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

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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.

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[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.

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> *…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]

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[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.

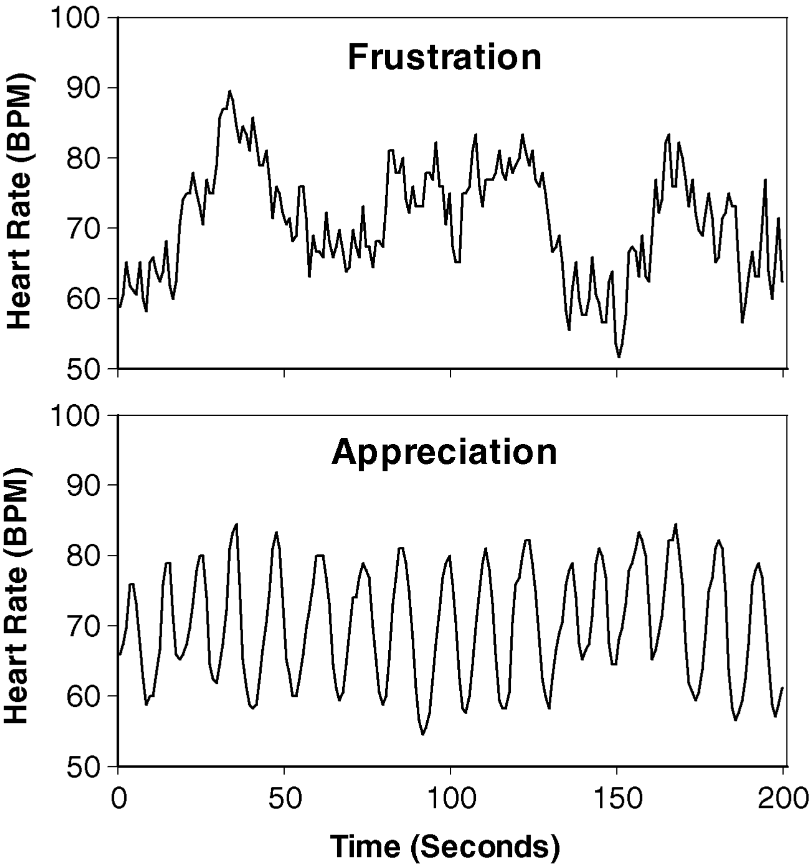

Figure 1. Emotions are reflected in heart rhythm patterns. The heart rhythm pattern shown in the top graph, characterized by its erratic irregular pattern (incoherence), is typical of negative emotions such as anger or frustration. The bottom graph shows an example of the coherent heart rhythm pattern 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.

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[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.

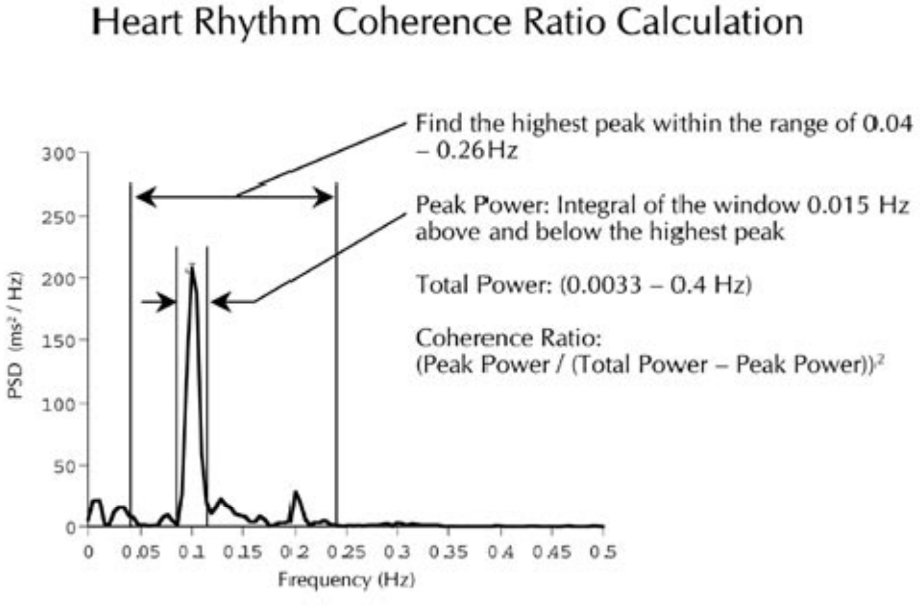

Figure 2. Heart rhythm coherence ratio calculation.

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

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[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.

