain Synchronization

The third way in which the picture is more complicated is that whereas Wölk and Velden's hypothesis considers only the alpha rhythm, there are other brain rhythms that are also synchronized to the heart. These include the beta rhythm as well as lower frequency brain activity. Thus, it is likely that the effects of macro-scale cardiovascular dynamics on other aspects of brain activity are also important in contributing to larger fluctuations in performance, such as those observed in the studies reported here.

Appendix D presents evidence from a number of studies confirming that a significant amount of alpha rhythm activity is indeed synchronized to the activity of the heart. We have also presented additional evidence showing that Wölk and Velden's contention appears to have an empirical basis, in that we found that the alpha rhythm is synchronized to the cardiac cycle. Moreover, our evidence suggests that alpha synchronization increases during psychophysiological coherence and that other brain rhythms—namely, the beta rhythm and lower frequency brain activity—also appear to be synchronized to the cardiac cycle.

System Dynamics: Centrality of the Heart in the Psychophysiological Network

To this point our concern has been describing the nature, organization, and measurement of six different psychophysiological modes. In particular we have focused on the psychophysiological coherence mode and its impact on various aspects of psychophysiological function, including pain perception, respiration, emotional processing, and cognitive performance. Now we turn to the basic question of system dynamics: how the heart, as the most powerful generator of rhythmic information patterns in the body, acts effectively to bind and synchronize the entire system. This helps explain the mechanisms that underlie the heart's role in the generation of system-wide coherence in the body as a whole. In addition to an overview of research in these areas, we also present our own findings, which, so far as we know, represent an original contribution.

A Systems Approach

Complex living systems, such as human beings, are composed of numerous interconnected, dynamic networks of biological structures and processes. The recent application of systems thinking in the life sciences has given rise to the understanding that the function of the human organism as an integrated whole is determined by the multi-level interactions of all the elements of the psychophysiological system. The elements influence one another in a network fashion rather than through strict hierarchical or cause-effect relationships. Thus, any node within the psychophysiological network—any organ, system, substance, or process—necessarily exerts an impact, whether pronounced or subtle, on the functioning of the system as a whole. And while certain nodes have a greater influence than others in a given network at a particular level of system organization, those nodes that constitute multi-level linkages across different subsystems and scales of organization will have a greater influence on the system as a whole. Abundant evidence indicates that proper coordination and synchronization—i.e., coherent organization—among the lateral and vertical networks of biological activity generated by these structures and subsystems is critical for the emergence of higher-order functions.

As we have seen thus far, one of the primary ways that information is encoded and communicated throughout our psychophysiological systems is in the language of dynamic patterns. In the nervous system, for example, it is well established that information is encoded in the *time interval between action potentials*—and, on a macro-scale, in the intervals between bursts of neural activity. Likewise, in the endocrine system, patterns of “pulses” of hormone release are used to convey biologically relevant information. This is an important principle of operation, as it appears that the body uses this same encoding and transmission strategy—encoding information in the time intervals between pulses of activity—in many systems and across very different time scales. This is biologically efficient in that the body is organized to use a common information communication mechanism across multiple systems.

There is substantial evidence that the heart plays a unique role in synchronizing the activity in multiple systems of the body and across different levels of organization, and thus in orchestrating the flow of information throughout the psychophysiological network. As the most powerful and consistent generator of rhythmic information patterns in the body, and possessing a far more extensive communication system with the brain than other organs, the heart is in continuous connection with the brain and other bodily organs and systems through multiple pathways: *neurologically* (through the transmission of neural impulses), *biochemically* (through hormones and neurotransmitters), *biophysically* (through pressure and sound waves), and *energetically* (through electromagnetic field interactions).

As we discuss each of these main communication pathways in more detail, it will become clear that the heart is a central node in the psychophysiological network that influences multiple systems, and is thus uniquely positioned to integrate and communicate information both across systems and throughout the whole organism. Because of the extensiveness of the heart’s influence on the physiological, cognitive, and emotional systems, the heart provides a point of access from which the dynamics of bodily processes can be quickly and profoundly affected. From this perspective, we will also see how intentional interventions that increase coherence in the heart's rhythms can facilitate a rapid shift to the psychophysiological coherence mode, with profound system-wide consequences.

In the light of these ideas, we can now postulate that information relative to global-scale integration (the organization and function of the body as whole) is encoded in the interbeat intervals of the heartbeat. Thus, the heart effectively acts as the central "conductor" of rhythmic activity in the body: the neural, hormonal, biophysical, and energetic patterns generated by the heart's rhythmic activity provide a global synchronizing signal for the system as a whole.

Neurological Interactions

Of all the organs in the body, the heart has the most extensive neural connection with the brain. Until relatively recently, much attention in biology has been focused on understanding how the brain regulates all organs in the body, including the heart. However, as discussed above, more recent understandings have begun to portray quite a different picture, in which the heart actually exerts a significant influence on the brain. In this section we describe the various ways in which the heart affects the brain and body via neurological pathways, and we examine in particular its influence on the activity and function of higher brain centers and processes. In order to understand this heart–brain relationship, it is necessary, first, to review some recent findings of how the brain processes information and how the organization of neurological activity is critical to brain function. This organization can be described in terms of the three concepts of coherence introduced at the beginning of this article: coherence as global order, as autocoherence, and as cross-coherence.

Coherence Within the Brain

The brain is often analogized to the functions of a computer. But in terms of information processing and computation the brain is nothing like a digital computer. It does not assemble thoughts and feelings from digitized bits of serial data. Rather, the brain is more like an analog processor that relates whole patterns and concepts to one another; it looks for similarities, differences, or relationships between them. The brain is a highly efficient processor and analyzer of information that is exquisitely sensitive to novelty—to rate of change and to the difference between patterns.

At the macro-level of organization, global coherence must be present in order for the brain and nervous system to function efficiently and effectively. This means that the neural activity, which encodes information, must be stable and coordinated. It also means that the various centers within the brain must be able to dynamically synchronize their activity in order for information to be smoothly processed and perceived.

For example, autocoherence and cross-coherence in the electrical activity of diverse regions of the brain are necessary for sensory perception to occur. Our "coherent" perception of an object in the external world actually comes from millions of units of fragmented sensory information that are made globally coherent by being brought together and organized into a single conscious experience.

A depiction of such macro-scale organization of neural activity is offered by studies using the electroencephalogram (EEG), which measures macro-scale activity occurring in the dendritic fields of the neurons. These fields reflect excitatory or inhibitory synaptic action over a large number of neurons. (A single scalp electrode provides estimates of synaptic action averaged over tissue masses containing between 10 million and 1 billion neurons.) There is a voluminous literature concerning the relations between the different brain rhythms found in the EEG and the many different aspects of cognition.[13] For example, the alpha rhythm amplitude is lower during mental calculations while the beta rhythms increase (Nunez, 2000).

Recent research has focused on the global organization of cooperative workings of local and regional cell groups in order to better understand the brain's dynamic complexity. At an operational level, coherence in this context is a specific quantitative measure of functional relations between paired locations. In general, this research has shown that separate regions in the brain can exhibit high coherence in specific frequency bands and, at the same time, low coherence in other bands. The resulting correlated activity between these brain regions is cross-coherence, which is thought to emerge either from direct neural connections between the regions, common input from the thalamus and other neocortical regions, or both (Nunez, 2000). However, cross-coherence also occurs between distant cortical structures that are not necessarily interconnected anatomically (Bressler, Coppola, & Nakamura, 1993). This raises the question of what other mechanisms might account for this communication among distant brain regions.

A notable example of such cross-coherence has been described by Rodolfo Llinas, Chief of Physiology and Neuroscience at the New York University School of Medicine. He observed that specific areas of the cortex emit a steady oscillation, at a frequency of around 40 cycles per second (40 Hz). He also found that remote areas of the cortex were phase-locked at this 40-Hz frequency, meaning that the waves they produced all oscillated in synchrony. This led Llinas and others to suggest that the neurons perform in synchrony because they follow a kind of conductor (Ratey, 2001).

The prime candidate for the brain's internal conductor is the many intralaminar nuclei, located within the thalamus. These nuclei receive and project long axons to many areas of the brain. They take in information, reply to it, and monitor the responses to their replies, thus creating elaborate feedback loops in which resonant activity (~40 Hz) is modified by incoming sensory input. If the intralaminar nuclei are damaged, the person enters a deep and irreversible coma. Indeed, it appears that it is only when the "conductor" synchronizes the brain's activity that we become conscious. When this happens with a sufficient number of neural networks, the oscillations become ordered and globally coherent. As they spread their influence, recruiting more networks to join them, consciousness arises (Ratey, 2001).

The thalamus appears to play an active role in the generation of all the global EEG rhythms, and it should be emphasized that phase synchrony has been shown to occur in all the frequency

---

[13] The main rhythms that have been identified are: the delta rhythm (0–4 Hz), the theta rhythm (4-8 Hz), the alpha rhythm (8-12 Hz), the beta rhythm (12-16 Hz), and most recently the gamma rhythm (~ 40 Hz).

bands found in the EEG, not just in the 40 Hz band.[14] For example, different types of synchronization occur in the alpha band during the different phases of memory processes (encoding and retrieval) (Fingelkurts, Krause, Kaplan, Borisov, & Sams, 2003), and cross-coherence increases in the theta band during mental calculations (Nunez, 2000). Coherence in the alpha band is also correlated to perceptual and decision-making processes, and it increases in the frontal cortex during task processing (Kolev, Yordanova, Schurmann, & Basar, 2001).

The organization of the many interconnected neural networks within the brain allows for maximal flexibility in adapting to changing demands, such as focus on an external sensory input or an internal process. However, the degree of coupling, which regulates synchronized activity in the network, varies depending on the needs of the moment. When the network is either excessively coupled or is too loosely coupled, the system is less able to dynamically recruit the appropriate neural support systems it needs to respond to a particular demand. For example, the alpha rhythm increases in amplitude and distribution when the neural populations in the brain are more tightly coupled, which occurs when the brain regions involved are not processing information. Under these circumstances cognitive performance is reduced, especially that involving the processing of external sensory information. In terms of optimizing performance, this means in general that one should not be too relaxed (increased coupling) or overly stimulated (decreased coupling). Thus, in the light of the results of our studies of cognitive performance and heart-brain synchronization discussed above, the psychophysiological coherence mode appears to be a condition under which optimal coupling, and thus improved performance, occurs across diverse systems in the body.

Relevant to this discussion are the findings from a recent study of long-term Buddhist practitioners. This study found that while the practitioners generated a state of “unconditional loving-kindness and compassion,” increases in gamma band oscillation and long-distance phase synchrony were observed (Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). The study’s authors suggest that the large increase in gamma band synchrony reflects a change in the quality of moment-to-moment awareness. Moreover, because the characteristic patterns of *baseline* activity in these long-term meditators were found to be different from those of a control group, the results suggest that an individual’s baseline state can also be altered with long-term practice.

The authors of this study describe the Buddhist meditation as an “objectless meditation” in which the practitioners do not directly attend to a specific object or the breath, but focus instead on cultivating a feeling of “unconditional loving-kindness and compassion.” In many ways, the focus of this practice is comparable to the focus of the Heart Lock-In technique of the HeartMath system. It would therefore be interesting to investigate whether HeartMath practitioners, when in a state of psychophysiological coherence, also produce the increases in gamma-band oscillation

---

[14] The electroencephalogram (EEG) provides a very large-scale measure of the activity occurring in the dendritic fields of the neurons. These fields reflect the excess of excitatory or inhibitory synaptic action over a large number of neurons. A single scalp electrode provides estimates of synaptic action averaged over tissue masses containing between 10 million and 1 billion neurons. Synchronizations of oscillatory neural discharges are thought to play a crucial role in the constitution of transient networks that integrate distributed neural processes into highly ordered cognitive and affective functions that can induce synaptic changes.

and long-distance phase-synchrony observed in this study. Although this study did not measure heart rhythm coherence, another study of Buddhist monks using the same meditative focus of "loving-kindness and compassion" found an increase in heart rhythm coherence during this practice (Rapgay, n.d.). Because these studies were both conducted with samples of Buddhist monks who were practicing the same meditative focus, this raises the possibility that heart rhythm coherence and increased gamma-band phase synchrony are linked in a deeper way. This is consistent with the hypothesis that heart rhythm coherence reflects a state of increased global coherence in the body's function as a whole.

In summary, the mechanisms that underlie the source of oscillatory rhythms in the thalamus are complex, and there are a number of different hypotheses concerning these. The mechanisms responsible for the synchronization of remote cells in the brain are even more complex, as there are both local and global levels of synchronization and also interactions between the local and global levels. Whatever the mechanisms turn out to be that facilitate synchronous activity in remote cell assemblies, it is clear that the *input from the heart* to the brain affects the activity of the thalamus and its ability to synchronize cortical activity. This is important in understanding the relationship between global coherence, emotional stability, and optimal performance.

More Than a Pump

Over the past several decades, several lines of scientific evidence have established that, far more than a mechanical pump, the heart functions as a sensory organ and as a complex information encoding and processing center. Groundbreaking research in the relatively new field of neurocardiology has demonstrated that the heart has an extensive intrinsic nervous system that is sufficiently sophisticated to qualify as a "little brain" in its own right. Pioneer neurocardiology researcher Dr. J. Andrew Armour first described the anatomical organization and function of the heart brain in 1991 (Armour, 1991). Containing over 40,000 neurons, its complex circuitry enables it to sense, regulate, and remember. Moreover, the heart brain can process information and make decisions about cardiac control independent of the central nervous system (Armour, 2003; Armour & Kember, 2004).

The heart brain senses hormonal, heart rate, and blood pressure signals, translates them into neurological impulses, and processes this information internally. It then sends the information to the central brain via afferent pathways in the vagus nerves and spinal column. When different hormones or neurotransmitters in the bloodstream are detected by the sensory neurites in the heart, the pattern in the afferent neural output sent to the brain is modified (Armour, 1994). In other words, in addition to its better-known functions, the heart is also a sensory center that detects and transmits information about the biochemical content of the regional blood flow.

Neurological signals originating in the heart have an important and widespread influence in regulating the function of organs and systems throughout the body. For example, it is now known that in addition to modulating the activity of the nervous and endocrine systems, input from the heart influences the activity of the digestive tract, urinary bladder, spleen, respiratory and lymph systems, and skeletal muscles (Chernigovskiy, 1967). In more specific terms, cardiovascular afferent signals regulate efferent ANS outflow, (Grossman, Janssen, & Vaitl, 1986) modulate pain perception (Randich & Gebhart, 1992) and hormone production (Drinkhill

& Mary, 1989), and influence the activity of the locus coeruleus and that of the pyramidal tract cells in the motor cortex (Coleridge et al., 1976; Svensson & Thoren, 1979). Also, spinal cord excitability varies directly with the cardiac pulse, as does physiological tremor of normal skeletal muscles (Forster & Stone, 1976).

Beyond the key role of cardiac afferent signals in physiological regulation, our earlier discussion also illuminates the heart's significant influence on perceptual and cognitive function via its input to higher brain centers. Our discussion has thus far covered behavioral data showing a relationship between the heart's input and cognitive performance, as well as electrophysiological studies demonstrating the synchronization of brain activity to the heart. Beyond these findings, there is also a considerable body of other electrophysiological evidence demonstrating the modulation of higher brain activity by cardiovascular afferent input (see Lacey & Lacey, 1970; McCraty, 2003; and Sandman et al., 1982, for reviews).

Experiments carried out in Germany by psychophysiologist Rainer Schandry have demonstrated that afferent input from the heart evokes cortical responses analogous to "classical" sensory event-related potentials. These experiments have shown that afferent input from the cardiovascular system is accompanied by specific changes in the brain's electrical activity. Schandry and colleagues found, as have we, that this activity is most pronounced at the frontocortical areas, a region particularly involved in the processing of visceral afferent information. In addition, psychological factors such as attention to cardiac sensations, perceptual sensitivity, and motivation have been found to modulate cortical heartbeat evoked potentials in a fashion analogous to the cortical processing of external stimuli (Lader & Mathews, 1970; Montoya, Schandry, & Muller, 1993; Schandry & Montoya, 1996; Schandry, Sparrer, & Weitkunat, 1986). In our own study, in which we investigated the electrophysiology of information processing in relation to intuition, we also found that the heart's afferent input significantly modulates frontocortical activity, especially during the psychophysiological coherence mode (McCraty et al., 2004a, 2004b).

The observation that the heart's afferent input modulates frontal activity is concordant with other findings that activity in the prefrontal cortex covaries with changes in the heart rhythm (Lane et al., 2001). This is consistent with the biological principle of reciprocal connections in neural systems. Therefore, in addition to the well-established routes (e.g., the thalamic pathway) by which cardiovascular afferent signals modulate higher cortical function, there may well be additional routes from the heart to the prefrontal cortex.

Biochemical Interactions

In addition to its extensive neurological interactions with the brain and body, the heart also communicates with the brain and body biochemically, by way of the hormones it produces. Although not typically thought of as an endocrine gland, the heart in fact manufactures and secretes a number of hormones and neurotransmitters that have a wide-ranging impact on body as a whole.

The heart was reclassified as part of the hormonal system in 1983, when a new hormone produced and secreted by the atria of the heart was discovered. This hormone has been variously termed atrial natriuretic factor (ANF), atrial natriuretic peptide (ANP), or atrial peptide. Nicknamed the “balance hormone,” and playing an important role in fluid and electrolyte homeostasis, it exerts its effects on the blood vessels, kidneys, adrenal glands, and many of the regulatory regions of the brain (Cantin & Genest, 1985, 1986). In addition, studies indicate that atrial peptide inhibits the release of stress hormones (Strohle, Kellner, Holsboer, & Wiedemann, 1998), reduces sympathetic outflow (Butler, Senn, & Floras, 1994), plays a part in hormonal pathways that stimulate the function and growth of reproductive organs (Kentsch, Lawrenz, Ball, Gerzer, & Muller-Esch, 1992), and may even interact with the immune system (Vollmar, Lang, Hanze, & Schulz, 1990). Even more intriguing, experiments suggest that atrial peptide can influence motivation and behavior (Telegdy, 1994).

Several years following the discovery of atrial peptide, a related peptide hormone with similar biological functions was identified. This was called brain natriuretic peptide (BNP) because it was first identified in porcine brain. It soon became clear, however, that the main source of this peptide was the cardiac ventricle rather than the brain, and brain natriuretic peptide is now sometimes called B-type natriuretic peptide (Mukoyama et al., 1991).

Armour and colleagues also found that the heart contains a cell type known as intrinsic cardiac adrenergic cells. These cells are so classified because they synthesize and release catecholamines (norepinephrine, epinephrine, and dopamine), neurotransmitters once thought to be produced only by neurons in the brain and ganglia outside the heart (Huang et al., 1996). More recently still, it was discovered that the heart also manufactures and secretes oxytocin, commonly referred to as the “love” or social “bonding hormone.” Beyond its well-known functions in childbirth and lactation, recent evidence indicates that this hormone is also involved in cognition, tolerance, trust, complex sexual and maternal behaviors, as well as in the learning of social cues and the establishment of enduring pair bonds. Remarkably, concentrations of oxytocin produced in the heart are in the same range as those produced in the brain (Gutkowska et al., 2000).

In a preliminary study (10 participants), we examined changes in the blood concentrations of oxytocin and atrial peptide before and after 10 minutes of maintaining the psychophysiological coherence mode, which was generated by a loving emotional focus. While an increase in oxytocin was observed for the whole sample, it was not statistically significant, although it likely would have been with a larger sample. On the other hand, despite the small number of cases, the decrease in atrial peptide was significant. As atrial peptide release is an index of the stretch and contractile force of the atrial wall of the heart, these data suggest that cardiovascular efficiency increases during the psychophysiological coherence mode. The results for the male and female subgroups in this study are shown in Figure 6.

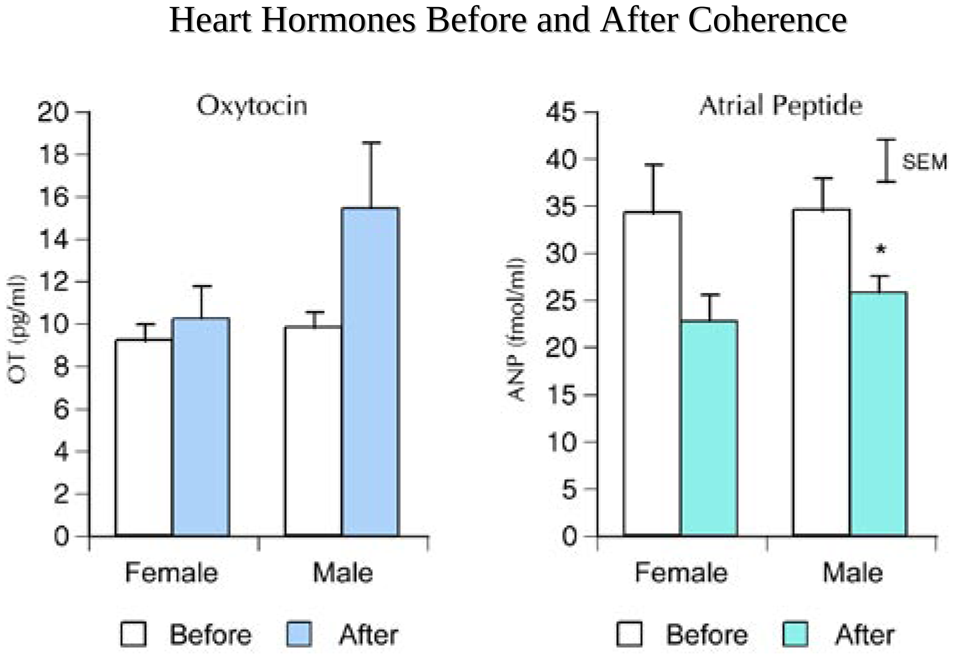


Figure 6. Oxytocin and atrial peptide changes during heart rhythm coherence. Graphs show changes in blood levels of oxytocin and atrial peptide for male and female subgroups from a resting baseline mode to after maintaining the coherence mode for 10 minutes.

In addition to changes in the *amount* of a heart hormone released into the blood affecting cellular and psychological systems, there is also evidence that the temporal *pattern* of the hormonal release has substantial effects independent of the amount of the hormone released. It has been known for some time that neurotransmitters, hormones, and intracellular "second messengers" are released in a pulsatile fashion. Pulsatile patterns of secretion are observed for nearly all of the major hormones, including ACTH, GH, LH, FSH, TSH, prolactin, beta-endorphin, melatonin, vasopressin, progesterone, testosterone, insulin, glucagon, renin, aldosterone, and cortisol, among many others.

Recent studies by German endocrinology researchers Georg Brabant, Klaus Prank, and Christoph Schofl have shown that, in much the same way that the nervous system encodes information in the time interval between action potentials, biologically relevant information is also encoded in the *temporal pattern* of hormonal release, across time scales ranging from seconds to hours (Schofl, Prank, & Brabant, 1995). As most heart hormones are released in synchronicity with the contractions of the heart, there is a rhythmic pattern of hormonal release that tracks the heart rhythm.

This is particularly relevant to our discussion of coherence, as it suggests that changes in heart rhythm patterns—such as those generated during psychophysiological coherence—impact the brain and body in yet another way: that is, they change the pattern of hormonal pulses released by the heart. Although the influence of these changes in hormonal pulse patterns on biological, emotional, and behavioral processes is still unknown, it is likely that the transmission of such hormonal information constitutes another pathway by which the effects of psychophysiological coherence on health, well-being, and performance are mediated.

Biophysical Interactions

With every beat, the heart generates a powerful pressure wave that travels rapidly throughout the arteries, much faster than the actual flow of blood. These waves of pressure create what we feel as our pulse. The heart sounds, generated by the closing of the heart valves and cardiac murmurs, can be heard all over the chest and can extend as far as the groin. Similarly, the pressure waves traveling through the arteries and tissues can affect every organ in the body, especially when the mechanisms that control blood pressure are compromised. In fact, the physical shock wave generated by the heartbeat expands the chest wall to such an extent that the heartbeat can be detected by measuring the chest expansion (this is called the ballistocardiogram).

Important rhythms also exist in the oscillations of blood pressure waves. In healthy individuals, a complex resonance occurs between blood pressure waves, respiration, and rhythms in the ANS. Because pressure wave patterns vary with the rhythmic activity of the heart, they represent yet another language through which the heart can communicate with the rest of the body. In essence, all of our cells sense the pressure waves generated by the heart and are dependent upon them in more than one way. At the most basic level, pressure waves force the blood cells through the capillaries to provide oxygen and nutrients to the cells. In addition, these waves expand the arteries, causing them to generate a relatively large electrical voltage. The waves also apply pressure to the cells in a rhythmic fashion, causing some of the proteins contained therein to generate an electrical current in response to the "squeeze."

Experiments conducted in our laboratory have shown that a change in the brain's electrical activity can be seen when the blood pressure wave reaches the brain, around 240 milliseconds after the contraction of the heart. An example is shown in Figure 7.

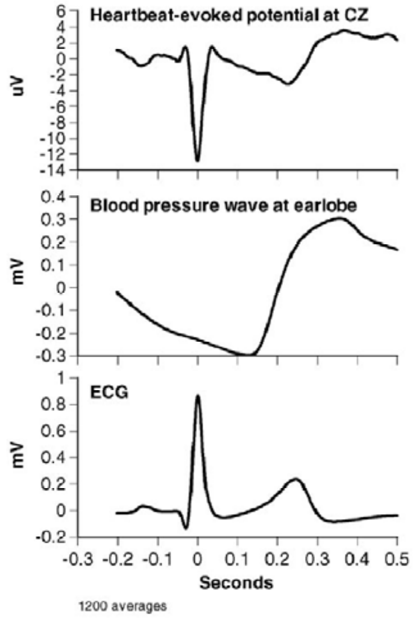


Figure 7. Evoked potentials in the EEG due to effects of the blood pressure wave. The top trace is the EEG recorded at the Cz location, and the middle trace is the blood pressure wave,

detected at the earlobe. Note that the blood pressure wave arrives at the brain around 240 milliseconds after the heartbeat, and a positive shift in the evoked potential in the EEG can be clearly seen upon its arrival.

We hypothesize that, in a similar manner to the encoding of information in the space between nerve impulses and in the intervals between bursts of hormonal activity, information is also contained in the interbeat intervals of the pressure waves produced by the heart. Given that these pressure waves can modulate brain activity and affect vital processes even down to the activity of biomolecules at the cellular level, this represents yet another, potentially important pathway by which information contained in changing heart rhythm patterns orchestrates system-wide effects.

Energetic Interactions

Thus far we have discussed the role of the heart in information processing and communication in terms of neurological, hormonal, and biophysical interactions. In this section we explore how the heart also communicates information to the brain and throughout the body via electromagnetic field interactions.

To understand how communication occurs via these biological fields requires an *energetic* concept of information—one in which data about *patterns* of organization are actually enfolded into the waves of energy generated by the body's activity and distributed throughout the body's electromagnetic field. This concept is quite different from the "lock and key" concept of biochemical interactions, in which communication occurs through the action of biochemicals, such as neurotransmitters, fitting into specialized receptor sites, much like keys open certain locks (McCraty et al., 1998). To explain how energetic communication occurs in biological systems, we take Pribram's holographic approach. He believes, as we do, that the communication of energetic information in biological systems is best understood in the terms of the information processing principles of holographic theory (McCraty et al., 1998; Pribram, 1991; Pribram & Bradley, 1998).

Of all the organs, the heart generates by far the most powerful and most extensive rhythmic electromagnetic field produced in the body. When electrodes placed on the surface of the body are used to measure the ECG, it is the electrical component of the heart's field that is detected and measured. This electrical voltage, about 60 times greater in amplitude than the electrical activity produced by the brain, permeates every cell in the body. Thus, the ECG can be detected by placing electrodes anywhere on the body, from the little toe to the top of the head. The magnetic component of the heart's field, which is approximately 5,000 times stronger than the magnetic field produced by the brain (Russek & Schwartz, 1996), is not impeded by the body's tissues and easily radiates outside of the body. This field can be measured several feet away from the body with sensitive magnetometers (McCraty et al., 1998). These energetic emanations and interactions provide a plausible mechanism for how we can "feel" or sense another person's presence and even their emotional state, independent of body language and other signals (McCraty, 2004).

The heart's ever-present rhythmic field has a powerful influence on communicative processes throughout the body. As already noted above, brain rhythms naturally synchronize to the heart's rhythmic activity, and the rhythms of diverse physiological oscillatory systems can entrain to the heart's rhythm. There is evidence that the heart's field may even play a regulatory role at the cellular level, in that we have found that changes in the cardiac field can affect the growth rate of cells in culture (McCraty et al., 1998).

As can be seen in Figure 20, (Appendix D) the electromagnetic waves generated by the heart are immediately registered in one's brain waves and can have quite a large effect on the heartbeat evoked potential. This same effect has been observed by Gary Schwartz and colleagues at the University of Arizona, who also suggest that energetic interactions between the heart and brain play an important role in psychophysiological processes (Russek & Schwartz, 1994, 1996; Song, Schwartz, & Russek, 1998).

Energetic Signatures of Psychophysiological Modes

Our research has shown that information about a person's emotional state is also communicated throughout the body and into the external environment via the heart's electromagnetic field (McCraty et al., 1998). As described earlier, the rhythmic beating patterns of the heart change significantly as we experience different emotions. Thus, negative emotions, such as anger or frustration, are associated with an erratic, *incoherent* pattern in the heart's rhythms, whereas positive emotions, such as love or appreciation, are associated with a sine-wave-like pattern, denoting *coherence* in the heart's rhythmic activity. In turn, these changes in the heart's beating patterns create corresponding changes in the frequency spectra of the electromagnetic field radiated by the heart.

This is observed when spectral analysis techniques are applied to the energy waveforms generated by the heart (ECG or MCG) in the same way that is typically done when analyzing waves generated by electrical activity in the brain. Different spectral patterns are correlated both with the patterns of beat-to-beat variability and with the current psychophysiological state. These spectral patterns can be interpreted as "information patterns" containing data about the psychophysiological state of the individual in that moment in time. Appendix E shows waterfall plots from the ECG data used to produce the examples of the six different psychophysiological modes described at the outset of this article. These reveal distinctive spectral patterns associated with each specific mode.

The Holographic Heart

The spectra of ECG recordings in Appendix E illustrate the enormous richness and complexity of the heart's activity and the voluminous density of information encoding and transmission that occurs, via the movement of energy, in the body's internal electromagnetic environment. As already noted, similar patterns of information are encoded in the space (time) between nerve impulses and in the intervals between bursts of hormonal activity and pressure waves. We propose, further, that information is encoded and communicated in same manner *in the intervals between heartbeats*. Such an information encoding strategy would allow communication via the neural and hormonal pulses that are produced with each heartbeat and also via the electromagnetic waves produced by the heart. As a means by which the heart can transmit information both throughout the body's psychophysiological networks and into the external environment, the validity of this energetic communication mechanism can be empirically verified. This concept of energetic communication provides the basis for explaining how information about the organization and state of the system as a whole is distributed throughout the body in an almost instantaneous way.

The heart's rhythmic energetic activity lies at the center of our account. The heart generates a continuous series of electromagnetic pulses in which the time interval between pulses varies in a dynamic and complex manner. These pulsing waves of electromagnetic energy give rise to fields within fields, which form interference patterns when they interact with magnetically polarizable tissues and structures. In more specific terms, we postulate that as pulsing waves of energy radiate out from the heart, the energy waves interact with organs and other structures to create interference patterns. At the same time, the endogenous processes in each of the other organs, structures, and systems, including those at the micro-scale of cells and membranes, also generate patterns of dynamic activity. These patterns of dynamic activity radiate out into the body's internal environment as energy oscillations, and they interact with the energy waves from the heart and to some degree with the energy waves of other organs and structures. In each of these interactions the energy waves encode the features of the objects and their dynamic activity as interference patterns. Because the heart generates by far the strongest energy field, which interacts with both the macro and micro scales of the body's organization, the waves it produces operate effectively as global carrier waves that encode the information contained in the interference patterns. These global carrier waves thus contain encoded information from *all* of the body's energetic interactions, and they distribute this information throughout all systems in the body. In this holographic-like process, the encoded information acts to *in-form* the activity of all bodily functions (McCraty et al., 1998). This energetic communication system thereby operates as a global organizing mechanism to coordinate and synchronize psychophysiological processes in the body as a whole.

This theory—that the heart encodes and distributes energetic information holographically—is based on the same model that neuropsychologist Karl Pribram has used to describe the neural processes in the brain that gives rise to perception and memory (Pribram, 1971, 1991). In this model, as Pribram makes clear, the neural impulses are only relaying information from one part of the brain to another. However, the actual processing of information occurs in the spectral domain of energy frequency—a domain outside space and time in which the waves of energy produced by the operation of the neural microstructure interact. Moreover, he has shown that that the same mathematics that Gabor (1948) used to describe the quantum-holographic principles involved in the physics of signal processing can also be used to describe the information processing that occurs in the electromagnetic interactions between the dendritic and axon fields of neurons (McCraty et al., 1998). While a discussion of this is beyond the scope of this article, Pribram and other brain scientists have presented a large body of compelling experimental evidence that supports the veracity of Pribram's bioenergetic model of information processing (King, Xie, Zheng, & Pribram, 1994; McCraty et al., 1998; Pribram, 1971, 1991; Santa Maria et al., 1995). Thus, in addition to the energetic information processing that occurs in the brain, as described by Pribram, we propose that there is also a heart-based global energetic system that encodes and distributes information to coordinate and organize the function of the body as a whole.[15] Thus, in addition to the energetic information processing that occurs in the brain, as described by Pribram, we propose that there is also a heart-based global energetic system that encodes and distributes information to coordinate and organize the function of the body as a whole.

There is compelling evidence to suggest that the heart's energy field is coupled to a field of information that is not bound by the limits of time and space. This evidence comes from a rigorous experimental study we conducted to investigate the proposition that the body receives and processes information about a future event before the event actually happens (McCraty et al., 2004a, 2004b). The study's results provide surprising, even astounding data showing that both the heart and brain appear to receive and respond to information about a future event. Even more tantalizing is the evidence that the heart appears to receive intuitive information *before* the brain. This suggests that the heart is directly coupled to a subtle energetic field of ambient information that surrounds the body, which, in turn, is entangled and interacts with the multiplicity of energy fields in which the body is embedded—including that of the quantum vacuum.

In short, it would appear that we are only just beginning to understand the fundamental role of a bioenergetic communication system in processing information from sources both within and outside the body to *in-form* physiological function, cognitive processes, emotions, and behavior. In this system, it thus seems clear that the energy field of the heart plays a crucial role.

Conclusion

> *The origin of feelings is the body in a certain number of its parts. But now we can go deeper and discover a finer origin underneath that level of description. . .*
> (Damasio, 2003, p. 132)

Damasio sums up the current understanding held by many of today's scientists of the genesis of feelings and emotions. This is the notion that the origin of the particular emotional feelings we experience in each moment lies in the substrata of our body's physiological processes. Positive feelings emerge from body states in which the physiological regulation of the processes of life is easy and free-flowing, while negative feelings reflect the strain of life processes that are difficult for the body to balance and that may even be out of control. This general understanding has roots in an earlier era in psychology and has recently reemerged in the scientific study of emotion. However, the geography of this realm is largely uncharted and has only just begun to be mapped. Needless to say, a more complete understanding awaits development. In this article we have thus endeavored to "go deeper" by offering an account of the "finer origin" of the psychophysiological processes involved in emotional experience.

In "going deeper," we based our approach on the premise that the body's physiological, cognitive, and emotional systems are intimately intertwined through ongoing processes involving reciprocal communication. We hold that an understanding of the workings of these systems must view their activity as emergent from the dynamic, communicative network of interacting

---

[15] See also the Appalachian Conferences volumes.

functions that comprise the human organism. To describe these communicative processes we adopted an information processing perspective. From this viewpoint, communication within and among the body's systems is seen to occur through the generation and transmission of *rhythms and patterns* of psychophysiological activity. This focus stands in contrast to the traditional approach, in which the amount of physiological activity is viewed as the primary basis of communication. We believe a focus on rhythms and patterns of psychophysiological activity illuminates a more fundamental order of information communication—one that signifies different emotional states, operates to integrate and coordinate the body's functioning as a whole, and also links the body to the processes of the external world.

In order to understand the functional significance of the morphology of patterns of physiological activity, we drew on the concept of coherence from the physics of signal processing. This is the notion that the degree of efficiency and effectiveness of a system's functioning is directly related to the degree to which there is a harmonious organization of the interaction among the elements of the system. Thus, a harmonious order in the rhythm or pattern of activity signifies a coherent system, whose efficient or optimal function is directly related, in Damasio's terms, to the "fluidity" of life processes. By contrast, an erratic, nonharmonious pattern of activity marks an incoherent system, whose function reflects the "strain" of life processes.

In operationalizing this approach, we used the pattern of the heart's rhythmic activity as our primary physiological marker, as it was the most sensitive measure of changes in emotional states. In reviewing the results of our empirical research, we identified six psychophysiological modes distinguished by their physiological, mental, and emotional correlates. These are: Mental Focus, Psychophysiological Incoherence, Psychophysiological Coherence, Relaxation, Extreme Negative Emotion, and Emotional Quiescence. We showed that different emotions are associated with different degrees of coherence in the activity of the body's systems. While positive emotions such as appreciation, care, and love drive the system toward increased physiological coherence, negative emotions drive the system towards incoherence.

In particular, we highlighted the importance of the psychophysiological coherence mode. Associated with the experience of sustained positive emotions, the coherence mode has numerous psychological and health-related benefits, which have been demonstrated by a growing body of research. Of note are the findings showing a direct relationship between this mode and cognitive performance, as well as data linking this mode to intuition.

Using our empirical findings as a point of departure, we constructed a typology—a conceptual "map"—of the reality of psychophysiological interaction. We differentiated twelve primary types of psychophysiological interaction, distinguished by their values on two theoretical dimensions. Each type describes a distinctive physiological substratum that underlies a different primary emotion or psychophysiological state. Six of the types signify emotional states typically experienced in the course of everyday life. Qualitatively distinct from the feelings of everyday life are six additional types of psychophysiological interaction. Discontinuous from the psychophysiological states of day-to-day life, these are hyper-states of extreme emotions reflecting the body's response to extraordinary circumstances. One interesting implication of the typology is the prediction of four additional hyper-states of psychophysiological interaction, beyond the two hyper-states that we have been able to document empirically.

While our findings on the psychophysiological modes showed that the patterns of the heart's rhythmic activity are clearly *reflective* of different emotional states, in the second part of this article we also presented an account of the heart's constructive role in the physiological processes by which emotional experience is *generated*. According to a model based on Pribram's theory, emotions result from the "mismatch" between familiar input patterns and current input patterns that are different or novel. The heart is the primary source of dynamic rhythmic patterns in the body and possesses extensive communication networks with the brain and other systems. With each beat, it not only pumps blood, but also transmits patterns of neurological, hormonal, pressure, and electromagnetic information through these networks. These multiple inputs to the brain from the heart contribute significantly to the familiar reference pattern and also to those deviations from the familiar that are experienced as changes in emotions.

We also presented evidence showing that the heart has a significant influence on the brain's neurological activity and even plays a role in modulating cognitive functions. While extensive evidence had previously established that sensory-motor integration and cognitive processing is modified by changes in heart rate (beat-to-beat cardiac accelerations and decelerations), our research has expanded this understanding. We found that macro-scale patterns of the heart's rhythmic activity also significantly affect cognitive performance and intentional behavior well beyond the micro-scale effects previously reported. We also demonstrated a significant relationship between heart rhythm patterns and cognitive performance, in that increased heart rhythm coherence leads to improved cognitive performance.

This along with other findings led us to propose that a global level of organization serves to bind and synchronize the body as a whole. In this function we believe that the heart is a key organ in orchestrating activity across multiple systems, encompassing both micro and macro levels of organization. We proposed that information is encoded in the interbeat intervals of the waveforms of neurological, hormonal, pressure, and electromagnetic activity generated by the heart. Because of the heart's wide-ranging linkage to the body's major systems, information encoded in the heart's rhythmic patterns both reflects and influences the ongoing dynamics of the body as a whole. Furthermore, when the heart's rhythmic activity shifts into coherence, synchronization and harmonious interaction within and among systems is the result. This, in turn, produces optimal states of health, physical activity, and cognitive performance. Thus, the heart is a critical nodal point in the psychophysiological network: it acts as the conductor in the human symphony, setting the beat that binds and synchronizes the entire system.

An important, though little investigated, way in which the heart acts as a global conductor is through its electromagnetic interactions. We proposed that the electromagnetic fields produced by the heart form a complex energetic network that connects the electromagnetic fields of the rest of the body. In doing so, the heart's energetic field acts as a modulated carrier wave that encodes and communicates information throughout the entire body, from the systemic to the cellular levels, and even conveys information outside the body between individuals. In these ways it provides a global signal that integrates the order of the system as a whole.

The concept of an energetic information field is not a new one. Indeed, many prominent scientists have proposed models in which information from all physical, biological and psychosocial interactions is enfolded as a spectral order outside the space/time world in the energy waveforms of the quantum vacuum. Holographic principles (Gabor, 1948) form the basis of most of these theories and have been used to describe how information about the organization of a whole is nonlocalized—enfolded and distributed to all parts and locations via the energy waveforms produced by interactions in the brain, (Pribram, 1971, 1991) social structures, (Bradley, 1987; Bradley & Pribram, 1998) and the universe (Bekenstein, 2003; Nadeau & Kafatos, 1999). We adopted a holographic perspective to describe how energy waveforms generated by the heart's electromagnetic field encode and distribute information about all structures and processes throughout the body from the cellular level to the body as a whole. Moreover, the energy fields produced by the heart and other bodily structures are transmitted externally. And because these energy fields are in continuous interaction with the multiplicity of energy fields in the environment, it appears that information about nonlocal events and processes is conveyed back to the body and processed as intuition.

We believe that the concept of energetic information holds promise as a way of understanding how the body's bioenergetic communication system operates to process information from sources both within and outside the body. Based on the evidence we have presented, it seems clear that the energy field of the heart plays a crucial role in in-forming physiological function, cognitive processes, emotions, and behavior.

We have endeavored to present a deeper understanding of the central significance of the heart in virtually all aspects of the body's function. As a principal and consistent source of rhythmic information patterns that impact the physiological, cognitive, and emotional systems, the heart thus provides an access point from which a change in system-wide function can be immediately effected. When positive emotions are used to shift the heart's pattern of activity into coherence, a global transformation in psychophysiological function occurs. As the evidence we have presented clearly shows, this transformation results in increased physiological efficiency, greater emotional stability, and enhanced cognitive function and performance. As a simple and direct means by which one can shift into a state of psychophysiological coherence, the HeartMath tools are a highly effective method to facilitate this transformation. In the case of Chris, with which we opened this article, the use of these tools proved to be a life-saving and life-changing intervention, leading to changes not only in his physical health, but also in his emotional life, work performance, and relationships. We believe that the growing use of these and similar heart-based tools around the globe by educators and students, health care workers and patients, and managers and employees, among others, can play a significant part in improving the "life processes" of humankind.

References

Adair, J., R., & Manning, J. W. (1975). Hypothalamic modulation of baroreceptor afferent unit activity. *American Journal of Physiology, 229*, 1357-1364.

Ahern, G., L., & Schwartz, G. E. (1985). Differential lateralization for positive and negative emotion in the human brain EEG spectral analysis. *Neuropsychologia, 23*(6), 745-755.

Arguelles, L., McCraty, R., & Rees, R. A. (2003). The heart in holistic education. *Encounter: Education for Meaning and Social Justice, 16*(3), 13-21.

Armour, J. A. (1991). Anatomy and function of the intrathoracic neurons regulating the mammalian heart. In I. H. Zucker & J. P. Gilmore (Eds.), *Reflex control of the circulation* (pp. 1-37). Boca Raton, FL: CRC Press.

Armour, J. A. (1994). Peripheral autonomic neuronal interactions in cardiac regulation. In J. A. Armour & J. L. Ardell (Eds.), *Neurocardiology* (pp. 219-244). New York, NY: Oxford University Press.

Armour, J. A. (2003). *Neurocardiology—Anatomical and functional principles* (Publication No. 03-011). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Retrieved from: http://store.heartmath.org/store/scientific-monographs/Tend-Report.

Armour, J., A., & Kember, G. C. (2004). Cardiac sensory neurons. In J. A. Armour & J. L. Ardell (Eds.), *Basic and clinical neurocardiology* (pp. 79-117). New York, NY: Oxford University Press.

Andersen, P., & Andersson, S. A. (1968). *Physiological basis of the alpha rhythm*. New York, NY: Appleton-Century-Crofts.

Ashby, W. R. (1956). *An introduction to cybernetics*. London: Chapman, & Hall.

Barrios-Choplin, B., McCraty, R., & Cryer, B. (1997). An inner quality approach to reducing stress and improving physical and emotional wellbeing at work. *Stress Medicine, 13*(3), 193-201.

Barrios-Choplin, B., McCraty, R., Sundram, J., & Atkinson, M. (1999). *The effect of employee self-management training on personal and organizational quality* (Publication No. 99-083). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Retrieved from http://www.heartmath.org/research/rp-effect-of-employee-self-management-training-on-personal-and-organizational-quality.html

Baselli, G., Cerutti, S., Badilini, F., Biancardi, L., Porta, A., Pagani, M., . . . Malliani, A. (1994). Model for the assessment of heart period variability interactions of respiration influences. *Medical and Biological Engineering and Computing, 32*(2), 143-152.

Baule, G., & McFee R. (1963). Detection of the magnetic field of the heart. *American Heart Journal, 55* (7), 95-96.

Bekenstein, J. D. (2003). Information in the holographic universe. *Scientific American, 289* (2), 58-65.

Bering, E. A. (1955). Choroid plexus and arterial pulsation of cerebrospinal fluid. *Archives of Neurology and Psychiatry, 73*, 165-172.

Birbaumer, N. (1975). *Physiologische psychologie*. Berlin, Germany: Springer.

Blakeslee, T., R., & Grossarth-Maticek, R. (1996). *Feelings of pleasure and well-being as predictors of health status 21 years later*. Retrieved from http://www.attitudefactor.com/PWItecharticle.htm

Bolte, A., Goschke, T., & Kuhl, J. (2003). Emotion and intuition: Effects of positive and negative mood on implicit judgments of semantic coherence. *Psychological Science, 14* (5), 416-421.

Bradford, E. J., Wesnes K. A., & Brett, D. (2005). Effects of peak performance training on cognitive function [Supplement]. *Journal of Psychopharmacology, 19* (5), A44.

Bradley, R. T. (1987). *Charisma and social structure: A study of love and power, wholeness and transformation*. New York, NY: Paragon House.

Bradley, R. T. (2002). Dialogue, information, and psychosocial organization. In N. C. Roberts (Ed.), *Dialogue and transformation* (pp. 243-288). London: Elsevier Science.

Bradley, R. T., & Pribram, K. H. (1998). Communication and stability in social collectives. *Journal of Social and Evolutionary Systems, 21* (1), 29-80.

Bressler, S. L, Coppola, R., & Nakamura, R. (1993). Episodic multiregional cortical coherence at multiple frequencies during visual task performance. *Nature, 366* (6451), 153-156.

Butler, G. C., Senn, B. L., & Floras, J. S. (1994). Influence of atrial natriuretic factor on heart rate variability in normal men. *American Journal of Physiology 267* (2, Pt. 2), H500-H505.

Callaway, E., III. (1962). Factors influencing the relationship between alpha activity and visual reaction time. *Electroencephalography and Clinical Neurophysiology, 14*, 674-682.

Callaway, E., III, & Yeager, C. L. (1960). Relationship between reaction time and electroencephalographic alpha phase. *Science, 132*, 1765-1766.

Cameron, O. G. (2002). *Visceral sensory neuroscience: Interoception*. New York, NY: Oxford University Press.