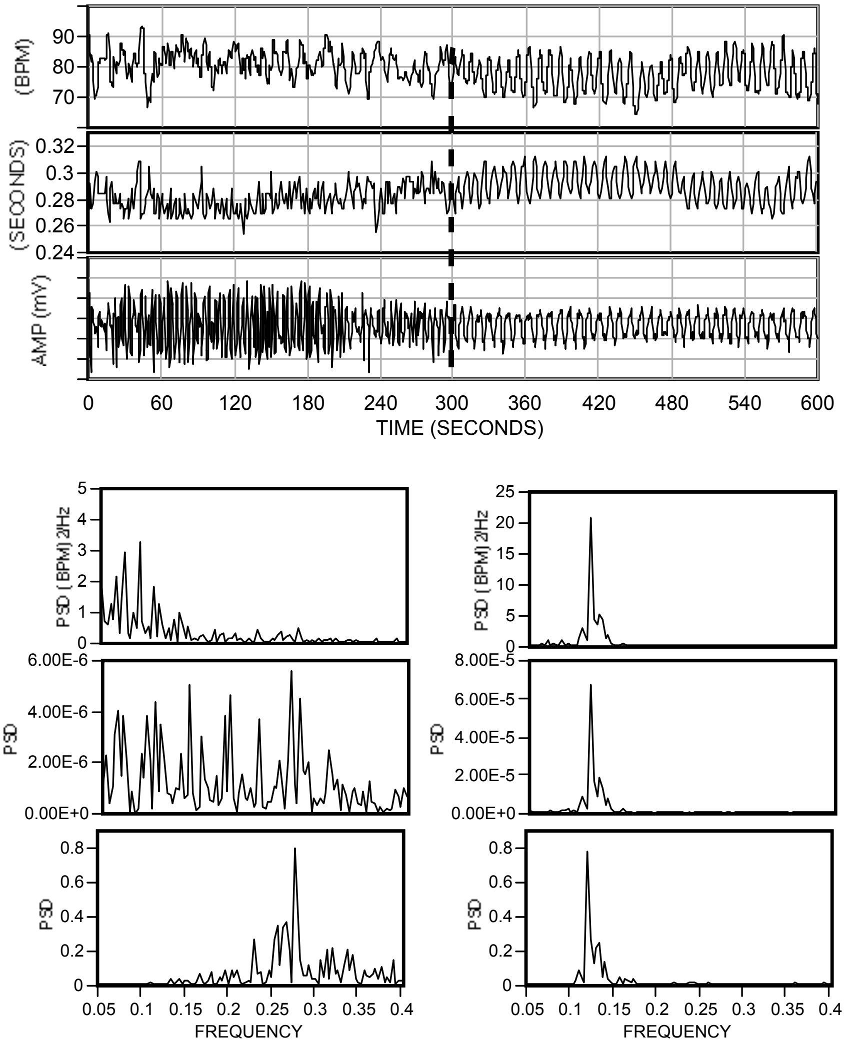

Figure 3. Entrainment. The top graphs show an individual's heart rate variability, pulse transit time, and respiration rhythms over a 10-minute period. At the 300-second mark, the individual used the Freeze-Frame positive emotion refocusing technique, causing these three systems to come into entrainment. 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).