Canli, T., Desmond, J. E., Zhao, Z., Glover, G., & Gabrieli, J. D. (1998). Hemispheric asymmetry for emotional stimuli detected with fMRI. *Neuroreport*. *9* (14), 3233-3239.

Cantin, M., & Genest, J. (1985). The heart and the atrial natriuretic factor. *Endocrine Reviews*, *6* (2), 107-127.

Cantin, M., & Genest, J. (1986). The heart as an endocrine gland. *Scientific American, 254* (2), 76-81.

Chernigovskiy, V. N. (1967) *Interoceptors*. Washington, DC: American Psychological Association.

Childre, D., & Cryer, B. (2000). *From chaos to coherence: The power to change performance*. Boulder Creek, CA: Planetary.

Childre, D., & Martin, H. (1999). *The HeartMath solution*. San Francisco: HarperSanFrancisco.

Childre, D., & Rozman, D. (2002). *Overcoming emotional chaos: Eliminate anxiety, lift depression and create security in your life*. San Diego: Jodere Group.

Childre, D., & Rozman, D. (2005). *Transforming stress: The HeartMath solution to relieving worry, fatigue, and tension*. Oakland, CA: New Harbinger Publications.

Childre, D. L. (1991). *Heart Zones* [CD]. Boulder Creek, CA: Planetary Publications.

Coleridge, H. M., Coleridge, J. C., & Rosenthal, F. (1976). Prolonged inactivation of cortical pyramidal tract neurons in cats by distention of the carotid sinus. *Journal of Physiology, 256*, 635-649.

Damasio, A. (2003). *Looking for Spinoza: Joy, sorrow, and the feeling brain*. Orlando, FL: Mariner, 2003.

Danner, D. D., Snowdon, D. A., & Friesen, W. V. (2001). Positive emotions in early life and longevity: Findings from the nun study. *Journal of Personality and Social Psychology*, *80* (5), 804-813.

Davidson R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition*, *20* (1), 125-151.

Davidson, R. J., Kabat-Zinn, J., Schumacher, J., Rosenkranz, M., Muller, D., Santorelli S. F., . . . Sheridan, J. F. (2003). Alterations in brain and immune function produced by mindfulness meditation. *Psychosomatic Medicine*, *65*(4), 564-570.

DeBoer, R. W., Karemaker, J. M., & Strackee, J. (1987). Hemodynamic fluctuations and baroreflex sensitivity in humans: A beat-to-beat model. *American Journal of Physiology*, *253* (3, Pt. 2), H680-H689.

Drinkhill, M. J., & Mary, D. A. (1989). The effect of stimulation of the atrial receptors on plasma cortisol level in the dog. *Journal of Physiology*, *413*, 299-313.

Dustman, R. E., & Beck, E. C. (1965). Phase of alpha brain waves, reaction time and visually evoked potentials. *Electroencephalography and Clinical Neurophysiology*, *18*, 433-440.

Fingelkurts, A., Krause, C., Kaplan, A., Borisov, S., & Sams, M. (2003). Structural (operational) synchrony of EEG alpha activity during an auditory memory task. *Neuroimage*, *20* (1), 529-542.

Foreman, R. (1997). Organization of visceral input. In T. L. Yaksh, Lynch, C. III, W. M. Zapol, M. Maze, J. F. Biebuyck, & L. J. Saidman (Eds.), *Anesthesia: Biologic Foundations* (pp. 663-683). Philadelphia: Lippincott-Raven Publishers.

Foreman, R. D. (1989). Organization of the spinothalamic tract as a relay for cardiopulmonary sympathetic afferent fiber activity. *Progress in Sensory Physiology*, *9*,1-51.

Foreman, R. D. (1994). Vagal afferent modulation of cardiac pain. In M. N. Levey & P. J. Schwartz (Eds.), *Vagal control of the heart: Experimental basis and clinical implications* (pp. 345-368). Armonk, NY: Futura Publishing.

Foster, A., & Stone, T. W. (1976). Evidence for a cardiovascular modulation of central neuronal activity in man. *Experimental Neurology*, *51*, 141-149.

Fredrickson, B. L. (2002). Positive emotions. In C. R. Snyder & S. J. Lopez (Eds.). *Handbook of positive psychology* (pp. 120-134). New York, NY: Oxford University Press.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist*, *56* (3), 218-226.

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition and Emotion*, *19* (3), 313-332.

Fredrickson, B. L., Manusco, R. A., Branigan, C., & Tugade, M. M. (2000). The undoing effect of positive emotions. *Motivation and Emotion*, *24*, 237-258.

Fredrickson, B. L., Tugade, M. M., Waugh, C. E., & Larkin, G. R. (2003). What good are positive emotions in crises? A prospective study of resilience and emotions following the terrorist attacks on the United States on September 11th, 2001. *Journal of Personality and Social Psychology*, *84* (2), 365-376.

Friedman, B. H., & Thayer, J. F. (1998). Autonomic balance revisited: Panic anxiety and heart rate variability. *Journal of Psychosomatic Research*, *44* (1), 133-151.

Frysinger, R. C, & Harper, R. M. (1990). Cardiac and respiratory correlations with unit discharge in epileptic human temporal lobe. *Epilepsia*, *31* (2), 162-171.

Gabor, D. (1946). Theory of communication. *Journal of the Institute of Electrical Engineers*, *93*, 429-457.

Gabor, D. (1948). A new microscopic principle. *Nature*, *161*, 777-778.

Grossman, P., Janssen, K. H. L., & Vaitl, D. (Eds.). (1986). *Cardiorespiratory and cardiosomatic psychophysiology*. New York, NY: Plenum Press.

Groves, D. A., & Brown, V. J. (2005). Vagal nerve stimulation: A review of its applications and potential mechanisms that mediate its clinical effects. *Neuroscience and Biobehavioral Reviews*, *29* (3), 493-500.

Gutkowska, J., Jankowski, M., Mukaddam-Daher, S., & McCann, S. M. (2000). Oxytocin is a cardiovascular hormone. *Brazilian Journal of Medical and Biological Research*, *33*, 625-633.

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology*, *48* (3), 263-274.

Hassert, D. L., Miyashita, T., & Williams, C. L. (2004). The effects of peripheral vagal nerve stimulation at a memory-modulating intensity on norepinephrine output in the basolateral amygdala. *Behavioral Neuroscience*, *118* (1), 79-88.

Hirsch, J. A., & Bishop, B. (1981). Respiratory sinus arrhythmia in humans: How breathing pattern modulates heart rate. *American Journal of Physiology*, *241* (4), H620-H629.

Ho, M. W. (1998). *The rainbow and the worm: The physics of organisms*. London: World Scientific Publishing.

Huang, M. H., Friend, D. S., Sunday, M. E., Singh, K., Haley, K., Austen, K. F., . . . Smith, T. W. (1996). An intrinsic adrenergic system in mammalian heart. *Journal of Clinical Investigation*, *98* (6), 1298-1303.

Isen, A. M. (1998) On the relationship between affect and creative problem solving. In S. W. Russ (Ed.), *Affect, creative experience, and psychological adjustment* (pp. 3-17). Philadelphia: Brunner/Mazel.

Isen, A. M. (1999). Positive affect. In T. Dalgleish & M. Power (Eds.), *Handbook of cognition and emotion* (pp. 522-539). New York, NY: John Wiley & Sons.

James, W. (1884). What is an emotion? *Mind*, *9* (34), 188-205.

Kennedy, J. L. (1959). A possible artifact in electroencephalography. *Psychological Review*, *66*, 347-352.

Kentsch, M., Lawrenz, R., Ball, P., Gerzer, R., & Muller-Esch, G. (1992). Effects of atrial natriuretic factor on anterior pituitary hormone secretion in normal man. *The Clinical Investigator*, *70* (7), 549-555.

King, J. S., Xie, M., Zheng, B., & Pribram, K. H. (1994). Spectral density maps of receptive fields in the rat's somatosensory cortex. In K. H. Pribram (Ed.). *Proceedings of the second Appalachian conference on behavioral neurodynamics: origins: Brain and self organization* (pp. 557-571). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kolev, V., Yordanova, J., Schurmann, M., & Basar, E. (2001). Increased frontal phase-locking of event-related alpha oscillations during task processing. *International Journal of Psychophysiology*, *39* (2-3), 159-165.

Kosel, M., & Schlaepfer, T. E. (2003). Beyond the treatment of epilepsy: New applications of vagus nerve stimulation in psychiatry. *CNS Spectrums*, *8* (7), 515-521.

Lacey, B. C., & Lacey, J. I. (1974). Studies of heart rate and other bodily processes in sensorimotor behavior. In P. A. Obrist, A. H. Black, J. Brener, & L. V. DiCara (Eds.), *Cardiovascular psychophysiology: Current issues in response mechanisms, biofeedback, and methodology* (pp. 538-564). Chicago: Aldine.

Lacey, J. I. (1967). Somatic response patterning and stress: Some revisions of activation theory. In M. H. Appley & R. Trumbull (Eds.), *Psychological stress: Issues in research* (pp.14-42). New York, NY: Appleton-Century-Crofts.

Lacey, B. C, & Lacey, J. I. (1964, October). *Cardiac deceleration and simple visual reaction in a fixed foreperiod experiment*. Paper presented at the meeting of the Society for Psychophysiological Research, Washington, D.C.

Lacey, J. I., & Lacey, B. C. (1970). Some autonomic-central nervous system interrelationships. In P. Black (Ed.), *Physiological correlates of emotion* (pp. 205-227). New York, NY: Academic Press.

Lader, M., & Mathews, A. (1970). Physiological changes during spontaneous panic attacks. *Journal of Psychosomatic Research*, *14* (4), 377-382.

Lane, R. D, Reiman, E. M., Ahern, G. L., & Thayer, J. F. (2001). Activity in medial prefrontal cortex correlates with vagal component of heart rate variability during emotion. *Brain and Cognition*, *47*, 97-100.

Langhorst, P., Schulz, G., & Lambertz, M. (1984). Oscillating neuronal network of the "common brainstem system." In K. Miyakawa, H. P. Koepchen, & C. Polosa (Eds.), *Mechanisms of blood pressure waves* (pp. 257-275). Tokyo: Japan Scientific Societies Press.

Langhorst, P., Schulz, G., & Lambertz, M. (1986). Integrative control mechanisms for cardiorespiratory and somatomotor functions in the reticular formation of the lower brain stem. In P. Grossman, K. H. L. Janssen, & D. Vaitl (Eds.), *Cardiorespiratory and cardiosomatic psychophysiology* (pp. 9-39). New York, NY: Plenum Press.

Lansing, R. W. (1957). Relation of brain and tremor rhythms to visual reaction time. *Electroencephalography and Clinical Neurophysiology, 9* (3), 497-504.

Lehrer, P., Sasaki, Y., & Saito, Y. (1999). Zazen and cardiac variability. *Psychosomatic Medicine*, *61*, 812-821.

Lehrer, P., Smetankin, A., & Potapova, T. (2000). Respiratory sinus arrhythmia biofeedback therapy for asthma: A report of 20 unmedicated pediatric cases using the Smetankin method. *Applied Psychophysiology and Biofeedback*, *25* (3), 193-200.

Lehrer, P. M, Vaschillo, E., Vaschillo, B., Lu, S. E., Eckberg, D. L., Edelberg, R., . . . Hamer, R. M. (2003). Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. *Psychosomatic Medicine, 65* (5), 796-805.

Lessmeier, T. J., Gamperling, D., Johnson-Liddon, V., Fromm, B. S., Steinman, R. T., Meissner, M. D, & Lehmann, M. H. (1997). Unrecognized paroxysmal supraventricular tachycardia: Potential for misdiagnosis as panic disorder. *Archives of Internal Medicine*, *157*, 537-543.

Lindsley, D. B. (1961) The reticular activating system and perceptual integration. In D. E. Sheer (Ed.). *Electrical stimulation of the brain* (pp. 331-349). Austin: University of Texas.

Luskin, F., Reitz, M., Newell, K., Quinn, T. G., & Haskell, W. (2002). A controlled pilot study of stress management training of elderly patients with congestive heart failure. *Preventive Cardiology*, *5* (4), 168-172, 176.

Lutz, A., Greischar, L. L., Rawlings, N. B., Ricard, M., & Davidson R. J. (2004). Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. *Proceedings of the National Academy of Sciences USA*, *101* (46), 16369-16373.

Mauskop, A. (2005). Vagus nerve stimulation relieves chronic refractory migraine and cluster headaches. *Cephalalgia*, *25* (2), 82-86.

McCraty, R. (2003). *Heart–brain neurodynamics: The making of emotions* (Publication No. 03-015). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Retrieved from http://store.heartmath.org/store/e-books/heart-brain-neurodynamics

McCraty R. (2004). The energetic heart: Bioelectromagnetic communication within and between people. In P. J. Rosch & M. S. Markov (Eds.), *Bioelectromagnetic medicine* (pp. 541-562). New York, NY: Marcel Dekker. (An expanded version of this publication, *The energetic heart: Bioelectromagnetic interactions within and between people*, is available at http://store.heartmath.org/store/e-books/energetic-heart)

McCraty, R., Atkinson, M., & Bradley, R. T. (2004a). Electrophysiological evidence of intuition: Part 1. The surprising role of the heart. *Journal of Alternative and Complementary Medicine*, *10* (1), 133-143.

McCraty, R., Atkinson, M., & Bradley, R. T. (2004b). Electrophysiological evidence of intuition: Part 2. A system-wide process? *Journal of Alternative and Complementary Medicine, 10* (2), 325-336.

McCraty, R., Atkinson, M., & Lipsenthal, L. (2000). *Emotional self-regulation program enhances psychological health and quality of life in patients with diabetes* (Publication No. 00-006). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Retrieved from http://www.heartmath.org/research/rp-emotional-self-regulation-program-enhances-psychological-health-and-quality-of-life-in-patients.html

McCraty, R., Atkinson, M., Lipsenthal, L., & Arguelles L. (2003). *Impact of the power to change performance program on stress and health risks in correctional officers* (Report No. 03-014). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath.

McCraty, R., Atkinson, M., Rein, G., & Watkins, A. D. (1996). Music enhances the effect of positive emotional states on salivary IgA. *Stress Medicine*, *12* (3), 167-175.

McCraty, R., Atkinson, M., Tiller, W. A., Rein, G., & Watkins, A. D. (1995). The effects of emotions on short-term heart rate variability using power spectrum analysis. *American Journal of Cardiology*, *76* (14), 1089-1093.

McCraty, R., Atkinson, M., & Tomasino, D. (2001). *Science of the heart: Exploring the role of the heart in human performance* (Publication No. 01-001). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Retrieved from http://www.heartmath.org/research/science-of-the-heart.html

McCraty, R., Atkinson, M., & Tomasino, D. (2003). Impact of a workplace stress reduction program on blood pressure and emotional health in hypertensive employees. *Journal of Alternative and Complementary Medicine*, *9* (3), 355-369.

McCraty, R., Atkinson, M., Tomasino, D., Goelitz, J., & Mayrovitz, H. N. (1999). The impact of an emotional self-management skills course on psychosocial functioning and autonomic recovery to stress in middle school children. *Integrative Physiological and Behavioral Science*, *34* (4), 246-268.

McCraty, R., Barrios-Choplin, B., Rozman, D., Atkinson, M., & Watkins, A. D. (1998). The impact of a new emotional self-management program on stress, emotions, heart rate variability, DHEA and cortisol. *Integrative Physiological and Behavioral Science*, *33* (2), 151-170.

McCraty, R., & Childre, D. (2004). The grateful heart: The psychophysiology of appreciation. In R. A. Emmons & M. E. McCullough (Eds.), *The psychology of gratitude* (pp. 230-255). New York, NY: Oxford University Press. (An expanded version of this publication, *The appreciative heart: The psychophysiology of positive emotions and optimal functioning*, is available at http://store.heartmath.org/store/e-books/appreciative-heart)

McCraty, R., & Tomasino, D. (2006). Emotional stress, positive emotions, and psychophysiological coherence. In B. B. Arnetz & R. Ekman (Eds.) S*tress in Health and Disease* (pp. 342-365), Weinheim, Germany: Wiley-VCH.

McCraty, R., & Tomasino, D. (2006). The coherent heart: Heart-brain interactions, psychophysiological coherence, and the emergence of system wide order (Publication No. 06-022). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath.

McCraty, R., & Tomasino, D. (2004, November). Heart rhythm coherence feedback: A new tool for stress reduction, rehabilitation, and performance enhancement. In *Proceedings of the First Baltic Forum on Neuronal Regulation and Biofeedback*, Riga, Latvia. Retrieved from http://www.heartmath.org/research/publications.html

Medalie, J. H., & Goldbourt, U. (1976). Angina pectoris among 10,000 men. II. Psychosocial and other risk factors as evidenced by a multivariate analysis of a five-year incidence study. *American Journal of Medicine*, *60* (6), 910-921.

Montoya, P., Schandry, R., & Muller, A. (1993). Heartbeat evoked potentials (HEP), Topography and influence of cardiac awareness and focus of attention. *Electroencephalography and Clinical Neurophysiology*, *88*, 163-172.

Moskowitz, J. T. (2003). Positive affect predicts lower risk of AIDS mortality. *Psychosomatic Medicine*, *65* (4), 620-626.

Mukoyama, M., Nakao, K., Hosoda, K., Suga, S., Saito, Y., Ogawa, Y., . . . Yasue H. (1991). Brain natriuretic peptide as a novel cardiac hormone in humans. Evidence for an exquisite dual natriuretic peptide system, atrial natriuretic peptide and brain natriuretic peptide. *Journal of Clinical Investigation*, *87* (4), 1402-1412.

Nadeau, R., & Kafatos, M. (1999). The non-local universe: The new physics and matters of the mind. New York, NY: Oxford University Press.

Nakaya, Y. (1984). Magnetocardiography: A comparison with electrocardiography. *Journal of Cardiography Supplement, 3,* 31-40.

Nunez, P. L. (2000). Toward a quantitative description of large-scale neocortical dynamic function and EEG. *Behavioral and Brain Sciences*, *23* (3), 371-398, discussion 399-437.

Nunn, C. M., & Osselton, J. W. (1974). The influence of the EEG alpha rhythm on the perception of visual stimuli. *Psychophysiology, 11* (3), 294-303.

Oppenheimer, S., & Hopkins, D. (1994). Suprabulbar neuronal regulation of the heart. In J.A. Armour & J. L. Ardell (Eds.), *Neurocardiology* (pp. 309-341). New York, NY: Oxford University Press.

Ostir, G. V., Markides, K. S., Black, S. A., & Goodwin, J. S. (2000). Emotional well-being predicts subsequent functional independence and survival. *Journal of the American Geriatrics Society*, *48* (5), 473-478.

Ostir, G. V., Markides, K. S., Peek, M. K., & Goodwin, J. S. (2001). The association between emotional well-being and the incidence of stroke in older adults. *Psychosomatic Medicine*, *63* (2), 210-215.

Peng, C. K., Buldyrev, S. V., Hausdorff, J. M., Havlin, S., Mietus, J. E., Simons, M., . . . Goldberger, A. L. (1994). Non-equilibrium dynamics as an indispensable characteristic of a healthy biological system. *Integrative Physiological and Behavioral Science*, *29* (3), 283-293.

Porges, S. W. (1992). Vagal tone: A physiologic marker of stress vulnerability. *Pediatrics*, *90* (3, Pt. 2), 498-504.

Pribram, K. H. (1971). *Languages of the brain*. New York, NY: Brandon House.

Pribram, K. H. (1991). *Brain and perception: Holonomy and structure in figural processing*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Pribram, K. H., & Bradley, R. T. (1998). The brain, the me, and the I. In M. Ferrari & R. Sternberg (Eds.), *Self-awareness: Its nature and development* (pp. 273-307). New York, NY: The Guilford Press.

Pribram, K. H, & Melges, F. T. (1969) Psychophysiological basis of emotion. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology* (pp. 316-341). Amsterdam: North-Holland Publishing Company.

Randich, A., & Gebhart, G. F. (1992). Vagal afferent modulation of nociception. *Brain Research Reviews*, *17,* 77-99.

Rapgay, L. (n.d.) Unpublished results.

Raschke, F. (1986a). Coordination in the circulatory and respiratory systems. In L. Rensing, U. an der Heiden, & M. C. Mackey (Eds.), *Temporal disorder in human oscillatory systems* (pp. 152-158). Berlin Springer-Verlag.

Raschke, F. (1986b). The hierarchical order of cardiovascular-respiratory coupling. In P. Grossman, K. H. L. Janssen, & D. Vaitl (Eds.), *Cardiorespiratory and cardiosomatic psychophysiology* (pp. 207-217). New York, NY: Plenum Press.

Ratey, J. J. (2001). *A user's guide to the brain perception, attention, and the four theaters of the brain*. New York, NY: Pantheon Books.

Rau, H., Pauli, P., Brody, S., Elbert, T., & Birbaumer, N. (1993). Baroreceptor stimulation alters cortical activity. *Psychophysiology*, *30* (3), 322-325.

Rein, G., Atkinson, M., & McCraty, R. (1995). The physiological and psychological effects of compassion and anger. *Journal of Advancement in Medicine*, *8* (2), 87-105.

Rice, D. M., & Hagstrom, E. C. (1989). Some evidence in support of a relationship between human auditory signal-detection performance and the phase of the alpha cycle. *Perceptual and Motor Skills*, *69* (2), 451-457.

Russek, L. G., & Schwartz, G. E. (1994). Interpersonal heart-brain registration and the perception of parental love: A 42 year follow-up of the Harvard Mastery of Stress Study. *Subtle Energies*, *5* (3), 195-208.

Russek, L. G., & Schwartz, G. E. (1996). Energy cardiology: A dynamical energy systems approach for integrating conventional and alternative medicine. *Advances*, *12* (4), 4-24.

Russek, L. G, & Schwartz, G. E. (1997). Feelings of parental caring predict health status in midlife: A 35-year follow-up of the Harvard Mastery of Stress Study. *Journal of Behavioral Medicine*, *20* (1), 1-13.

Sandman, C. A, Walker, B. B., & Berka, C. (1982). Influence of afferent cardiovascular feedback on behavior and the cortical evoked potential. In J. T. Cacioppo & R. E. Petty (Eds.), *Perspectives in cardiovascular psychophysiology* (189-222). New York, NY: The Guilford Press.

Santa Maria, M., King, J., Xie, M., Zheng, B., Pribram, K. H., & Doherty, D. (1995). Responses of somatosensory cortical neurons to spatial frequency and orientation: A progress report. In J. S. King & K. H. Pribram (Eds.), *Scale in conscious experience: Is the brain too important to be left to specialists to study*? Mahwah, NJ: Lawrence Erlbaum Associates.

Schandry, R., & Montoya, P. (1996). Event-related brain potentials and the processing of cardiac activity. *Biological Psychology*, *42*, 75-85.

Schandry, R., Sparrer, B., & Weitkunat, R. (1986). From the heart to the brain: A study of heartbeat contingent scalp potentials. *International Journal of Neuroscience*, *30*, 261-275.

Schofl, C., Prank, K., & Brabant, G. (1995). Pulsatile hormone secretion for control of target organs. *Wiener Medizinische Wochenschrift*, *145* (17-18), 431-435.

Schore, A. N. (1994). *Affect regulation and the origin of the self: The neurobiology of emotional development*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Seeman, T. E, & Syme, S. L. (1987). Social networks and coronary artery disease: A comparison of the structure and function of social relations as predictors of disease. *Psychosomatic Medicine*, *49* (4), 341-354.

Siddle, B. K. (1995). *Sharpening the warrior's edge: The psychology and science of training*. Millstadt, IL: PPCT Research Publications, PPCT Management Systems.

Siegel, G., Ebeling, B. J., Hofer, H. W., Nolte, J., Roedel, H., & Klubendorf, D. (1984). Vascular smooth muscle rhythmicity. In K. Miyakawa, H. P. Koepchen, & C. Polosa (Eds.), *Mechanisms of blood pressure waves* (pp. 319-338). Tokyo: Japan Scientific Societies Press.

Song, L. Z., Schwartz, G. E., & Russek, L. G. (1998). Heart-focused attention and heart-brain synchronization: Energetic and physiological mechanisms. *Alternative Therapies in Health and Medicine, 4* (5), 44-62.

Strohle, A., Kellner, M., Holsboer, F., & Wiedemann K. (1998). Atrial natriuretic hormone decreases endocrine response to a combined dexamethasone-corticotropin-releasing hormone test. *Biological Psychiatry, 43* (5), 371-375.

Svensson, T. H, & Thoren, P. (1979). Brain noradrenergic neurons in the locus coeruleus: Inhibition by blood volume load through vagal afferents. *Brain Research, 172* (1), 174-178.

Telegdy, G. (1994). The action of ANP, BNP and related peptides on motivated behavior in rats. *Reviews in the Neurosciences, 5* (4), 309-315.

Tiller, W. A., McCraty, R., & Atkinson, M. (1996). Cardiac coherence: A new, noninvasive measure of autonomic nervous system order. *Alternative Therapies in Health and Medicine, 2* (1), 52-65.

Turpin, G. (1986). Cardiac-respiratory integration: Implications for the analysis and interpretation of phasic cardiac responses. In P. Grossman, K. H. L. Janssen, & D. Vaitl (Eds.), *Cardiorespiratory and cardiosomatic psychophysiology* (139-155). New York, NY: Plenum Press.

Van der Molen, M. W., Somsen, R. J. M., & Orlebeke, J. F. (1985). The rhythm of the heart beat in information processing. In P. K. Ackles, J. R. Jennings, M. G. H. Coles (Eds.), *Advances in psychophysiology* (Vol. 1) (pp. 1-88). London, England: JAI Press.

Velden, M., & Juris, M. (1975). Perceptual performance as a function of intra-cycle cardiac activity. *Psychophysiology, 12* (6), 685-692.

Vollmar, A. M., Lang, R. E., Hanze, J., & Schulz, R. (1990). A possible linkage of atrial natriuretic peptide to the immune system. *American Journal of Hypertension, 3* (5, Pt. 1), 408-411.

Walker, B. B., & Walker, J. M. (1983). Phase relations between carotid pressure and ongoing electrocortical activity. *International Journal of Psychophysiology, 1* (1), 65-73.

Wesnes, K. A, Ward, T., McGinty, A., & Petrini O. (2000). The memory enhancing effects of a Ginkgo biloba/Panax ginseng combination in healthy middle-aged volunteers. *Psychopharmacology, 152* (4), 353-361.

Wolf, S. (1995). Oscillatory functions affecting outcome of coronary heart disease: The hazard of too much or too little stability. *Integrative Physiological and Behavioral Science, 30* (2), 118-126.

Wölk, C., & Velden, M. (1987). Detection variability within the cardiac cycle: Toward a revision of the “baroreceptor hypothesis.” *Journal of Psychophysiology, 1*, 61-65.

Wölk, C., & Velden, M. (1989). Revision of the baroreceptor hypothesis on the basis of the new cardiac cycle effect. In N. W. Bond & D. A. T. Siddle (Eds.), *Psychobiology: Issues and applications* (pp. 371-379). North-Holland: Elsevier Science Publishers.

Wölk, C., Velden, M., Zimmerman, U., & Krug, S. (1989). The interrelation between phasic blood pressure and heart rate changes in the context of the “baroreceptor hypothesis.” *Journal of Psychophysiology, 3*, 397-402.

Zhang, J. X., Harper, R. M., & Frysinger, R. C. (1986). Respiratory modulation of neuronal discharge in the central nucleus of the amygdala during sleep and waking states. *Experimental Neurology*, *91*, 193-207.

Rollin McCraty, Ph.D. *of Boulder Creek, California, is the GCMS project coordinator. McCraty, who has been with the Institute of HeartMath since its creation in 1991, is IHM's executive vice president and director of research. A psychophysiologist, Dr. McCraty's research interests include the physiology of emotion, with a focus on the mechanisms by which emotions influence cognitive processes, behavior, and health. A fellow of the American Institute of Stress, McCraty is a member of the International Neurocardiology Network, American Autonomic Society, Pavlovian Society and Association for Applied Psychophysiology and Biofeedback. He and his team regularly participate in studies with scientific, medical and educational institutions worldwide, including Stanford University, Arizona State University, Wake Forest University, Clemson University and the Miami Heart Research Institute. His research has appeared in many journals, including the American Journal of Cardiology, Journal of the American College of Cardiology, Stress Medicine and Biological Psychology.* www.heartmath.org
Email: rollin@heartmath.org

Mike Atkinson *of Boulder Creek, California, the Institute of HeartMath's Research Center laboratory manager, is responsible for key development and implementation aspects of the Global Coherence Monitoring System. He has extensive experience gathering, processing and performing statistical analysis of a wide range of psychophysiological data. Atkinson is co-holder of three patents related to physiological coherence monitoring used in organizational, educational and health-care settings. Short-term and 24-hour HRV assessments he designed are used internationally by physicians, researchers and health organizations. Atkinson, co-author of several psychological surveys used to assess stress, emotions and organizational effectiveness, has played a key role in many laboratory and field research studies examining the effects of stress and emotions on bodily systems, including heart-brain interactions and cognitive performance. He has co-written many scientific papers published in numerous professional journals.* www.heartmath.org

Dana Tomasino *has a research background in molecular biology and psychophysiology, and a passion for using an energy-based approach to elucidate fundamental patterns and processes that connect and unify the cellular/molecular, physiological, emotional, social, and spiritual dimensions of experience. With her colleagues at the Institute of HeartMath, she has studied heart–brain interactions and the mechanisms by which positive emotions influence cognitive processes, intuition, behavior, and health.*

Raymond Trevor Bradley, Ph.D. *originally from New Zealand and now Capitola, California, has been pioneering the multidisciplinary application of physics, information science, neuropsychology, psychophysiology, and sociology in research to understand fundamental processes in social collectives. Dr. Bradley has conducted a vast array of research, including studies on the psychophysiological basis of intuitive foreknowledge and nonlocal communication, his current area of interest. He has published four research monographs and the book, Charisma and Social Structure: A Study of Love and Power, Wholeness and Transformation. His research has led him to write more than 40 articles in sociology,* *psychology, neuroscience, psychophysiology and management science. Bradley directs the Institute for Whole Social Science, is senior research scientist at the Institute of HeartMath and a longtime member of the HeartMath Scientific Advisory Board.* www.heartmath.org/research/publications.html

Appendixes

Appendix A: Modes of Psychophysiological Function

In the course of our research on the relationship between HRV and emotion, we observed that certain psychophysiological states were consistently associated with distinct psychological and behavioral correlates as well as with specific patterns of physiological activity throughout the body. As these systemic patterns were found to hold over many trials across diverse study populations, we concluded that they constituted six general categories of psychophysiological function, which we call *modes*, each of which is distinguished by a unique set of characteristics. Although there is individual variation within each mode, there are broader empirical commonalities that are characteristic of each mode and that differentiate the six modes from one another.

Four of these psychophysiological modes are readily generated in the context of everyday life. We have termed these modes *Mental Focus* (associated with impassive emotions experienced while attention is directed to performing familiar, cognitively engaging tasks or actions), *Psychophysiological Incoherence* (associated with negative emotions such as anger, anxiety, etc.), *Relaxation* (associated with calm emotions experienced while resting from the effort and stress of everyday life), and *Psychophysiological Coherence* (associated with positive emotions such as appreciation, care, compassion, etc.). We have also identified two additional modes, *Emotional Quiescence* and *Extreme Negative Emotion*, which both appear to belong to a qualitatively different category of psychophysiological function. These two modes are physiologically and experientially distinct from the other four modes and are generated under more extraordinary life circumstances. Before moving on to describe the emotional tone and empirical characteristics of each of these modes, it is necessary to provide some information on the heart rhythm data presented in the graphs in this section.

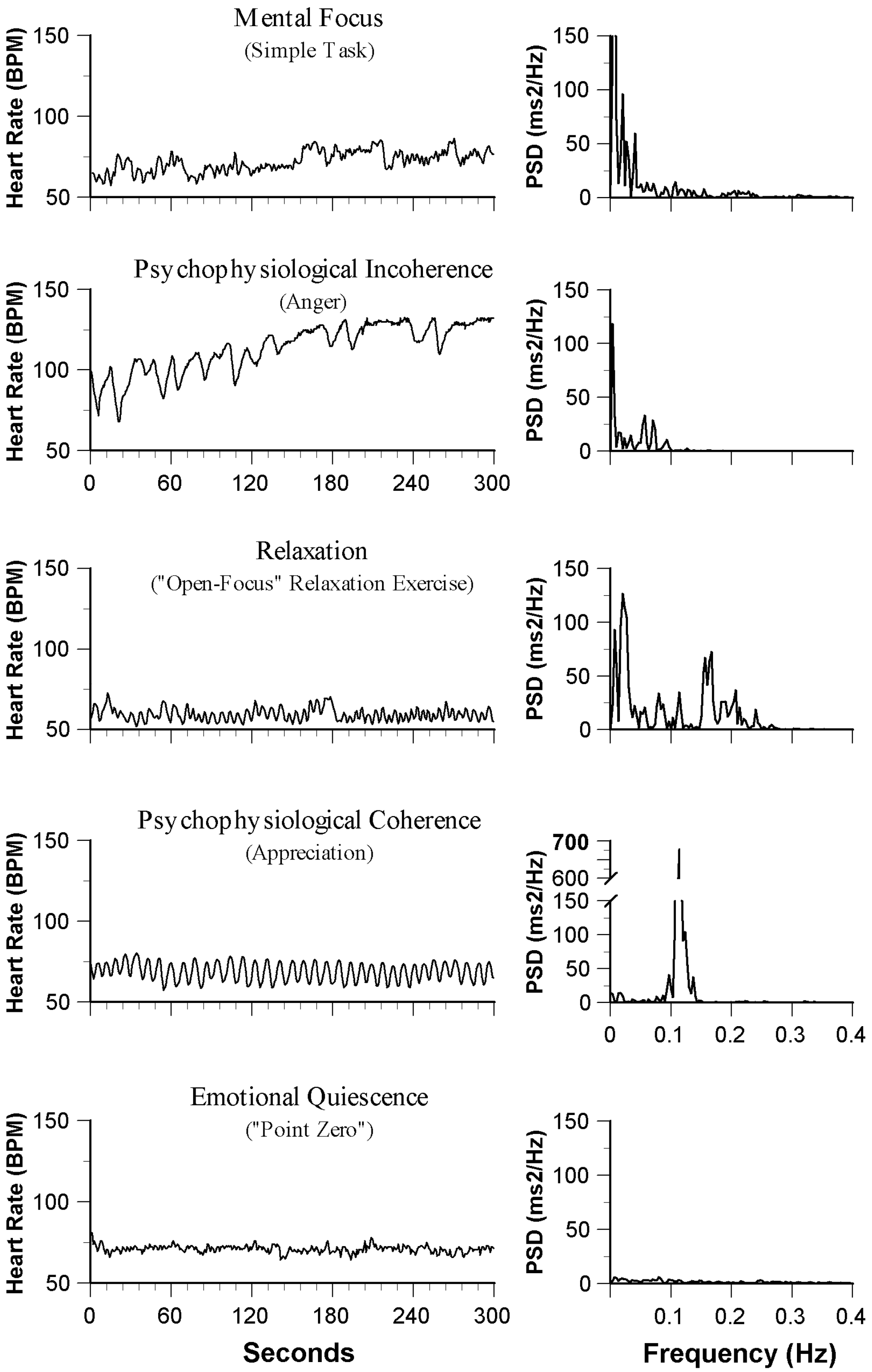


Figure 8. Heart rhythm patterns during different psychophysiological modes.

The left-hand graphs are heart rate tachograms, which show beat-to-beat changes in heart rate. To the right are the heart rate variability power spectral density (PSD) plots of the tachograms at left. While there are individual variations in the HRV patterns associated with each mode, the examples depicted are typical of the characteristic aspects of the more general patterns observed for each mode. *Mental Focus* is characterized by reduced HRV. Activity in all three frequency bands of the HRV power spectrum is present. Anger, an example of the *Psychophysiological Incoherence* mode, is characterized by a lower frequency, more disordered heart rhythm pattern and increasing mean heart rate. As can be seen in the corresponding power spectrum to the right, the rhythm during anger is primarily in the very low frequency region, which is associated with sympathetic nervous system activity. In this example, the anger was intense enough to drive the system into an extreme state, where the heart rhythm trace became flat (indicating very low HRV) around 200 seconds. *Relaxation* results in a higher frequency, lower amplitude rhythm, indicating reduced autonomic outflow. In this case, increased power in the high frequency region of the power spectrum is observed, reflecting increased parasympathetic activity (the relaxation response). *Psychophysiological Coherence*, which is associated with sustained positive emotions (in this example, appreciation), results in a highly ordered, sine-wave-like heart rhythm pattern. As can be seen in the corresponding power spectrum, this psychophysiological mode is associated with a large, narrow peak in the low frequency region, centered around 0.1 Hz. Note the scale difference in the amplitude of the spectral peak during the coherence mode. This indicates system-wide resonance, increased synchronization between the sympathetic and parasympathetic branches of the nervous system, and entrainment between the heart rhythm pattern, respiration, and blood pressure rhythms. The coherence mode is also associated with increased parasympathetic activity, thus encompassing a key element of the relaxation response, yet it is physiologically distinct from relaxation because the system is oscillating at its resonant frequency and there is increased harmony and synchronization in nervous system and heart–brain dynamics. The *Emotional Quiescence* mode is characterized by state-specific very low HRV. Due to the low HRV, the power spectrum has very little power in any of the three frequency regions.

Figure 8 shows the typical heart rhythm patterns and the associated HRV power spectra for the six psychophysiological modes we have identified. These patterns are reflective of the ongoing adjustments of the various physiological systems in relation to the ever-changing processes in the body and in the external environment. The normal variability in heart rate is due to the synergistic action of the two branches of the ANS, which act to maintain cardiovascular parameters in their optimal ranges and to permit appropriate reactions to changing external or internal conditions. In a healthy individual, the heart rate estimated at any given time represents the net effect of the parasympathetic (vagus) nerves, which slow heart rate, and the sympathetic nerves, which accelerate it. We use the term *adaptive variability* to denote these ongoing moment-by-moment accommodations. Within normal parameters, greater amplitudes of oscillation are associated with health. Thus, the amplitude of rhythmic physiological processes, such as heart rhythms, may index the health status of the individual’s nervous system and capacity to respond to environmental demands (Friedman & Thayer, 1998; Peng et al., 1994; Porges, 1992; Wolf, 1995).

The left-hand graphs are heart rate tachograms, which show the beat-to beat changes in heart rate (heart rhythms) in the different modes. These patterns have been identified in recordings obtained both in the laboratory and in real-life circumstances from a database of more than one thousand cases.

To the right are shown the heart rate variability power spectral density (PSD) plots for each of the heart rhythms. To discriminate and quantify sympathetic and parasympathetic activity and total autonomic nervous system activity, the HRV data must be converted into their spectral components. This is done by applying a mathematical transformation, the Fast-Fourier Transform. The resultant power spectrum reduces the heart rhythm into its constituent frequency components. These are divided into three main frequency ranges, each of which corresponds to a specific physiological activity and rhythm.

The very low frequency (VLF) range (0.0033–0.04 Hz) is primarily an index of sympathetic activity, while power in the high frequency (HF) range (0.15–0.4 Hz), representing more rapid beat-to-beat changes in heart rate, is primarily due to parasympathetic activity. The frequency range encompassing the 0.1 Hz region is called the low frequency (LF) range (0.04–0.15 Hz) and reflects activity in the feedback loops between the heart and brain that control short-term blood pressure changes and other regulatory processes. The physiological factors contributing to activity in the LF range are complex, reflecting a mixture of sympathetic and parasympathetic efferent and afferent activity as well as vascular system resonance.

The six psychophysiological modes we have identified will next be distinguished in terms of their emotional tone and associated heart rhythm and ANS activation patterns. It should be noted that these modes can also be distinguished on the basis of the patterns of their associated energetic (electromagnetic) activity; this is discussed in Appendix E.

Modes of Everyday Psychophysiological Function

Mental Focus

The top graph in Figure 8 depicts a typical heart rhythm pattern and the associated HRV power spectrum during a period of “mental focus.” We use this term to describe an impassive emotional state experienced while performing a familiar, routine task or action. This state is primarily one of mental attention to the task at hand and, as such, is characterized by little or no emotional arousal, either of a positive or negative nature, and low motor activity. In the example shown in Figure 8, the research subject was sitting quietly while focused on a routine computer task. As depicted in the heart rhythm graph (left-hand side), the HRV pattern is relatively constrained in its overall amplitude variation, and there is less higher frequency variability as compared to the pattern for relaxation.

The HRV power spectrum (right-hand side of Figure 8) shows some activity in all three frequency bands, as would be expected from examining the heart rhythm trace. The multiple peaks present in the VLF region indicate that the organization of oscillations in this band is unstable and variable; this is apparent in the heart rhythm data as well. The fact that the overall heart rate remains relatively constant (approximately 70 bpm), indicates, in this example, that there was not an increased activation of the sympathetic nervous system. However, there appears to be less synchronized activity in overall ANS function as compared to the coherence or relaxation modes, which is reflected in the more erratic heart rhythm pattern. The power in the HF band is much lower than that in the Relaxation mode, indicating there is less parasympathetic activity. This typically correlates with shallower, faster breathing rhythms. There is also reduced power in the LF band, which is a common finding in tasks that require primarily mental focus with little motor activity. In sum, these data show that there is reduced autonomic activity and overall HRV during periods of mental focus when compared to the relaxation or coherence modes.

Psychophysiological Incoherence

Psychophysiological Incoherence is associated with negative emotions, such as anger, frustration, and anxiety. While there is some variation within this mode in the morphology of the associated HRV waveforms, Psychophysiological Incoherence is generally typified by an erratic and disordered heart rhythm pattern (see the example of frustration in Figure 1). The example of this mode shown in Figure 8 was recorded when this individual was experiencing an episode of anger during an argument with his wife while sitting still in a car. In this case, the emotion of anger was sufficiently intense to activate the sympathetic nervous system, resulting in a more pronounced VLF rhythm and an increasing mean heart rate. As can be seen in the corresponding power spectrum to the right, there is a single large peak in the VLF region, which indicates sustained sympathetic activation, whereas the HF region shows virtually no activity. The activity in the LF region remains strong because the physiological mechanisms regulating blood pressure are active in order to maintain control and inhibit sympathetic outflow so that the blood pressure does not reach levels that will harm the system.

In addition to the Psychophysiological Incoherence mode, which is the main pattern observed in this recording, parts of this same recording also show another pattern of psychophysiological response that is indicative of a different mode, evident in the segments circled in Figure 8. This pattern illustrates what happens when an individual experiences an extreme negative emotion—in this case, intense anger. Extreme negative emotions such as this can lead to excessive sympathetic activation, in which the heart rate increase approaches the range of maximum function and where the heart rate variability pattern almost flattens out. We believe that this psychophysiological pattern is indicative of a "hyper-state" of extreme negative emotional experience, which is described in more detail below.

Relaxation

The Relaxation mode is a state of emotional calm experienced when resting from the activity and stress of everyday life. It is characterized by a higher frequency, lower amplitude rhythm, and a virtually steady heart rate (approximately 60 bpm in this example) once the system has stabilized in this mode. In the beginning of the shift into relaxation, however, there is also typically a decrease in heart rate, which indicates a reduction in overall autonomic outflow and a shift in autonomic balance towards increased parasympathetic activity. This example (Figure 8) is from a case in a study in which the research subjects were instructed to sit quietly and not to engage in any active cognitive or emotional processing or to use any specific meditative or emotional management techniques. The increased parasympathetic activity can be clearly seen in the relatively large peak in the HF band of the power spectrum. There is also activity in both the VLF and LF bands because the sympathetic and blood pressure control rhythms are still active (as would be expected), although there is shift to increased parasympathetic activity (the relaxation response) and lower overall HRV. This same rhythm and power spectral signature are also seen during periods of restful sleep.

It is imperative that the Relaxation mode not be confused or confounded with the Psychophysiological Coherence mode described next. There is typically an overall reduction in ANS outflow and a shift in ANS balance towards increased parasympathetic activity during periods of rest or relaxation, or with structured relaxation or meditation techniques (resulting in lower HRV). Although the coherence mode is also associated with increased parasympathetic activity, and thus encompasses a key element of the relaxation response, relaxation and meditation are *not* usually associated with significant increases in physiological coherence. Not only are there fundamental differences between the physiological correlates of relaxation and coherence, but the associated psychological states are also markedly different. Many relaxation and mediation techniques (with specific exceptions) are essentially disassociation techniques, whereas the psychological states associated with coherence are directly related to activated positive emotions.[16]

Psychophysiological Coherence

The example of the Psychophysiological Coherence mode shown in Figure 8 was generated when this research participant was instructed to activate and sustain a genuine feeling of "appreciation." The graph shows how sustained, modulated positive emotions, such as appreciation or love, are associated with a highly ordered, smooth, sine-wave-like heart rhythm pattern (coherence). It is important to understand that although the coherence mode is typically associated with increased parasympathetic activity, whether a shift in heart rate (either up or down) occurs depends on the preceding psychophysiological state of the individual. The coherence mode thus does not necessarily involve a change in *heart rate* per se, or a change in the *amount* of heart rate variability. Rather, it is signified by a shift to a distinctive heart rhythm *pattern*.

As can be seen in the corresponding power spectrum, this psychophysiological mode is associated with an unusually high-amplitude peak in the LF band, centered around 0.1 Hz. To appreciate the magnitude of this difference relative to the other five modes, it is important to observe that there is a scale difference in the amplitude of the spectral peak in the LF region in the coherence mode[17] (note the changed ordinate scale for Appreciation relative to the other

---

[16] Meditation and relaxation techniques can be inappropriately thought to induce coherence when they are combined with specific breathing techniques, because certain paced breathing rhythms also induce the physiological coherence mode.

[17] When speaking of coherence in a psychophysiological context, it is important to note the distinction between types of patterns that are associated with organized, healthy function and those that underlie pathology. Within normal parameters, a greater amplitude of oscillation in heart rate variability and most other physiological processes is associated with health. Thus, the amplitude of the oscillations associated with the heart's rhythm is a general index of the status of the individual's nervous system and capacity to respond to change. In other words, the greater the amplitude of "organized" rhythmic physiological variability, the greater the response potential or possible range of behavior. This is relevant to our discussion of coherence because many illnesses are characterized by a reduction in the complexity of the patterns of activity generated by the body's systems (i.e., previously complex rhythms and patterns become strikingly periodic and predictable). For example, a low overall HRV is associated with autonomic neuropathy and autonomic deinnervation (as found in heart transplant recipients) and is

modes): the top of the peak is near 700 while it is below 150 in all of the other examples. This indicates system-wide resonance, increased synchronization between the sympathetic and parasympathetic branches of the nervous system, and entrainment between the heart rhythm pattern, respiration, and blood pressure rhythms.

One may observe that the heart rhythm in both the relaxation and coherence modes can manifest a sine-wave-like pattern. In the psychophysiological coherence mode, however, this pattern occurs at a lower frequency and typically with a higher amplitude. Even more significantly, in the coherence mode increased synchronization, resonance, and entrainment across multiple bodily systems occur, all of which reflect a level of global organization that is not present in the relaxation mode.

Although in relaxation increased autocoherence can occur in the breathing rhythm (as in the example shown in Figure 8) and it is also possible to have a type of entrainment between the respiration and heart rhythms, these characteristics are *not* reflective of the system-wide entrainment or resonance that typify psychophysiological coherence. The type of entrainment that is sometimes observed in the relaxation mode occurs in the high frequency range of the HRV power spectrum and is associated with respiratory sinus arrhythmia (RSA), which is discussed in detail in the main text.