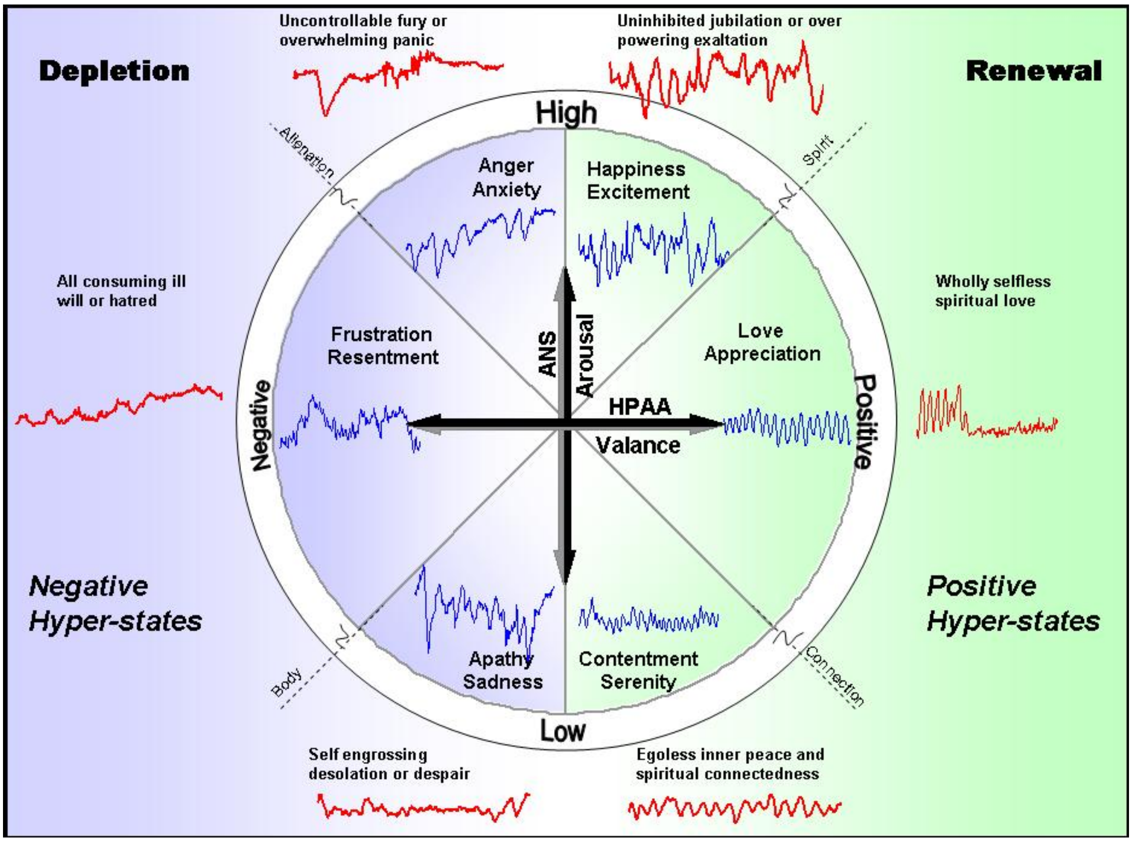

Figure 4. Graphic depiction of everyday states and hyper-states of psychophysiological interaction distinguished by the typology. Two qualitatively different categories of psychophysiological interaction are depicted—the area within the inner circle represents the

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

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[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).

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[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

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[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.