We have found that as the respiratory rate is lowered, there is a tipping point (typically below 0.26 Hz) at which the heart rate variability pattern, blood pressure rhythm and respiratory rhythms suddenly entrain. In essence, the system jumps to a different physiological mode and settles into a new oscillatory rhythm at its resonant frequency. In the majority of people, the lower and upper thresholds for the onset of the coherence mode are approximately 0.04 and 0.26 Hz, respectively, in the HRV power spectrum, but the rhythm typically settles at the system's resonant frequency of ~0.1 Hz.

Modes Distinguished by Low Variability

As noted previously, we have empirical evidence of two additional modes that appear to belong to a qualitatively different category of psychophysiological function than the four modes of everyday function just described. What sets these patterns apart is that they are not typically experienced in the course of normal everyday life but, instead, occur under extraordinary or unusual circumstances. Also, they are physiologically and experientially distinct—physiologically, they are both associated with very low heart rate variability; experientially, they are at opposite ends of the spectrum, with one mode being associated with an uncommon sense of inner peace and the other mode associated with extreme negative emotions such as anger and rage.

---

predictive of increased risk of sudden cardiac death and all-cause mortality. Low HRV is also associated with depression, anxiety and many other psychological disorders.

This loss of variability and complexity is quite different from the type of coherence we are describing. The coherent mode described here is not characterized by a loss of variability, but rather by the emergence of a more organized variability. Additionally, it is important to note that these are not steady states, such as those associated with disease; rather, they are highly dynamic and changing.

Emotional Quiescence

In addition to the psychophysiological coherence mode, there is also another, less common mode—"Emotional Quiescence"—that emerges when certain individuals undergo an extra-ordinary transition to enter a distinctive heart-focused psychophysiological state (see Figure 9). The specific HeartMath tool that practitioners use to enter this mode is called the Point Zero technique.

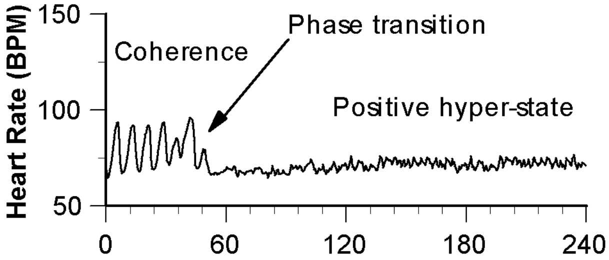


Figure 9. Phase-shift to a positive hyper-state. This figure shows a typical example of the phase transition observed in a subject moving from the Psychophysiological Coherence mode to a positive hyper-state we call Emotional Quiescence. Note the abrupt change from the larger-amplitude sine-wave-like heart rhythm pattern distinguishing the Coherence mode to the much higher-frequency and lower-amplitude rhythm marking the Emotional Quiescence positive hyper-state.

The subjective experience of this mode is a state in which the intrusion of mental and emotional "chatter" is reduced to a point of internal quietness, to be replaced by a profound feeling of peace and serenity and a deep sense of being centered in the heart.[18] First-person descriptions include a heightened awareness of the movement of energy both within one's body and between oneself and other people; the feeling of being "totally alive" and "fully present" in the moment; the experience of an all-embracing, non-judgmental love (in the largest sense); and a sense of increased connectedness with one's higher self or spirit, and with "the whole." It is important to point out that many experienced mediators who have learned the Point Zero technique describe their subjective experience of Emotional Quiescence as a distinctly different state than is typically experienced through meditation approaches.

Physiologically, when an individual enters the Emotional Quiescence mode, either the sympathetic and parasympathetic outflow from the brain to the heart is substantially reduced, or an energetic control acting at the level of the heart itself is activated to such a degree that the beat-to-beat oscillations in the HRV waveform become nearly zero. It is also possible that both occur simultaneously. This leads to an HRV power spectrum with unusually low power in all the

---

[18] In earlier publications we used the term "internal coherence" to describe the physiological aspects of this mode; however, we now feel that this terminology is confusing, as the term "coherence" is better used in the broader context which embraces entrainment, resonance, and synchronization. We also used the term "amplified peace" in earlier publications to describe the subjective inner state.

frequency bands.[19] As shown in Figure 8, the heart rhythm is almost a flat line and therefore the power spectrum has almost no power in any of the frequency bands due to the lack of heart rate variability.

Extreme Negative Emotion

At the opposite end of the emotional spectrum lies a second unusual non-everyday psychophysiological mode. Individuals can enter this mode when experiencing extremely activated negative emotions, such as those that occur during episodes of intense fear, anger, or rage. In the Extreme Negative Emotion mode the heart rhythms are also reduced to a flat-line appearance. However, in contrast to Emotional Quiescence, the underlying physiological mechanism is quite different. In this mode the HRV becomes very low due to excessive sympathetic outflow to the heart, which both drives the heart rate up to very high rates and inhibits parasympathetic outflow to the heart. At higher heart rates there is less time for variation in the beat-to-beat heart rate to occur,[20] and this combined with the inhibition of parasympathetic outflow reduces the amplitude of the variations in heart rate to nearly zero. An example of this mode can be seen in the latter part of the heart rhythm trace shown in Figure 10. Although the HRV power spectra for the Extreme Negative Emotion and Emotional Quiescence modes appear very similar, these modes are readily distinguished by the overall heart rate and by the ECG spectrum (discussed later).

---

[19] It is important to note that the individuals we have studied have the ability to enter this mode at will and thus demonstrate exceptional self-regulation because their HRV is normally quite large. This can be a source of confusion, as low HRV is usually associated with pathology. However, the state-specific, short-term low HRV associated with the Emotional Quiescence mode (or that seen in meditation) is markedly different from the low HRV found in pathological conditions. In pathology the HRV is *always* low and is associated with impaired function of the autonomic nervous system, heart, or brain stem centers.

[20] The link between heart rate and HRV is termed cycle length dependence. In healthy individuals as heart rate increases, HRV decreases, and vice versa.

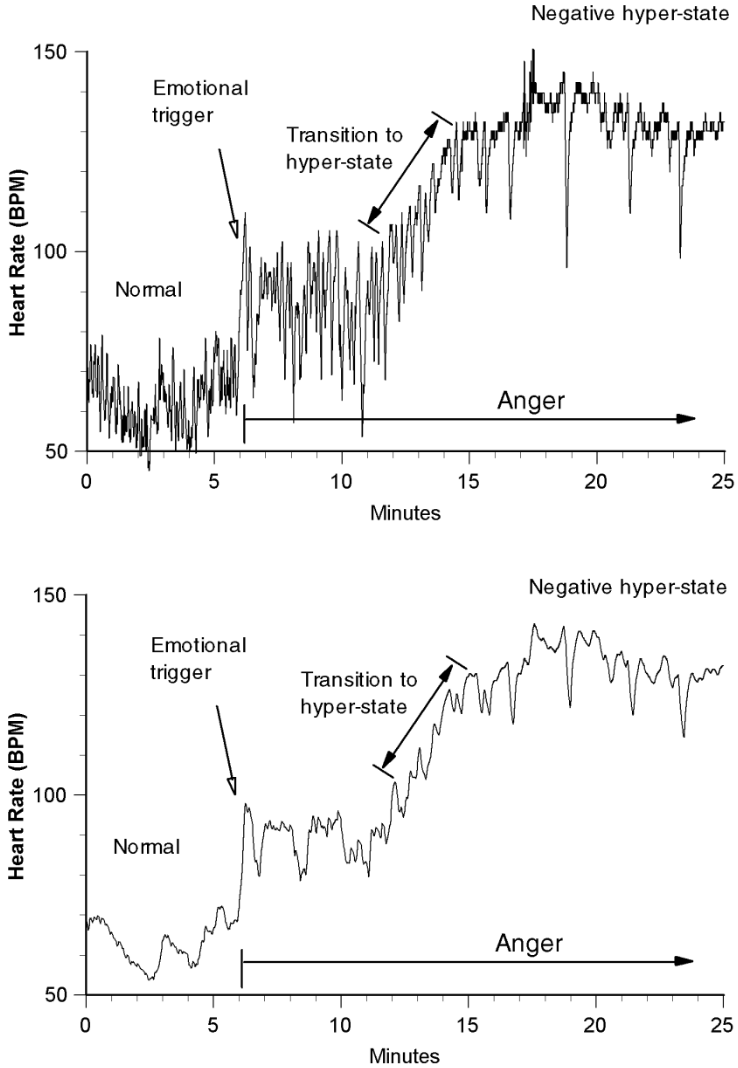


Figure 10. Phase-shift to a negative hyper-state. The heart rhythm data shown in the top graph were recorded from a male who was riding in a car and got into an argument with his wife. Before the argument and resulting emotional activation, the graph shows a period of “normal” psychophysiological activity. Clearly apparent is the point (spike) at which the subject’s emotion of anger was triggered. This was followed by a period (from about 6-12 minutes in the record) of sympathetic activation and increased heart rate. Next, there is evidence of a relatively rapid transition, which culminates in a phase-shift into a negative hyper-state of intense anger. As is evident from this case, the negative hyper-state is characterized by a high heart rate and significantly reduced HRV. The large downward spikes in the hyper-state waveform pattern, which indicate periodic drops in heart rate, result from the subject taking deep breaths. The bottom graph depicts a 10-second moving average of the heart rhythm data displayed in the top graph. This is shown to highlight the general morphology of the changes in heart rate and rhythm and the phase-transition between the states.

It should be noted that a similar pattern of physiological activity (high heart rate and low HRV) can also occur with sustained extreme physical exertion. As just described above, when the heart rate is driven so high that it all but reaches the heart’s physical limit, there is little space for variation so that a greatly reduced HRV results. However, it is rare that an individual's system is driven to this extreme state through physical exertion. The fact that extreme negative emotions alone can drive the physiological systems to this same extreme state underscores the profound impact that such emotions can have on the body.

Extreme anger or rage is subjectively experienced as an intense, highly focused state that is usually directed outward. Individuals describe their subjective experience of this state as one that is highly energized and seething with negative emotion, with a feeling of increased physical power and a corresponding reduction in sensitivity to physical pain.

The empirical documentation of these two hyper-states of psychophysiological function has led us to postulate that there are at least four additional hyper-states that have yet to be discovered and empirically mapped. The basis for this expectation will become clear in the conceptual map we develop of emotional states and their associated distinguishing physiological characteristics.

Appendix B: Previous Research

The Baroreceptor Hypothesis: A Micro-Scale Perspective

Some of the most influential work on the relationship between heart–brain interactions and performance was conducted in the 1960s and 1970s by psychophysiologists John and Beatrice Lacey, who postulated a causal role of the cardiovascular system in sensory-motor performance (Lacey, 1967; Lacey & Lacey, 1970, 1974). From a large body of electrophysiological and behavioral data they developed the "baroreceptor hypothesis," which is also known as the "Lacey hypothesis."

The Laceys' hypothesis postulated that the cardiovascular system exerts a modulating influence on higher centers of the brain, including the cortex, via afferent input from the baroreceptors (mechanosensory neurites) in the heart, aortic arch, and carotid arteries (Lacey, 1967; Ostir et al., 2001). It was proposed that cortical activity is briefly inhibited as a result of this afferent input, and therefore that sensory intake will be enhanced at times when baroreceptor discharge is minimal. As some mechanosensory neurites are activated in a pulsating fashion in phase with the systolic blood pressure wave, the Laceys expected sensory-motor integration and performance to oscillate with this same rhythm. Behaviorally, this should be reflected in reduced perceptual and perceptual-motor performance in the case of an increase in baroreceptor activity and, accordingly, a performance increase in the case of reduced baroreceptor activity. The conclusion from such a finding would be that the cardiovascular system plays an instrumental role in modulating sensory input and perception.

The Laceys' experimental work did in fact confirm a relationship between the heart's activity and cognitive performance. A major focus of their research investigated subjects' performance on reaction time tasks involving sensory intake. They found that a deceleration in heart rate during the anticipatory period preceding such a task was associated with improved cognitive performance (faster reaction time), and conversely, an acceleration in heart rate was associated with reduced cognitive performance (slower reaction time) (Ostir et al., 2001). They also observed in these experiments that the greater the magnitude of the heart rate deceleration, the faster the reaction time (Lacey & Lacey, 1964, 1970, 1974). These observations were consistent with the Laceys' hypothesis: by their reasoning, a heart rate deceleration prior to receiving information from the environment was seen as an adaptive response to enhance sensory processing by increasing the probability that information will arrive at a time when the brain is minimally inhibited as a result of baroreceptor activity. This follows from the rationale that fewer ventricular contractions prior to environmental intake will result in less baroreceptor discharge and thus reduce cardiac-related cortical inhibition.

Although the Laceys' own findings appeared to be consistent with the baroreceptor hypothesis, the results of numerous subsequent experiments by independent researchers investigating this relationship at normal heart rates have been highly inconsistent and contradictory (for reviews, see Sandman et al., 1982; van der Molen et al., 1985). Most of these studies sought to clarify the relationship between cardiovascular activity and perceptual processing by examining performance changes *within* a single cardiac cycle—that is, the period from one heartbeat to the next. Since it could be determined at what time the pulse wave reaches the baroreceptors and how long it takes for the neural impulses to reach the cortex, the precise timing of the expected inhibitory effect could be predicted.

Among the experiments that did show "cardiac cycle effects," different forms of performance change were found, and reductions in sensory or sensory-motor performance were observed at nearly *every part* of the cardiac cycle—a finding unexplainable by the baroreceptor hypothesis. However, while most of these studies presumed that blood pressure was the relevant factor, they relied only on heart rate data and assumed that blood pressure would drop with heart rate decreases and increase when heart rate increased. Unexpectedly, later studies found that heart rate and blood pressure are quite independent of each other under certain circumstances. In fact, it has been shown that in the protocol used (reaction time task with a warning stimulus) in most of the studies designed to test the Lacey hypothesis, blood pressure *increases* as heart rate decreases (Wölk, Velden, Zimmerman, & Krug, 1989). Clearly, then, these data were not consistent with the baroreceptor hypothesis, which predicted that *reduced* afferent activity preceded the processing of a significant external event.

The next major advancement in the understanding of how the activity of the heart modulates performance was provided by psychophysiologists Christoph Wölk and Manfred Velden of the University of Osnabrück in Germany. These researchers revised the Laceys' original hypothesis based on the results of several studies in which they presented a large number of auditory discrimination tasks (participants were asked to detect a tone embedded in noise) in very small steps (33 milliseconds) over the cardiac cycle. These experiments showed that performance actually fluctuated across the entire cardiac cycle at a rhythm around 10 Hz. In addition, as can be seen in Figure 11, there was an increase in the amplitude of the performance oscillation starting around 300 milliseconds after the R-wave.

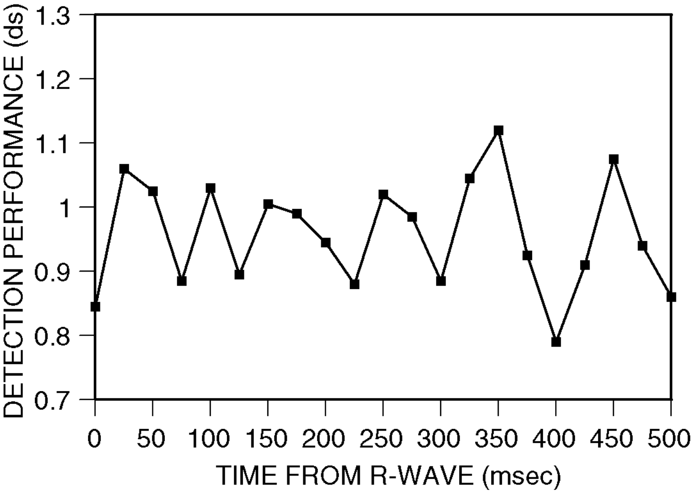


Figure 11. Performance over the cardiac cycle. By presenting a large number of performance tasks (detection of a masked audio stimulus) to subjects at differing times post R-wave, it was found that perceptual performance fluctuates with a frequency of about 10 Hz.[94] Figure shown with permission of C. Wölk and M. Velden.

The revised hypothesis proposes that the modulating influence of the activity of the mechanoreceptors on cortical function is not exerted directly, but rather is mediated via a synchronizing effect of the pulsating afferent input from the heart on cells in the thalamus, which in turn synchronizes the brain's cortical activity (Velden & Juris, 1975; Wölk & Velden, 1987, 1989). It has long been thought that alpha wave activity emerges from a state of cortical–thalamic resonance, evoked by afferent neural activity (Andersen & Andersen, 1968; Birbaumer, 1975). Wölk and Velden reasoned that as the observed oscillation in performance was in the same frequency range as the EEG alpha rhythm (~8–12 Hz), the afferent input from the heart was modulating the alpha rhythm.[21] This line of reasoning is consistent with the well-established finding that sensory-motor performance is dependent on the phase and amount of the alpha rhythm. Namely, higher levels of alpha activity are related to a decrease in performance; so also is the presentation of a stimulus during the higher-amplitude phase of the alpha rhythm (Callaway, 1962; Dustman & Beck, 1965; Nunn & Osselton, 1974; Rice & Hagstrom, 1989).[22] Thus, if the alpha rhythm was synchronized to the heart, then oscillations in performance should also be synchronized to the heart.

In Wölk and Velden's revised baroreceptor hypothesis, the periodic fluctuations in perceptual performance over the cardiac cycle are due to the alpha cycle effect (performance depends on the phase of the alpha cycle in which the stimulus is presented). This, in turn, is caused by neuronal activity evoked by cardiovascular afferent input at the level of the thalamus. They called this effect "cardiac driving," in analogy to "photic driving," where rhythmic stimulation with a visual stimulus induces an increase in EEG alpha activity. Wölk and Velden assumed that the amount of cardiac driving depends on heart rate. Thus, they inferred that a heart rate deceleration is effectively a modulation mechanism the organism uses to prevent the onset of synchronized alpha activity when attending to external sensory information, as this synchronized activity would interfere with the transmission and processing of the information. They conclude, "This means that the synchronized brain activity resulting from the baroreceptor stimulation does not just stand for a state of brain inhibition, but constitutes the mechanism by which perceptual performance can be modulated" (Wölk & Velden, 1989, p. 373).

One of Wölk and Velden's important revisions to the baroreceptor hypothesis is that it is *heart rate*, and not blood pressure, that is the relevant aspect of cardiovascular activity in terms of its synchronizing effect on thalamic cells and therefore on the cortex. In neurological terms,

---

[21] The observation that the brain's alpha rhythm is related to cardiovascular activity was first reported in 1955, when it was proposed that the transfer of mechanical energy from the contraction of the heart to the cerebrospinal fluid was a mechanism that may initiate and sustain synchronous brain activity (Bering, 1955; see also Kennedy, 1959). Sandman, Walker, and Berka (1982), who have extensively studied the influence of afferent cardiovascular feedback on the brain, published data in the early 1980s that supported this idea (Walker & Walker, 1983); however, the degree to which alpha activity is synchronized to the cardiac cycle still remained to be quantified.

[22] It was proposed in 1961 that the EEG alpha rhythm is a direct reflection of a relatively large homogenous area of cortex synchronously undergoing cycles of alternating excitations and inhibitions at the same frequency as the alpha rhythm. This was thought of as a "neuronic input shutter," which periodically prevents the perception and processing of information by the brain as elemental operations are switching on and off (Lindsley, 1961). Although this micro-rhythm clearly exists, the alpha rhythm also likely reflects a large-scale structural synchrony related to integrative brain functions, such as sensory, motor, and cognitive processes (Fingelkurts et al., 2003).

thus, it is the *pattern* and *stability* of the afferent input that is significant here, and not the strength or number of the neural bursts originating from the mechanoreceptors (Wölk & Velden, 1989). In this model, in situations involving the intake of sensory information, a decrease in heart rate translates into a reduction in the probability of the occurrence of EEG alpha activity.

In essence, Wölk and Velden concluded that while the baroreceptor hypothesis in its original form is correct with respect to the modulating effect on sensory-motor performance by the heart, the underlying mechanisms proposed in the original version of the hypothesis were incorrect. Their findings explain why the results of previous studies were so variable and contradictory—on the basis of the original hypothesis, most researchers were expecting to find a performance rhythm of a much slower frequency, and thus they traced performance over time in steps far too large to detect a ~10 Hz oscillation (Wölk & Velden, 1987, p. 63).

Appendix C: Research on Coherence and Cognitive Performance

HeartMath Institute Research

To test our heart rhythm coherence hypothesis, we conducted a study that examined the effect of the psychophysiological coherence mode on cognitive performance. Thirty healthy individuals (13 males, 17 females; age range 26-52, mean age 44) previously screened for their ability to maintain psychophysiological coherence were randomly divided into matched experimental and control groups and stratified by age and gender. We monitored the participants' ECG, pulse transit time, and respiration continuously throughout the experiment. Heart rhythm coherence, derived from the ECG, was calculated for all subjects during each phase of the testing sequence. To determine cognitive performance, we measured participants' reaction times in an auditory discrimination task that requires focus and attention, accurate discrimination, and quick and accurate reactions.

Following a 10-minute baseline period, participants performed the first of two 10-minute auditory discrimination tasks. Then the experimental group was asked to use the Heart Lock-In emotional restructuring technique (Childre & Rozman, 2002) for a 10-minute period, while the control group was instructed to relax for 10 minutes without adopting a specific mental or emotional focus. Immediately following this, all participants performed a second 10-minute auditory discrimination task, the results of which were compared to the first. This enabled us to determine if changes occurred in cognitive performance in either of the two groups and if heart rhythm coherence was related to cognitive performance.

We found, first, that there was a significant increase in heart rhythm coherence ($p < 0.05$) in the experimental group who used the Heart Lock-In technique, but not in the relaxation control group. Furthermore, the experimental group demonstrated a mean decrease of 37 milliseconds in their reaction times—corresponding to a significant ($p < 0.05$) improvement in cognitive performance—whereas the control group showed no change (Figure 12). In addition, there was a significant relationship ($r^2 = 0.21$; $p = 0.015$) between the degree of heart rhythm coherence and performance (reaction time) across all subjects and conditions: increased coherence was associated with decreased reaction times (improved performance). Figure 13 shows a representative example of one participant's heart rhythms during each of the three conditions. Note the development of a more sine-wave-like (coherent) heart rhythm pattern during use of the Heart Lock-In technique. Also noticeable are differences in heart rhythms between the first and second auditory discrimination tasks.

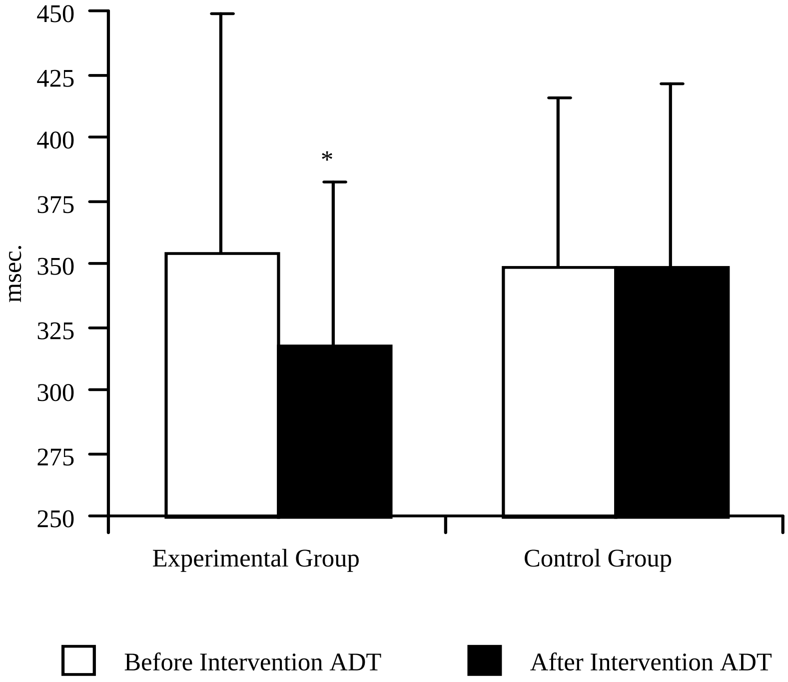


Figure 12. Reaction time changes. Mean reaction times for the experimental versus control group during the first (pre-intervention) and second (post-intervention) auditory discrimination tasks (ADT). The experimental group, who maintained the psychophysiological coherence mode prior to the second ADT, demonstrated a significant reduction in mean reaction time, indicative of improved cognitive performance. In contrast, control group participants, who engaged in an open-focus relaxation period during the interval between tests, showed virtually no change in mean reaction time from the first to the second discrimination task. *$p < 0.05$.

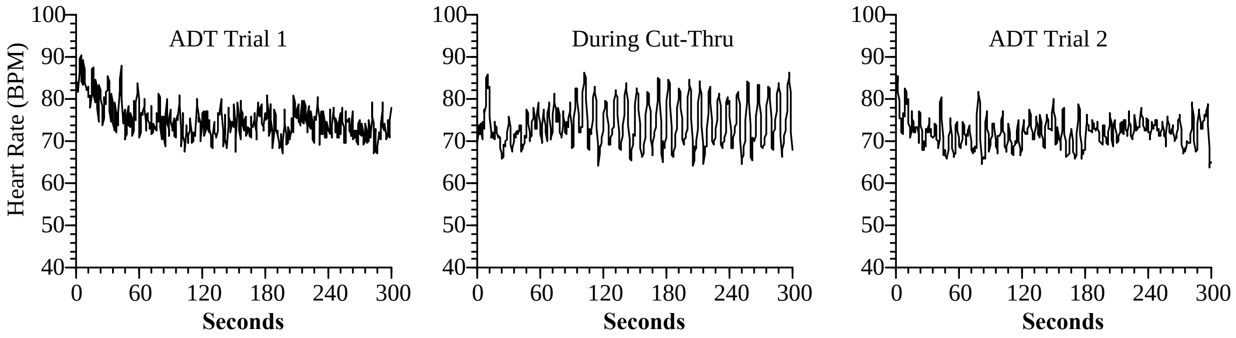


Figure 13. Representative example of heart rhythm pattern changes across conditions from an experimental group participant. Note the development of a coherent heart rhythm pattern during use of the Heart Lock-In technique. Also noticeable are the differences in heart rhythms during the first and second auditory discrimination tasks (ADT).

This experiment demonstrated that cognitive performance can be improved by maintaining psychophysiological coherence prior to a performing a task and that there appears to be a carry-over effect of the coherence mode on subsequent cognitive performance. Importantly, these findings suggest a physiological link between positive emotions and improvements in faculties such as motor skills, focused attention, and discrimination. More broadly, these results provide evidence for our hypothesis regarding the influence of macro-scale patterns of heart activity—specifically, heart rhythm coherence—on cognitive processes: they suggest that the *overall organization* of the heart's rhythmic activity, and thus the pattern of cardiac afferent input to the brain, can significantly inhibit or facilitate cortical function.

From the evidence provided by this study, it appears that macro-scale patterns of cardiac activity can produce a larger effect on the inhibition/facilitation of cognitive performance than the much smaller inhibition/facilitation fluctuations in performance observed by Wölk and Velden. As Wölk and Velden proposed, these smaller fluctuations in performance are likely related to the alpha rhythm, which in turn is driven by afferent input from the heart. A relationship between performance and the phase of the alpha cycle has been documented by a number of studies of both visual and auditory perception (Bradford, Wesnes, & Brett, 2005; Callaway, 1962; Childre & Cryer, 2000; Dustman & Beck, 1965; Nunn & Osselton, 1974; Rice & Hagstrom, 1989). For those studies that used a reaction-time protocol, the *maximum* reported magnitude of these small fluctuations in reaction time (i.e., the difference between fastest and slowest phases) was 6.3 milliseconds (Dustman & Beck). Compared to the results of these studies, our research found an approximately *six times* greater improvement in performance (a mean improvement of 37 milliseconds in reaction time) after the study participants maintained a state of psychophysiological coherence. It is thus likely that heart–brain interactions occurring on a much longer time scale have a markedly larger impact on cognitive performance and intentional behavior. Seen from this viewpoint, the small-magnitude fluctuations in performance observed by Wölk and Velden may reflect the ongoing background behavior of the system.

UK Research

Additional evidence consistent with the heart rhythm coherence hypothesis has been provided by an independent study conducted in the UK by Dr. Keith Wesnes at Cognitive Drug Research Ltd. (Wesnes, Ward, McGinty, & Petrini, 2000). To test the long-term effects of psychophysiological coherence on cognitive performance, Dr. Wesnes used a comprehensive battery of cognitive performance tests called the Cognitive Drug Research measurement system (CDR), designed to assess the effects of pharmaceuticals on cognitive function. The CDR system is a set of computer-based tasks that includes tests of attention, concentration, vigilance, short-term (working) memory and long-term (episodic) memory. This battery of tests has been used in clinical trials worldwide for over 20 years, and an extensive database of normal performance and drug placebo effects has been developed.

The study utilized an experimental design with pre and post measures. Eighteen healthy volunteers (6 females, 12 females; age range 20-53, mean age 32 years) were recruited for the study. The study participants were fully trained on the CDR system and completed four full runs through the assessment prior to the baseline data collection in order to ensure they understood the tasks and had overcome the learning process. To measure heart rate variability and heart rhythm coherence, each research participant's ECG was recorded for a 10-minute period *prior* to administration of the CDR test battery. In addition, participants completed a short self-administered questionnaire that measured calmness and alertness.

After collection of the baseline measures, the study participants attended a one-day training program where they learned the Freeze-Frame, Heart Lock-In, and Coherent Communication[23] techniques. They also practiced using these tools while facilitated by the Freeze-Framer, a computerized heart rhythm coherence biometric feedback system, to ensure they were making the shift into the coherence state and could identify what that state felt like. They were instructed to use the Freeze-Frame technique whenever they experienced stress or emotional discord, and to use the Heart Lock-In technique three times per week for at least 10 minutes. In addition, they were encouraged to practice using the Coherent Communication technique when engaged in conversation with others.

Seven weeks later the research participants were again administered a 10-minute ECG, answered the questionnaire, and completed the CDR battery of tests using exactly the same protocol as was followed for baseline data collection.

For data analysis, the standard time and frequency domain HRV measures and coherence levels were computed. The pre and post results are shown in Table 1 and Figure 14. In relation to baseline measurement, a significant increase in heart rhythm coherence (Coherence: t-test 4.00, $p < 0.001$) was observed post-intervention before the participants were administered the CDR tests. This change is graphically depicted in Figure 14 (showing the group mean HRV power spectra), where the increase in power around the 0.1 Hz frequency range indicates a pronounced increase in heart rhythm coherence. It is worth noting that this increase in heart rhythm coherence occurred even though the participants were not specifically instructed to use any of the tools they had learned in the program.

---

[23] This technique incorporates a process whereby individuals maintain a state of coherence while listening to others in order to increase the effectiveness of communication (Lansing, 1957).

Table 1. CDR Cognitive Performance Study: Pre and Post Results

	Before (N=18)			After (N=18)				
	Mean	SD	SEM	Mean	SD	SEM	t	*p* <
Quality of Episodic Memory	227.87	63.24	14.90	256.58	76.45	18.02	3.23	0.01
Quality of Working Memory	1.74	0.22	0.05	1.78	0.18	0.04	1.87	ns
Self-Rated Alertness	53.29	12.09	2.85	57.64	8.98	2.12	2.02	ns
Self-Rated Calmness	49.33	7.11	1.68	55.11	10.44	2.46	2.44	0.05
Systolic BP, mmHg	122.50	16.22	3.82	123.64	13.97	3.29	0.49	ns
Mean RR interval, ms	797.65	81.03	19.10	825.44	103.38	24.37	1.02	ns
Mean heart rate, BPM	76.40	7.32	1.72	74.61	9.20	2.17		
Standard deviation of RR intervals, ms	57.59	20.12	4.74	79.65	28.10	6.62	3.97	0.001
5-min High frequency, ms^2	298.21	267.37	63.02	246.39	221.68	52.25		
Ln(5-min High frequency)	5.21	1.16	0.27	5.05	1.00	0.24	-0.69	ns
5-min Low frequency, ms^2	550.73	676.65	159.49	1841.62	1587.90	374.27		
Ln(5-min Low frequency)	5.80	0.99	0.23	6.98	1.18	0.28	3.91	0.01
5-min Very low frequency, ms^2	427.97	442.10	104.21	414.03	312.56	73.67		
Ln(5-min Very low frequency)	5.69	0.78	0.18	5.72	0.66	0.16	0.15	ns
5-min Total power, ms^2	1294.70	1032.73	243.42	2516.76	1727.81	407.25		
Ln(5-min Total power)	6.85	0.83	0.20	7.51	0.88	0.21	3.59	0.01
Coherence	0.13	0.19	0.05	6.49	7.96	1.88		
Ln(Coherence)	-2.84	1.14	0.27	-0.15	2.52	0.59	4.00	0.001
Low frequency / high frequency ratio	3.20	4.23	1.00	11.92	9.36	2.21		
Ln(Low frequency / high frequency ratio)	0.58	0.99	0.23	1.92	1.17	0.28	3.49	0.01

Paired T-Test

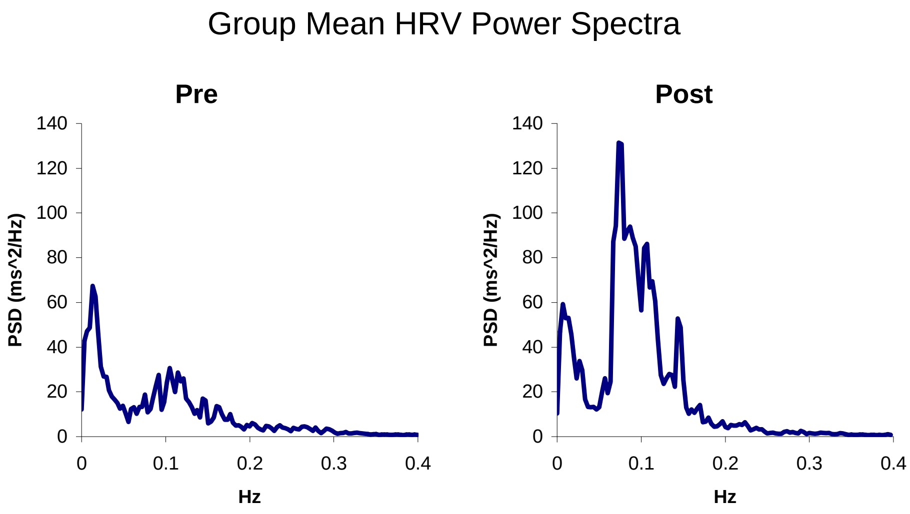


Figure 14. Group mean HRV power spectra calculated from 10-minute ECGs recorded before subjects completed the battery of cognitive performance tasks. The left-hand graph shows the mean HRV power spectrum *before* subjects were trained in the HeartMath coherence-building techniques, while the right-hand graph shows the mean power spectrum *after* they learned and practiced the techniques for seven weeks. Note the increase in power around the 0.1 Hz frequency range, indicating a pronounced increase in heart rhythm coherence. This shift is particularly notable, as subjects were not specifically instructed to use the techniques during the "post" recording.

The results of the pre and post analysis of the cognitive performance tests showed a significant improvement ($p = 0.0049$) in the quality of episodic (long-term) memory and a marginally significant improvement ($p = 0.078$) in the quality of working (short-term) memory (Figure 15).[24] [25] Analysis of the questionnaire data also showed that the research subjects reported feeling significantly calmer at the end of the study than they did at the beginning (t-test 2.44, $p < 0.05$).

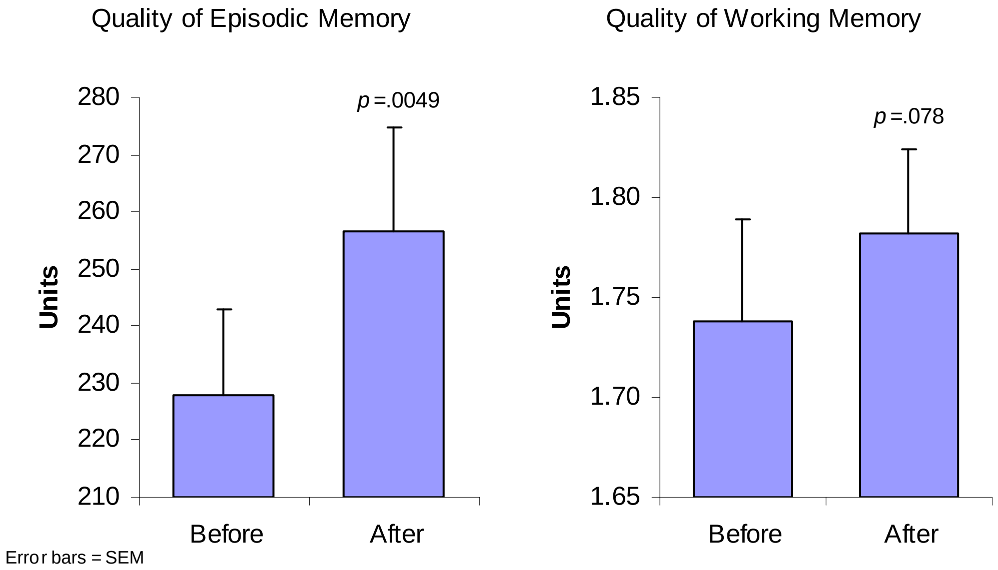


Figure 15. Mean improvements in quality of episodic (long-term) memory and quality of working (short-term) memory after practicing the HeartMath coherence-building tools for a 7-week period.

The finding of the observed gain of 12.6% in the quality of long-term memory over the 7-week period during which coherence-building techniques were practiced is notable, in that Dr. Wesnes reports the magnitude of improvement was significantly higher than the improvement in quality of memory obtained in a large clinical 14-week trial of the effects of a phytopharmaceutical memory enhancer (a gingko/ginseng combination) on the memory of healthy volunteers (Wesnes et al., 2000).

In an effort to explain the observed pre-post changes in the quality of episodic memory and in self-rated calmness, two stepwise multiple regressions were run. Of the ten independent variables included in each analysis, improvement in coherence was the only variable with sufficient statistical power to meet the criterion for entry into the stepwise analysis (p of F to enter = 0.05;

---

[24] Quality of Episodic Memory is a composite measure constructed from accuracy measures on the four tests in the CDR system that assess episodic memory. Quality of Working Memory is a composite measure constructed from accuracy measures on the two CDR system tests that assess working memory.

[25] Also observed was a positive trend in the composite scores reflecting the ability of the participants to pay attention and the speed with which they were able to retrieve information from memory. However, the improvements in these measures did not reach statistical significance.

p of F to remove = 0.10).[26] The results show that the change in coherence is quite strongly related to the observed changes in episodic memory and calmness: it accounts for 21% of the variance in the improvement in long-term memory ($F = 5.4$, $p < 0.05$; adj. $R^2 = 0.21$), and it accounts for 42% of the variance in the reported increase in calmness ($F = 13.18$, $p < 0.01$; adj. $R^2 = 0.42$).

In his review of the study's results, Dr. Wesnes concluded that learning and practicing the HeartMath positive emotion-focused coherence-building techniques appears to enhance an individual's memory capacity and also improves self-reported calmness. Moreover, he was able to show that the improvements were unlikely to be due to training or expectation effects, and that they compare favourably to the improvements produced by a proven phytopharmaceutical preparation.

HeartMath's TestEdge Program on Test Anxiety and Performance

Further support for the heart rhythm coherence hypothesis comes from a controlled field study, funded by U.S. Department of Education, involving tenth grade students in two large California high schools. Conducted by the Institute of HeartMath in collaboration with Claremont Graduate University's School of Educational Studies in 2004-2006, the study was designed to assess the efficacy of HeartMath's TestEdge program as a means of reducing student test anxiety and improving learning and test performance. The TestEdge program is designed to help students alleviate emotional stress and improve performance by teaching them tools enabling them to stabilize emotions and generate the psychophysiological coherence state. The program instructs students in how to apply HeartMath coherence-building tools and technologies in test preparation, to increase retention and relevance of academic material, and to more effectively handle stress and challenges, both at school and at home.

After random selection of the intervention school, the experimental protocol required training the school's tenth grade teachers in the tools and techniques of the TestEdge program before classes started. Once school began, the teachers trained and coached their students in the coherence-building techniques throughout the term. The Freeze-Framer heart rhythm coherence feedback system was used to facilitate students' practice of the techniques and to verify their attainment of the coherence state. Students practiced using the tools during stressful situations, such as prior to taking tests or when learning new or difficult subject matter, before taking the California High School Exit Exam (CAHSEE) midway through the term and the California Standards Test (CST) at the end of the school term.

Scores from the two standardized tests, and pre and post data from an instrument designed to measure student sociodemographic characteristics, attitudes about school, perceptions of feelings, emotions, relationships, and test anxiety (using an eight-item version of the Spielberger Test Anxiety Inventory) were collected from 749 tenth grade students across both schools.

---

[26] Excluded variables were Change in: Systolic Blood Pressure, Mean RR Interval, Standard Deviation of RR Intervals, Ln(5-min High Frequency), Ln(5-min Low Frequency), Ln(5-min Very Low Frequency), Ln(5-min Total Power), Ln(Low Frequency / High Frequency Ratio) and Baseline Age.

Additionally, to assess students' ability to generate the coherence state using the techniques learned in the program, an electrophysiological study was conducted in which pre- and post-intervention recordings of HRV were obtained from a subgroup of students in both schools.

Figure 16 shows, for the whole sample, the relationship between baseline test anxiety and the CAHSEE Math and English-Language Arts test scores. Clearly apparent is the inverse relationship between stress and academic performance, as measured by the Test Anxiety Inventory (TAI) and the two standardized tests.

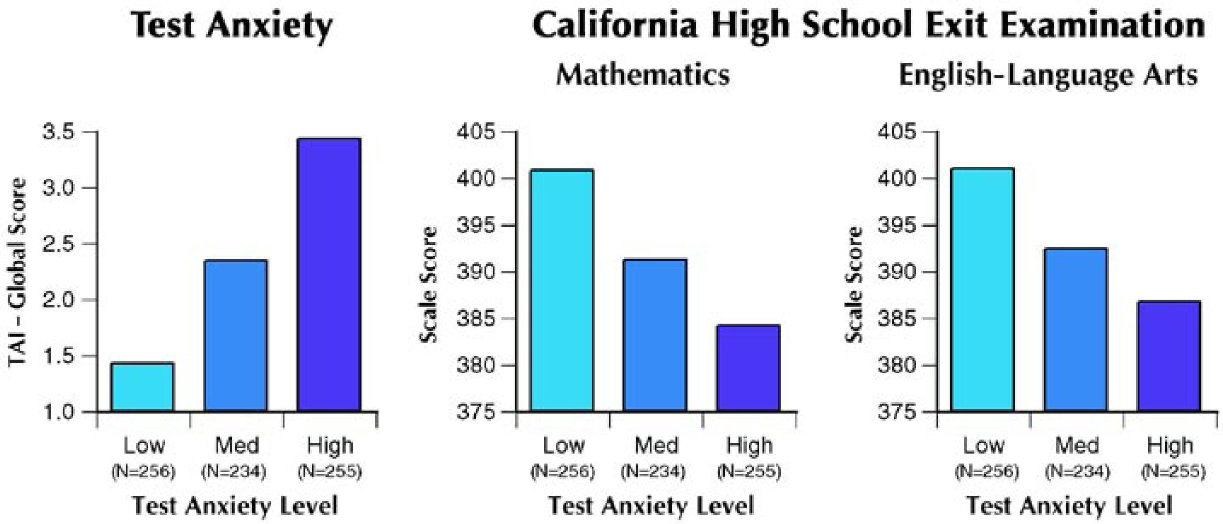


Figure 16. California High School Exit Exam scores by baseline test anxiety level. Baseline test anxiety, measured by the Test Anxiety Inventory (TAI)-Global Scale score, and mid-term CAHSEE–Mathematics and CAHSEE–English-Language Arts scores have each been classified into approximately equal-size tertile groupings of students with low, medium, and high mean scores. A strong, statistically significant ($p < 0.001$), negative relationship is clearly apparent between test anxiety level and level of performance on the two standardized tests.

Results from an analysis of a subsample of students at the end of the study present quite a different picture following the HeartMath intervention (see Figure 17). Students were matched by their ninth grade CST Math test type and were selected from classes in the two schools with similar class average scores. An ANCOVA was then performed to control for baseline differences between the schools on the dependent variable—test performance. The post-intervention mean tenth grade CST Math test score for the students in both schools was closely matched (359.71 versus 360.58, $p = 0.891$, not significantly different). What is notable, when intellectual ability is controlled in this way, is that the post-intervention mean test score in tenth grade CST English-Language Arts is significantly higher for the intervention school—by a margin of approximately 10 points—than it is for the control school (413.44 versus 402.96, $p = 0.035$). Moreover, this improvement in test performance is associated with a significant reduction of test anxiety in the intervention school relative to the control school (1.99 versus 2.22, $p < 0.05$).

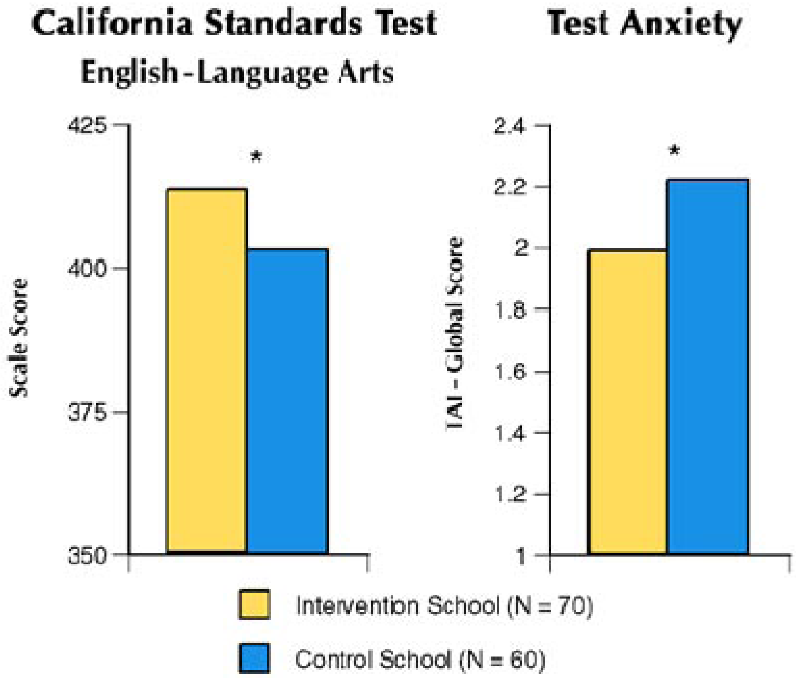


Figure 17. Test anxiety and California Standards Test scores by intervention status. Data from a subsample of students (matched on ninth grade CST–Mathematics test type and selected from classes with comparable mean scores), showing post-intervention results from an ANCOVA in which means have been adjusted for baseline differences. *$p < 0.05$.

However, a key question of inference, in interpreting these results, concerns the degree to which the HeartMath intervention actually resulted in the expected physiological changes in heart rhythm coherence in students, and the degree to which coherence is associated with their self-reports of reduced test anxiety over the course of the study. Corroborating evidence comes from the electrophysiological sub-study involving a random sample of students from both schools, stratified by test anxiety level and gender. In this sub-study, to simulate a stressful testing situation, students completed an experimental procedure that included a computerized version of the Stroop color-word conflict test (a standard protocol used to induce psychological stress), while continuous HRV recordings were gathered. During the pre-intervention administration, students were asked to prepare themselves to take the test using whatever methods they typically used when preparing to perform a challenging test or activity. In the post-intervention session, students in the intervention group were instructed to use one of the positive emotion-focused coherence-building techniques they had learned in the TestEdge program to ready themselves for the test, while the control group students again used their own methods. This was done in an effort to document, with objective electrophysiological measures, that students in the intervention school had learned how to self-induce the coherence state prior to taking a stressful test.