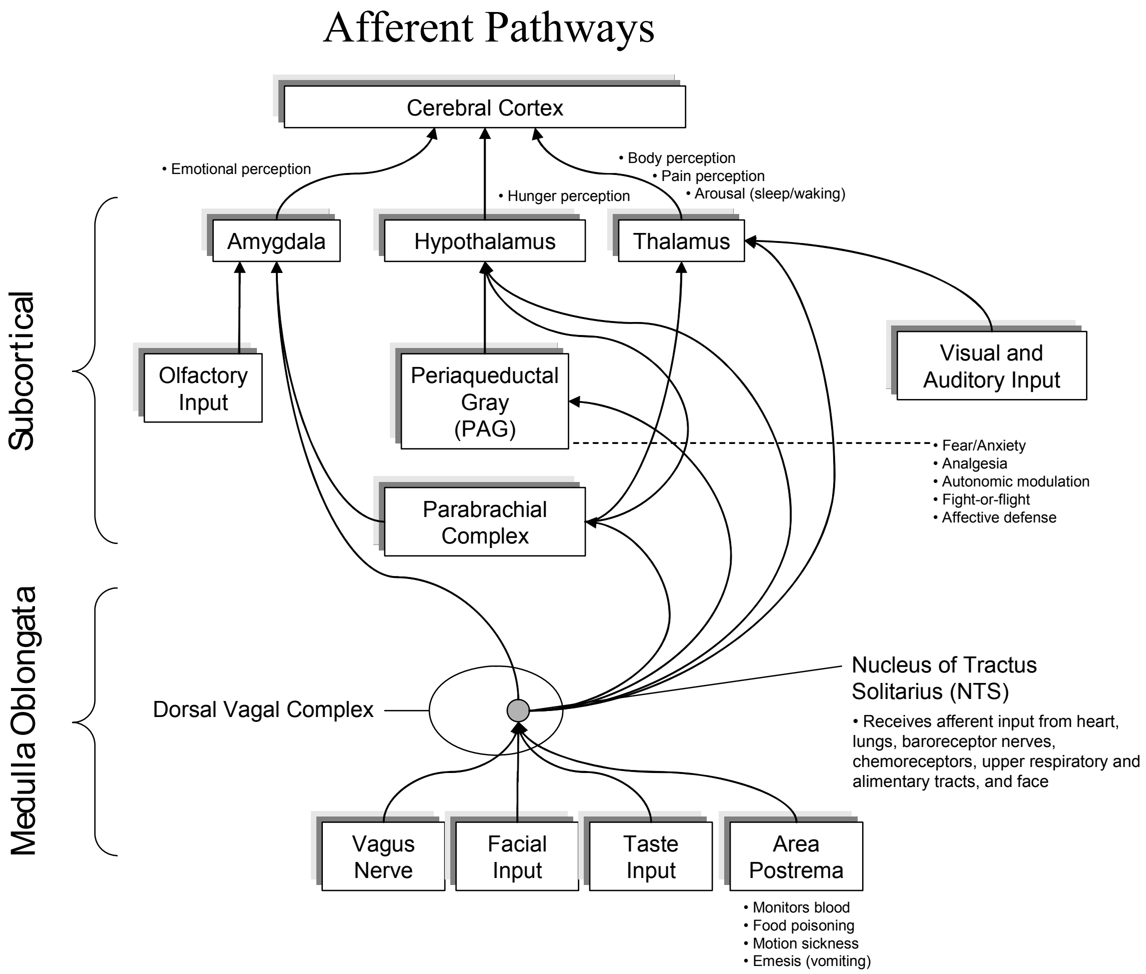

Figure 5. Diagram of the currently known afferent pathways by which information from the heart and cardiovascular system modulates brain activity. Note the direct connections from the NTS to the amygdala, hypothalamus, and thalamus. Although not shown, there is also evidence emerging of a pathway from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

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[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

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[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.

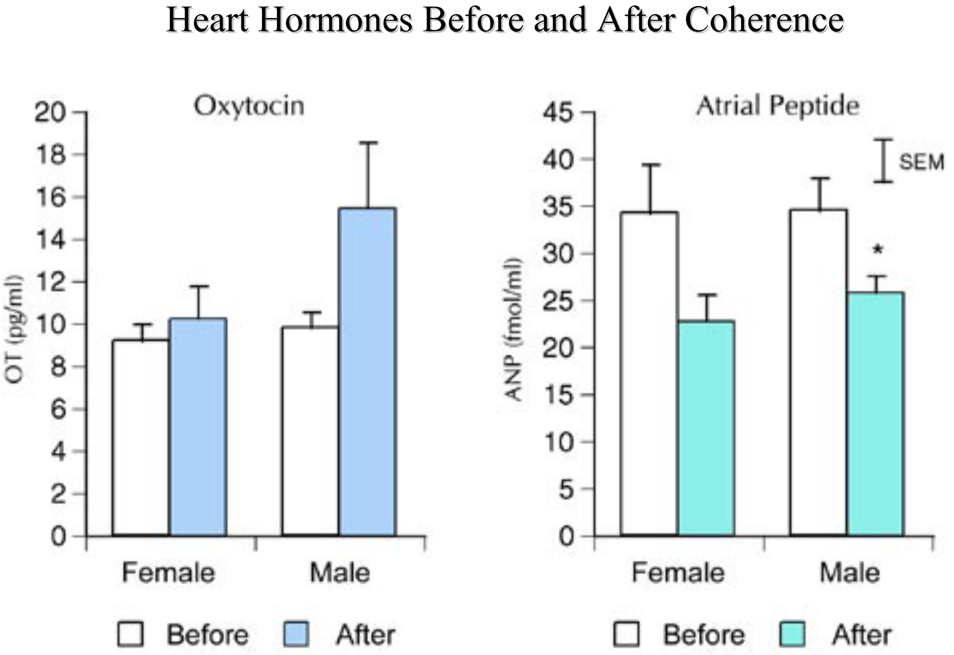

Figure 6. Oxytocin and atrial peptide changes during heart rhythm coherence. Graphs show changes in blood levels of oxytocin and atrial peptide for male and female subgroups from a resting baseline mode to after maintaining the coherence mode for 10 minutes.

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.

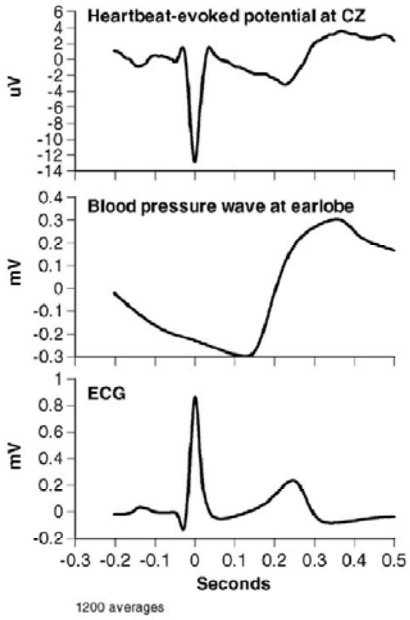

Figure 7. Evoked potentials in the EEG due to effects of the blood pressure wave. The top trace is the EEG recorded at the Cz location, and the middle trace is the blood pressure wave,

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

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[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.

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