Results reveal a significant increase in heart rhythm coherence for students in the intervention school, indicating they were less stressed, which is consistent with the expected outcome. Overall, the results from the physiological study present compelling objective evidence that the students in the experimental group had learned how to shift into the coherent state and better manage their emotions when preparing for a stressful task or situation, such as taking an important test.

Beginning with an analysis of pre-intervention recordings, we found no significant differences between the two schools—either during the baseline resting period or during the stress preparation period. We then performed an ANCOVA in which post-intervention heart rhythm coherence was defined as the dependent variable and pre-intervention heart rhythm coherence was defined as the covariate; intervention status was designated as the fixed factor. We found a significant difference ($p < 0.001$) in post-intervention heart rhythm coherence between the two groups of students during the test preparation phase of the protocol. As graphically depicted in Figure 18, a notable increase in mean heart rhythm coherence is observed in the intervention group (3.26 pre-intervention, 4.53 post-intervention), whereas a reduction is evident in the control group (3.16 and 2.83, respectively). The intervention group in this sub-study also registered a significant pre–post reduction in test anxiety as compared to the control group (1.98 versus 2.27, $p < 0.01$).

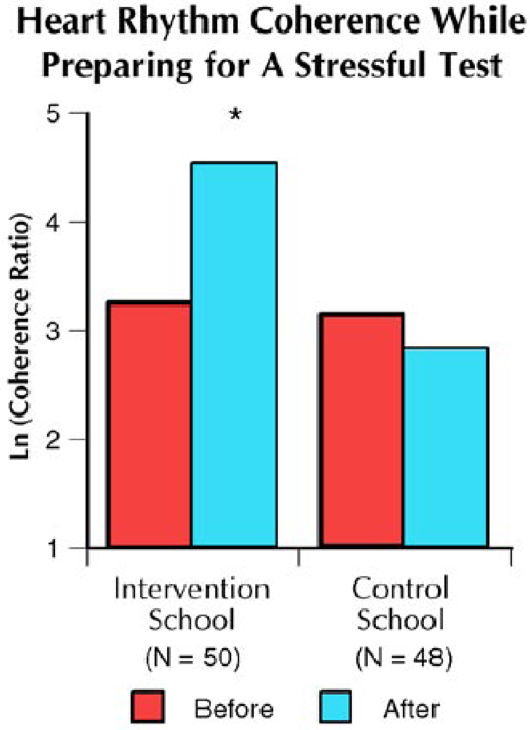


Figure 18. Heart rhythm coherence while preparing for a stressful test. Data are shown from the electrophysiological sub-study, in which a stratified random sample of students from the intervention and control schools was administered the Stroop stress test in a controlled experiment, while heart rate variability was continuously recorded. These graphs quantify heart rhythm coherence during the stress preparation phase of the protocol, before and after the TestEdge intervention. The intervention group demonstrated a significant increase in heart rhythm coherence in the post-intervention recording, when they used a HeartMath positive emotion-focused technique to prepare for the stressful test, as compared to the control group, who used their own usual stress preparation methods. *$p < 0.05$.

Figure 19 presents examples of typical patterns observed in the HRV recordings collected during the stress preparation phase of the electrophysiological sub-study, pre- and post-intervention. Shown are examples from four students (two from the intervention group and two from the control group), who are also in the subsample matched on ninth grade CST Math test type. Pre- and post-intervention test anxiety and CST–English-Language Arts test score data are also shown for each student. For the students in the intervention school, the pre-intervention HRV pattern while preparing to take the Stroop stress test is highly erratic and irregular, suggesting an enduring state of psychophysiological incoherence. However, in these students' post-intervention HRV recordings, a marked shift to increased heart rhythm coherence in the stress preparation period is readily apparent. This suggests that students were able to self-generate a state of psychophysiological coherence by applying the positive emotion-focused technique to prepare for a stressful test. By contrast, both the pre and post HRV recordings for the students in the control school signify an ongoing incoherent psychophysiological state during the stress preparation phase. Interestingly, these examples also show that the students who learned to generate psychophysiological coherence demonstrated a corresponding reduction in test anxiety and an increase in academic test scores, while the control group students experienced an increase in test anxiety and reduced academic test performance.

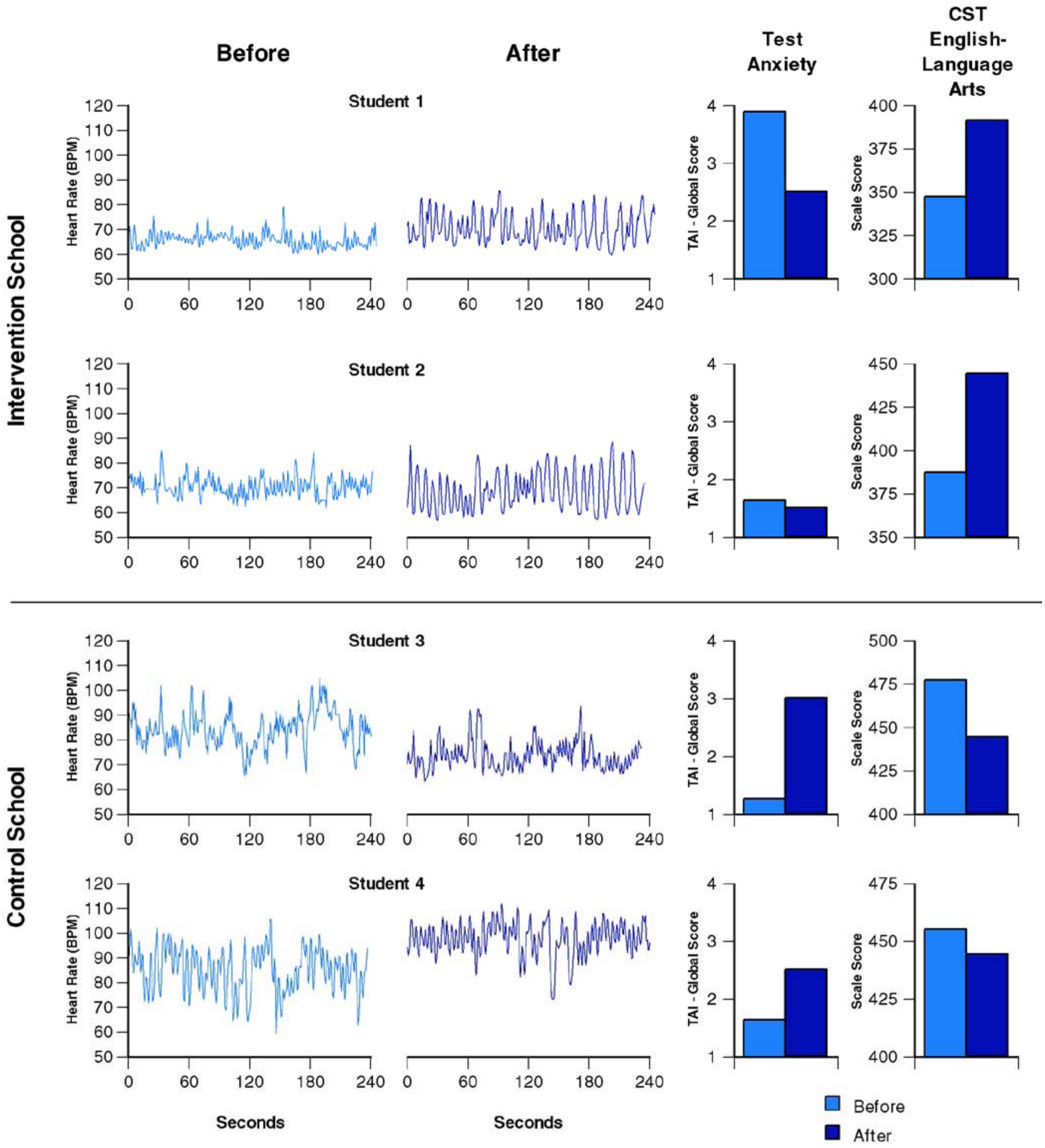


Figure 19. Typical heart rate variability patterns in students preparing for a stressful test. HRV recordings from the electrophysiological study, showing four students' heart rhythm patterns while they prepared themselves for the Stroop stress test, both before and after the TestEdge intervention. Pre- and post-intervention test anxiety level (TAI-Global Scale score) and the CST–English Language Arts test score for each student are also shown. For the two students in the intervention school, the recordings show a shift from an erratic, irregular heart rhythm pattern (left-hand side), signaling a state of psychophysiological incoherence before the intervention, to a sustained sine-wave-like pattern (increased heart rhythm coherence), indicative of the psychophysiological coherence state after the intervention. By contrast, both the pre and

post HRV recordings for the two students in the control school signify an ongoing incoherent psychophysiological state.

In sum, the results show that high school students can be trained to self-generate heart rhythm coherence and that they are able to effectively apply this skill prior to taking a challenging or stressful test. The data suggest that when students self-manage their stress using coherence-building methods, it enables them to achieve both a significant reduction in testing-related anxiety and a corresponding improvement in standardized test scores—a real-world measure of cognitive performance.

Appendix D: Heart Brain Synchronization

As noted in our earlier discussion, central to Wölk and Velden's hypothesis regarding the heart's influence on cognitive performance is a key untested postulate: that the brain's alpha rhythm is synchronized to the cardiac cycle. Independently of Wölk and Velden's work, we had been pursuing the question of the synchronization of heart and brain activity, which, so far as we know, had not been previously quantified. Here we present evidence from two studies conducted in our laboratory which confirm that a significant amount of alpha rhythm activity is indeed synchronized to the activity of the heart. The findings from these studies confirm Wölk and Velden's ideas and offer further evidence that broadens the understanding of heart–brain synchronization.

In our research we used heartbeat evoked potential analysis to examine the distribution of EEG activity that is synchronized to the cardiac cycle. Heartbeat evoked potential analysis involves the use of signal averaging techniques[27] to trace the flow and processing of afferent neurological signals from the heart through the different regions of the brain. The resulting waveforms, which represent EEG (brain) activity that is time-locked to the ECG (heart activity), are called *heartbeat evoked potentials.* The peak of the ECG R-wave is used as the timing source for the signal averaging process. An example is depicted in Figure 20. Here, in each of the EEG signal averaged waveforms, a peak can be seen that is aligned with the R-wave of the ECG. This peak reflects energetic and volume conduction mechanisms, while the later potentials reflect the processing of the afferent signals and the effects of the blood pressure wave reaching the different areas of the brain.

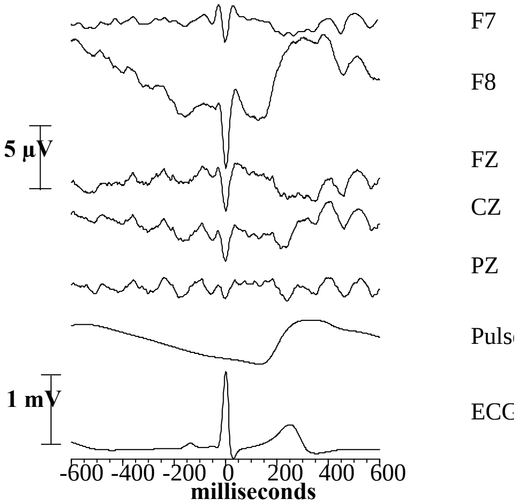


Figure 20. Heartbeat evoked potentials. This figure shows an example of typical heartbeat evoked potential waveforms along the medial line of the scalp (Fz, Cz, and Pz) and the frontal

---

[27] Signal averaging is a technique for detecting patterns in biological and bioelectromagnetic phenomena. This is accomplished by superimposing any number of equal-length epochs, each of which contains a repeating periodic signal. This procedure distinguishes any signal that is time-locked to the periodic signal while eliminating variations that are not time-locked to the periodic signal.

area (F7 and F8). The electromagnetic and volume conduction effects of the electrical activity of the heart can clearly be seen in the waveforms (large negative-going peaks occurring exactly in sync with the ECG R-wave). In this example, there is less synchronized activity in the brain potentials immediately after the ECG R-wave, indicating the processing of afferent information. The pulse wave is also shown, indicating when the blood pressure wave reached the brain. Increased alpha synchronization can be clearly seen later in the waveforms, around 250 milliseconds post R-wave, which is the time the blood pressure wave reaches the brain.

In the first study, the ratio of alpha–ECG synchronization was compared at baseline and during the psychophysiological coherence mode in ten participants. EEG recordings using electrodes along the midline (Oz, Pz, Cz, Fz) and the lateral frontal sites (F7, F8) were obtained from the research participants. Heartbeat evoked potentials were obtained using a 200-sweep-wide window that was moved across the first 10 minutes of the recording for each condition for each participant. Figure 21 shows an example of one heartbeat evoked potential waveform with the presence of the alpha rhythm. The two time intervals between 50-250 milliseconds (period 1) and 250-600 milliseconds (period 2) post R-wave were each subjected to a separate spectral analysis in which the spectral amplitude in the 8–12 Hz region was calculated for each sweep average.

The first period of the heartbeat evoked potential (50-250 milliseconds post R-wave) is the time interval when afferent signals from the heart reach the lower brain areas. It was observed that there were substantial individual differences between participants in this region. The main difference appeared to be that in about half the participants there was a desynchronization of the alpha rhythm, indicating an increase in the processing of the afferent information, while in others there was increased alpha synchronization.

The second period of the heartbeat evoked potential (250-600 milliseconds post R-wave) is believed to reflect the higher cognitive centers' processing of the sensory input and is also within the time interval when the blood pressure wave reaches the brain. Substantial individual differences were observed in this period as well. The main differences were in the later part of the evoked potentials and were observed primarily in the frontal regions of the brain. In the lower brain regions, the arrival of the blood pressure wave appears to mask the processing of some of the cardiovascular afferent information. This masking is a result of the impact of the arrival of the blood pressure wave having an additional effect on synchronizing brain activity to the heart. Therefore, the 250–600 millisecond region of the evoked potential appears to primarily reflect synchronized activity due to biophysical interaction of the blood pressure wave with the brain. This finding clearly supports Wölk and Velden's hypothesis and it is consistent with their findings of an increase in the amplitude of the performance oscillations starting around 300 milliseconds after the R-wave (see Figure 11).

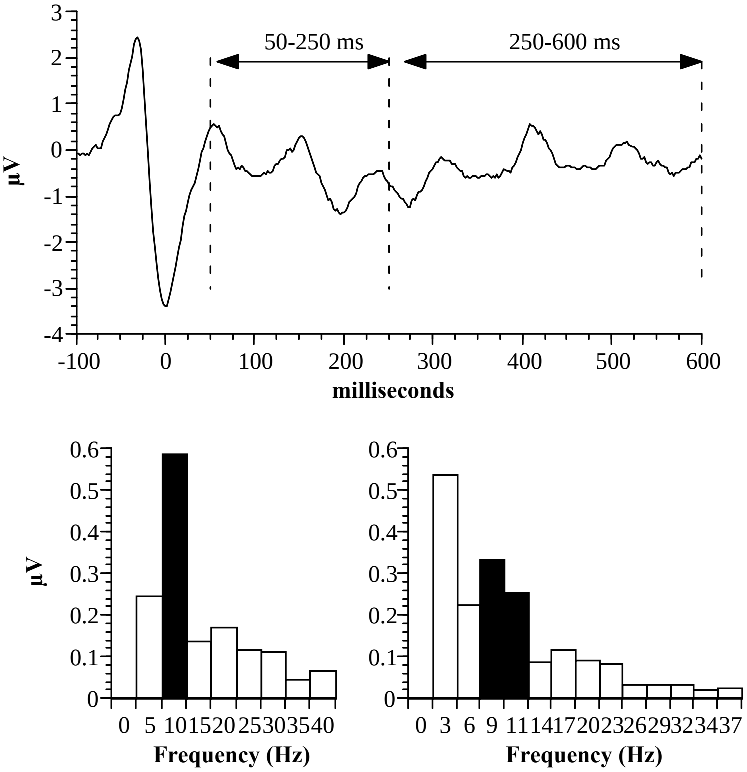


Figure 21. Quantification of alpha rhythm–ECG synchronization. In order to quantify the amount of alpha activity that is synchronized to the heart, a spectral analysis of the heartbeat evoked potential waveforms is performed. In this example the waveform is divided into two segments that represent different physiological mechanisms. The segment between 50–250 milliseconds reflects the processing of afferent signals, while the segment between 250–600 milliseconds reflects a combination of afferent processing and effects of the blood pressure wave reaching the brain.

Because of the prevalence of the alpha rhythm in EEG recordings, in determining the degree of alpha–ECG synchronization it is important to distinguish measurement of alpha activity that is truly synchronized to the cardiac cycle and spurious measurement in which alpha activity is only coincidentally synchronized to the heart. To control for the effects of this potential measurement artifact, the same procedure described above was repeated using the same ECG as the signal source, but with the interbeat intervals randomized.

As shown in Figure 22, there was significantly more alpha rhythm synchronization when the actual interbeat intervals were used for the signal source as compared to the randomized controls. This finding, too, is consistent with the idea underlying Wölk and Velden’s postulate.

In addition to the alpha–ECG synchronization observed, this study found that a significant amount of lower frequency brain activity (< 8 Hz) was also synchronized to the cardiac cycle (Figure 23).[28]

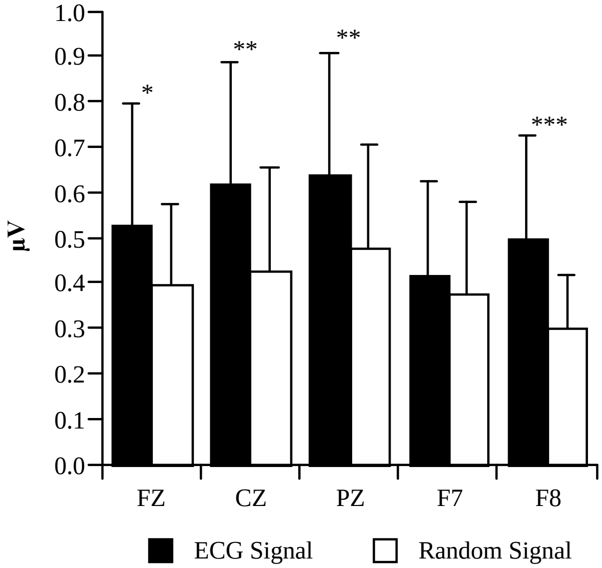


Figure 22. Alpha rhythm–ECG synchronization. This figure shows the alpha band spectral magnitude derived from the heartbeat evoked potential waveforms at different EEG sites in the range from 50–600 milliseconds post R-wave. It also compares the spectral magnitude of the real ECG as the signal source to a randomized control signal having the same mean interbeat interval and standard deviation as the original ECG signal. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

---

[28] Because the time window in the EEG record post R-wave is only 600 milliseconds long, there is not enough time to adequately resolve these lower frequencies with spectral analysis. However, the amount of synchronized activity in the EEG at these lower frequencies can be quantified by comparing the standard deviations of the evoked potential waveforms to those of the randomly generated control signals.

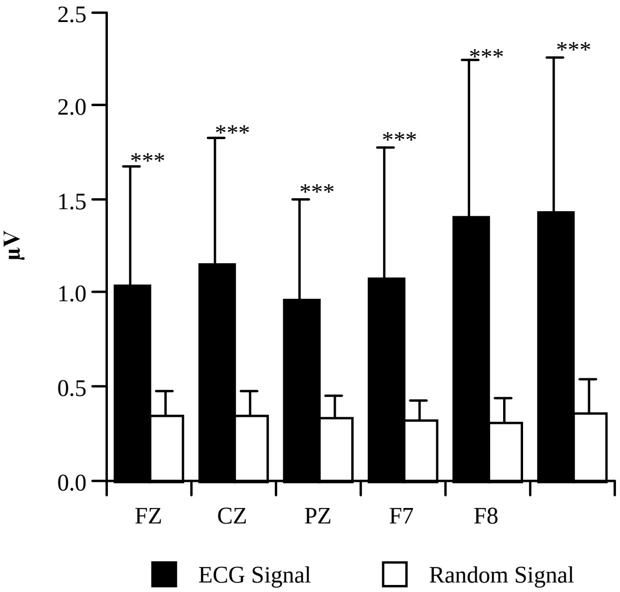


Figure 23. Low frequency synchronization. The standard deviation of the evoked potential waveforms in the range between 50–600 milliseconds was used to quantify the lower-frequency activity in the EEG that is synchronized to the cardiac cycle. The ECG and a randomized control signal for dividing the signals into segments were compared. There was a significant difference at all EEG sites, with the ECG signal resulting in higher standard deviation values. This indicates a significant synchronization of low frequency brain activity to the heart. ***$p < 0.001$.

Given our previous findings on the effect of psychophysiological coherence in increasing the synchronization among multiple body systems, we wondered whether this mode was also related to a change in heart–brain synchronization—specifically if ECG–alpha synchronization would increase as well. To determine if the ratio of ECG–alpha synchronization increased when participants were in the psychophysiological coherence mode, the study participants were asked to use the Heart Lock-In technique for 10 minutes after a 10-minute baseline period had been recorded. The degree of heart rhythm coherence and the alpha rhythm magnitude in the heartbeat evoked potentials during these two conditions were then compared.

During the period that the subjects used the Heart Lock-In technique, significant increases in heart rhythm coherence and in ECG–alpha synchronization were observed, as shown in Figure 24. Under this condition, there were significant increases in synchronized alpha activity at most sites in the range between 50–250 milliseconds, while in the 250–600 millisecond range there was a significant increase only at the Fz (midline frontal) location.

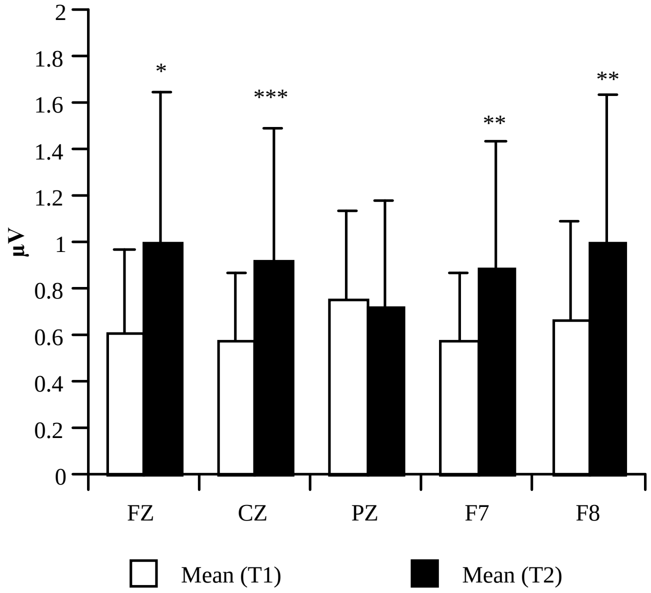


Figure 24. Increase in alpha rhythm–ECG synchronization during heart rhythm coherence. There was a significant increase in alpha wave synchronization to the ECG in the 50–250 millisecond region at most EEG sites during the use of the Heart Lock-In technique (high heart rhythm coherence). T1 = resting baseline; T2 = during heart rhythm coherence. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

In a second study we recorded 19 channels of the EEG from 30 participants, who were measured in both baseline and psychophysiological coherence modes. The research participants used the Heart Lock-In technique to enter the psychophysiological coherence mode by self-generating feelings of appreciation as they listened to music designed to foster positive emotions (Childre, 1991). Relative to baseline values, we found both a significant increase in heart rhythm coherence in the psychophysiological coherence condition and also a significant increase in the percentage of ECG–alpha synchronization in the left hemisphere, centered around the temporal lobe.

Figure 25 shows the whole group mean topographical maps of the percentage of alpha activity that was synchronized to the heartbeat during the resting baseline and coherence modes. The plots are controlled for total amount of alpha activity (synchronized alpha/total alpha), which did not change significantly, and show only the amount of synchronized activity. As can be seen, the areas with the highest degree of synchronization shift from the right frontal area during the baseline period to the left hemisphere, centered around the temporal area and radiating outward from there during coherence. While this change was most pronounced at EEG site T3 (left temporal area), the activity at adjacent sites was also significantly more synchronized to the heart during the psychophysiological coherence mode.[29]

---

[29] It is of interest to note that these observations are related to findings indicating that increased left hemisphere activity is associated with happiness and euphoria (Ahern & Schwartz, 1985; Canli et al., 1998; Davidson, 1992). It is clear that both the right and left hemispheres are involved in the processing

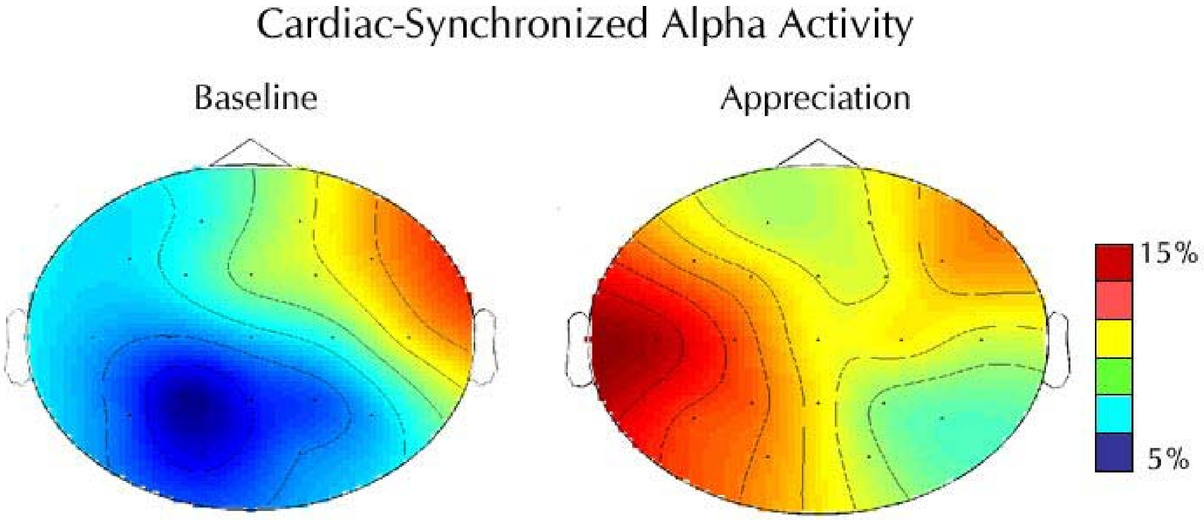


Figure 25. Alpha activity synchronized to the cardiac cycle. Group mean topographical maps for 30 subjects, showing the percentage of alpha activity in different regions of the brain that is synchronized to the heartbeat during a resting baseline as compared to during actively feeling appreciation (psychophysiological coherence mode).

To determine if there were gender differences in the amount and distribution of the EEG activity synchronized to the heart, we performed an analysis of baseline data by gender for both the alpha and beta rhythms. Figure 26 is a topographic map showing the magnitude and distribution of the alpha rhythm synchronized to the heart over the entire scalp for both males and females under baseline conditions. The females have more synchronized alpha activity in the frontal areas, while the males have more synchronized alpha in the parietal areas. Figure 27 shows the data from the same participants for the beta rhythm. The data from the beta rhythm analysis also shows a distinctive distribution pattern of synchronized activity to the heart. The females in this sample had significantly more background beta activity than the males, and, as can be seen in the topographic maps, the beta rhythm is more synchronized in the frontal regions.

---

and regulation of emotion; however, there is still a lack of clarity regarding the roles of hemispheres and how they interact in the emergence and perception of emotional experience.

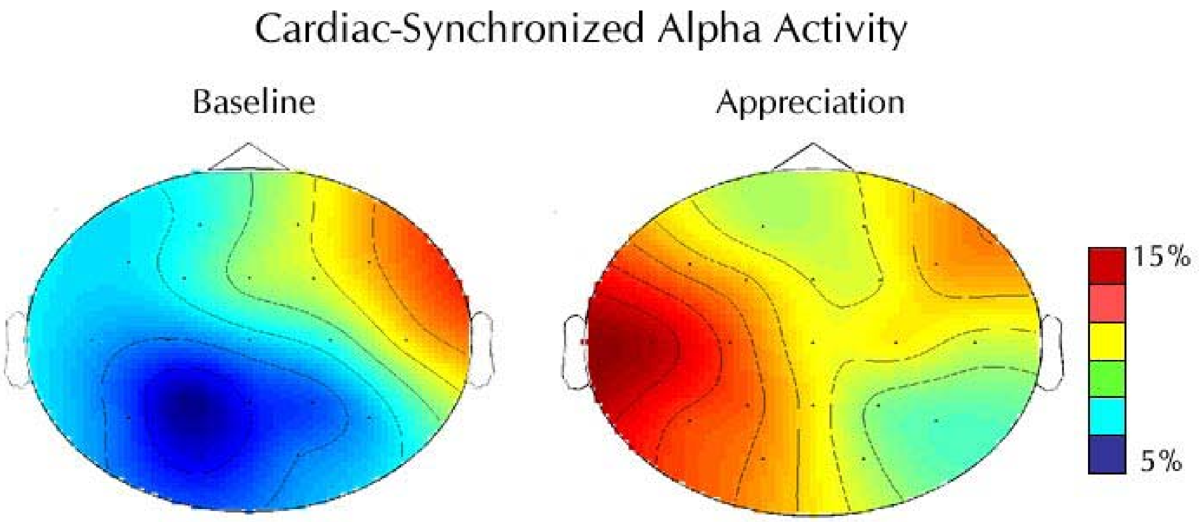


Figure 26. Alpha activity synchronized to the cardiac cycle. Group mean topographical maps for male and female participants showing the distribution of alpha activity that is synchronized to the heartbeat during a resting baseline period.

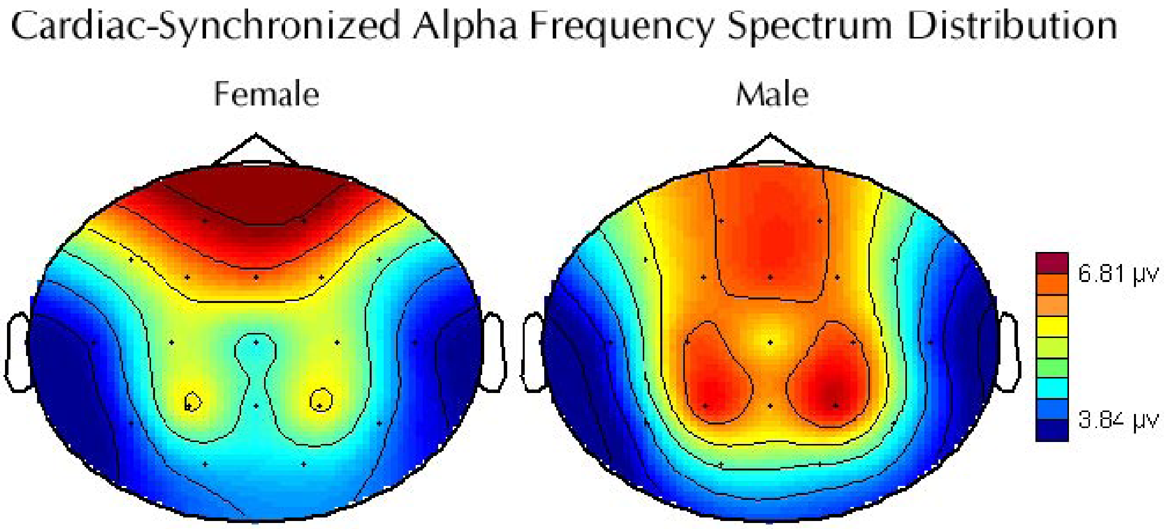


Figure 27. Beta activity synchronized to the cardiac cycle. Group mean topographical maps for male and female participants showing the distribution of beta activity that is synchronized to the heartbeat during a resting baseline period.

Appendix E: Energetic Signatures of Psychophysiological Modes

Figures 28 through 33 show waterfall plots of consecutive amplitude spectra from the ECG data used to produce the examples of the six different psychophysiological modes described at the outset of this article: Mental Focus, Psychophysiological Incoherence (anger), Relaxation, Psychophysiological Coherence (appreciation), Extreme Negative Emotion (intense anger), and Emotional Quiescence. Each trace in the waterfall plots is the spectrum of the actual electrocardiogram recording of an individual over a 6-second period. (These spectra should not be confused with the power spectra of the HRV waveforms, such as those shown earlier in this article.) Together, the set of traces recorded cover a continuous time period (approximately 2 ½ minutes) and show the degree of stability in the structure of the waves of electrical activity generated by the heart during this time. As can be seen, although there are commonalities across the modes, there are also *distinctive spectral patterns* associated with each specific mode.

There is a direct relationship between the heart rhythm patterns (HRV) and the spectral information encoded in these radiating fields. This is due to the fact that the distribution of the harmonic relationships and magnitudes of the various peaks in the ECG spectrum are dependent on the length of the interbeat intervals (the temporal space between consecutive heartbeat spikes) and the distribution pattern of the interbeat intervals within the heart rate series (heart rhythm patterns). This relationship between the heart rhythm pattern and the ECG spectral patterns will be discussed in more detail as we describe the energetic signature of each psychophysiological mode.

The waterfall plots of the ECG spectra shown in Figures 28 through 33 were all derived from the same recordings of ECG signals that were used to measure the heart rhythms and the HRV spectra of those heart rhythms shown in Figure 8. Our interest in reviewing these spectra is to highlight the distinctive energetic features of each mode. For certain modes these features are readily apparent, while for others they are more subtle.

Mental Focus

Figure 28 shows the waterfall plot of the ECG spectra for the Mental Focus mode. Referring back to Figure 8, the heart rhythm pattern for this mode showed an overall suppression of HRV, with a slight increase in heart rate over the session. The lowered HRV produces an ECG spectrum that has a series of harmonics extending out to approximately 25 Hz. The lower the HRV (that is, the more uniform the time interval between each consecutive heartbeat), the more standing waves emerge and are organized in a harmonic order in the ECG spectrum (see Extreme Negative Emotion and Emotional Quiescence for examples). There are also two sets of peaks that occur in most of the individual spectra in the range of 3–5 Hz and 7–8 Hz. These peaks are due to the low frequency rhythm (~10-second rhythm) that occurs in the heart rhythm pattern. The presence of this rhythm during the Mental Focus mode can be seen in the HRV spectrum shown in Figure 8. However, it is not as prominent as it is in the Relaxation mode, nor is it the main rhythm, as in the Coherence mode (appreciation).

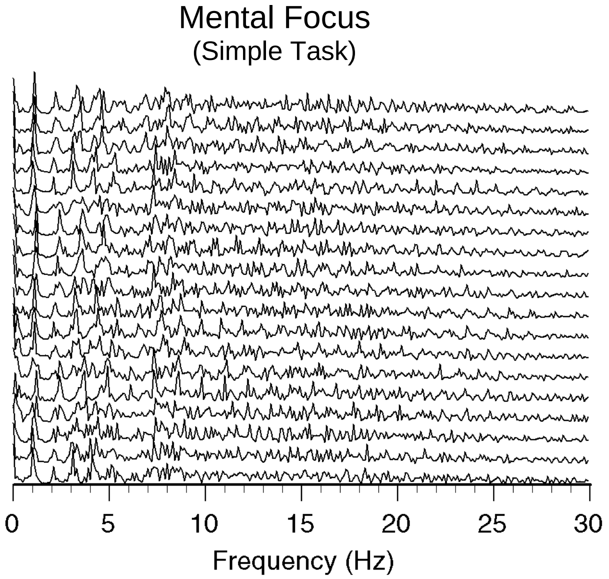


Figure 28. Waterfall plot of ECG spectra for the Mental Focus mode. Relative to a "normal" waking state, there is less amplitude in the spectral peaks during Mental Focus due to the reduced HRV in this mode; yet a stable structure of standing waves and harmonics is maintained throughout the consecutive spectra.

Psychophysiological Incoherence

Figures 29 and 30 show the waterfall plots of the ECG spectra for an individual's experience of two distinct levels of anger, which are examples of the Psychophysiological Incoherence mode and the hyper-state associated with the Extreme Negative Emotion mode, respectively. In this case we are using a single individual's experience of anger to show how the activation of extreme negative emotion (negative hyper-state) is differentiated from ordinary anger (incoherence). Thus, the ECG spectra are shown for two different segments in a single heart rhythm trace that represent the two modes, each of which is described separately in our discussion here. (The full heart rhythm trace is shown in Figure 10.)

Figure 29 shows the ECG spectra for the first part of the heart rhythm data displayed in Figure 10 (approximately 6–11 minutes), representing the Psychophysiological Incoherence mode. It is evident that the ECG spectra do not exhibit a coherent pattern from one trace to the next, nor do they display the harmonic pattern of waves seen in most of the other examples of the different modes. Therefore, when the heart rhythm is incoherent, so are the spectral patterns in the ECG.

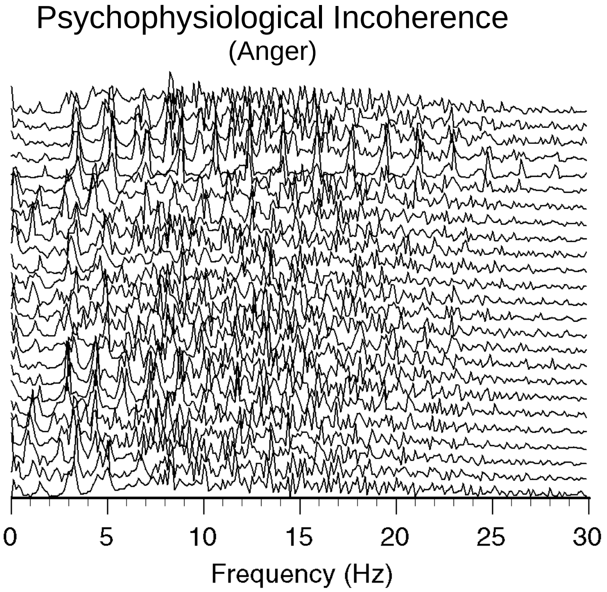


Figure 29. Waterfall plot of ECG spectra for the Psychophysiological Incoherence mode. In this example, anger is used to illustrate the mode, although most negative emotions also lead to incoherence. Note the lack of a coherent structure from spectrum to spectrum and the absence of harmonics in the spectra.

Extreme Negative Emotion

Figure 30 displays the ECG spectra for the heart rhythm data beginning around 15 minutes in the anger trace in Figure 10, where the HRV trace can be seen to flatten out (low HRV). This segment represents the Extreme Negative Emotion mode. As discussed earlier, most negative emotions produce increased incoherence in the heart rhythms—that is, the pattern of heart activity becomes more erratic. However, anger, in particular, is an emotion that can also lead to high sympathetic activation, which in turn can inhibit parasympathetic activity and drive the heart rate to a high level. Together, these responses result in low HRV.

It can be seen that the ECG spectra in this state appear quite different from those in the Incoherence mode, in that they exhibit a series of high-amplitude standing waves that persist from one epoch to the next in the series. This pattern emerges because the interbeat intervals in the ECG have become uniform (low HRV). The spacing between the peaks in the ECG spectrum is a reflection of the time interval between heartbeats. Higher heart rates (short interbeat interval) produce an ECG spectrum in which the peaks in the harmonic series will be further apart. This can be seen by comparing the ECG spectra for the Emotional Quiescence mode (Figure 33) to those for the Extreme Negative Emotion mode (Figure 30). In Emotional Quiescence, the heart rate is much lower than in intense anger. This means that the time interval between each consecutive beat is much greater, and therefore the peaks in the ECG spectra are much closer together than those observed for intense anger. In both the Emotional Quiescence and Extreme Negative Emotion modes, a strong, consistent pattern of standing waves is produced in the electromagnetic field radiated by the heart. This pattern is indicative of a highly coherent order.

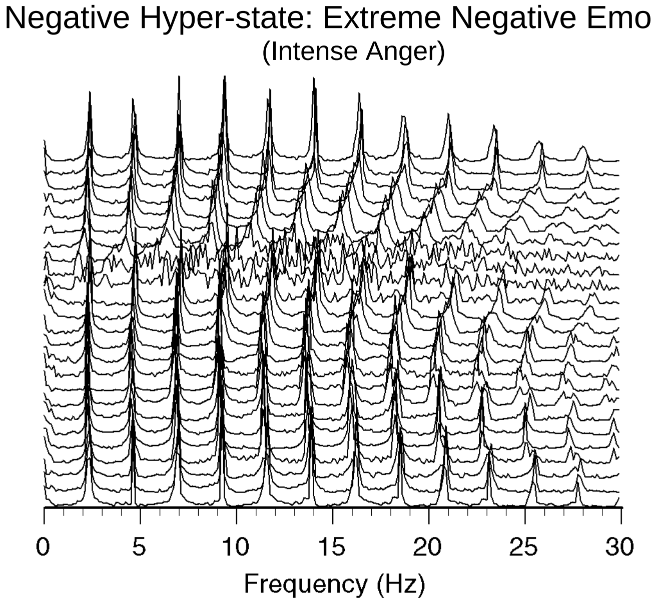


Figure 30. Waterfall plot of ECG spectra for the Extreme Negative Emotion mode. The standing wave pattern is due to the very low HRV in this mode (see text for discussion).

Relaxation

Figure 31 shows the ECG spectra for the Relaxation mode. The spectra for this mode display some similarity to those for the Mental Focus and Coherence modes, in that they have in common the two sets of peaks in the ranges of 3–5 Hz and 7–8 Hz, which are observed in most of the individual spectra. This characteristic is due to the presence of the low frequency rhythm in the HRV. However, in the Relaxation Mode, these peaks are higher in amplitude than those for Mental Focus. This is because the low frequency rhythm is more prominent in Relaxation than it is in Mental Focus, as is evident in the HRV power spectra in Figure 8. Moreover, the spectra manifest a greater density of variability, and hence complexity, while still organized as a coherent structure. The greater complexity is the result of greater high frequency variability in the heart rhythm pattern, which is also apparent in the associated HRV power spectrum (Figure 8).

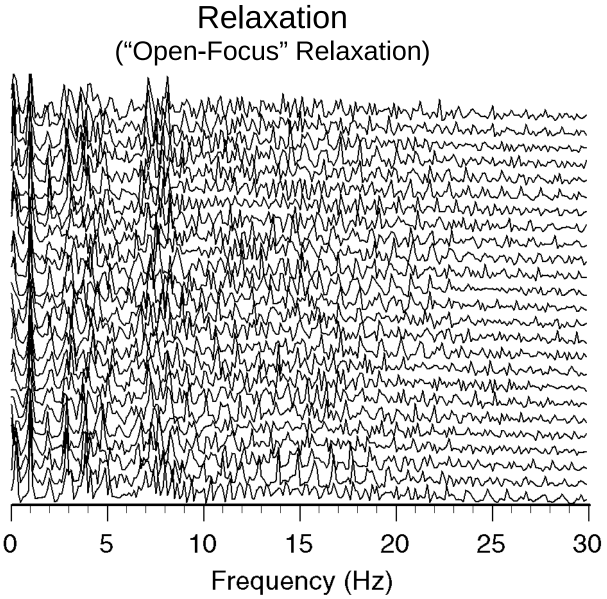


Figure 31. Waterfall plot of ECG spectra for the Relaxation mode. These spectra maintain a coherent structure and rich complexity.

Psychophysiological Coherence

Figure 32 shows the ECG spectra for an individual's experience of "appreciation," used to illustrate the Psychophysiological Coherence mode. A strong, consistent pattern of standing waves can be seen in the two sets of peaks occurring in the 3–5 Hz and 7–8 Hz ranges. This is due to the prominence of the low frequency rhythm in the HRV. Even though there is also a high density of variability (complexity) in the pattern of standing waves, a coherent order persists across the individual spectra. A complex yet coherent order of energy movement is optimal for encoding information as a signal. Conversely, when the rhythm of energy has little variability, there is less potential for the encoding of information. Thus, the electromagnetic field generated by the heart in the Coherence mode appears well suited for effective information communication. By comparison, the electromagnetic fields of the other modes display less variability and complexity and therefore do not have the same potential—the "requisite variety"—for information encoding and transmission (Ashby, 1956).

It is apparent that the ECG spectrum alone does not provide an adequate means to clearly differentiate the Coherence, Relaxation, and Mental Focus modes, as their ECG spectra all have a similar appearance. However, as shown earlier, these three modes are clearly differentiated by their heart rhythm pattern (HRV). For this reason, the heart rhythm pattern and HRV power spectrum are generally used as the major identifiers of the psychophysiological modes.

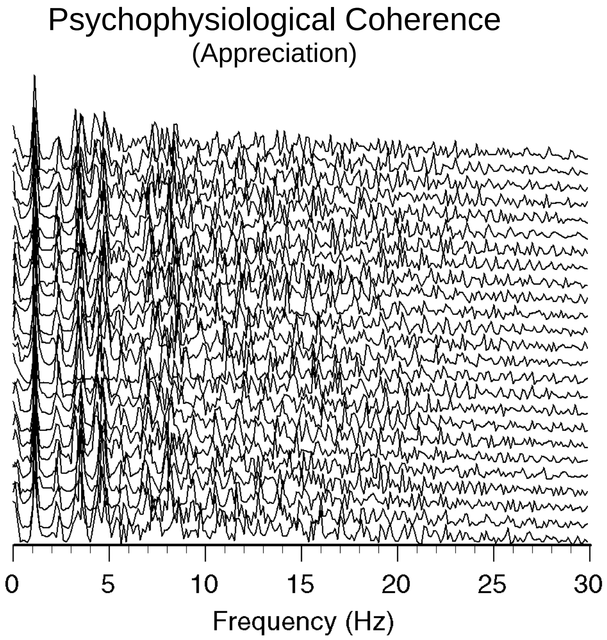


Figure 32. Waterfall plot of ECG spectra for the Psychophysiological Coherence mode. These spectra display a rich complexity and high amplitude, yet retain a coherent structure from spectrum to spectrum.

Emotional Quiescence

Figure 33 shows the ECG spectra for the Emotional Quiescence mode. As discussed earlier, Emotional Quiescence is a peaceful, heart-focused psychophysiological state signified by unusually low HRV. Its ECG spectral profile has a pronounced standing wave-like pattern that, as a harmonic series, is relatively uniform in that it is consistent from epoch to epoch. This persisting "standing wave" pattern in the spectrum of the ECG indicates that the heart is generating a highly coherent electromagnetic field in this mode. Based on subjective reports of this mode, it would appear that the organization of this electromagnetic field reflects a psychophysiological order that is highly conducive to states of peace and serenity and also receptive to experiences of spiritual connectedness.

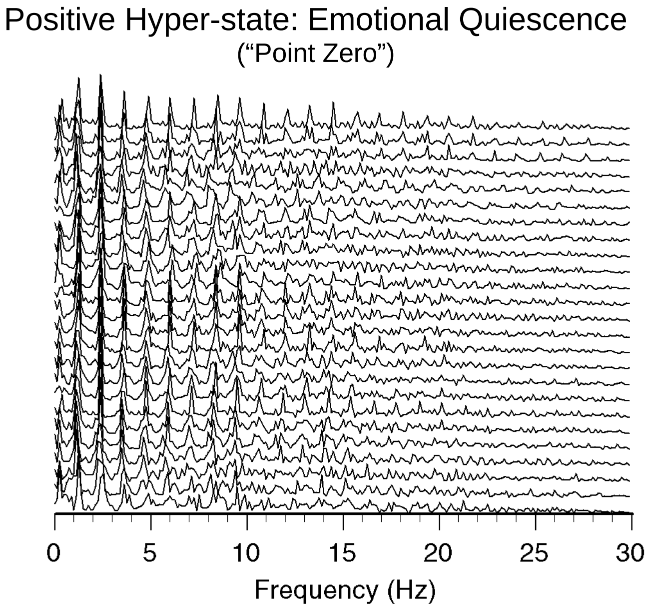


Figure 33. Waterfall plot of ECG spectra for the Emotional Quiescence mode. The coherent structure of standing waves that is constant from spectrum to spectrum is due to the very low HRV in this mode.