

---

# 14 Methods for Real-Time Assessment of Operational Stress during Realistic Police Tactical Training

*Riccardo Fenici*

## INTRODUCTION

Numerous studies have shown that factors related to organizational structure, inappropriate authoritarian management, poor interpersonal relationships with supervisors, lack of adequate participation in planning and of autonomy in performing duties, and lack of recognition for work accomplishments are usually reported as the major source of stress for police officers. On the other hand, there are other risk factors such as alteration of normal sleep patterns because of shift schedules, daily exposure to interpersonal violence, personal endangerment with fear of revenge from criminals, and interactions with an ambivalent public, which induce chronic emotional effects that jeopardize the physical and psychological balance of police officers with their families. A chronic burden of negative emotions such as anger, anxiety, or depression can lead to psychological burnout, whereas continuous activation of the stress response systems (i.e. the Hypothalamus-Pituitary-Adrenal axis and the Autonomic Nervous System [ANS]) can induce alterations of the neuroautonomic and endocrine balance, leading to higher incidence of hypertension, cardiovascular disease, metabolic syndrome, and even cancer.

Under such unfavorable basal conditions, law enforcement officers may be suddenly called to respond to critical situations implying an appropriate use of tactics and force to protect their lives and the lives of others. In front of a potentially lethal threat, although in the grip of “fight or flight”-induced psychophysiological alterations, the police officer is required to maintain vigilance, dynamic threat assessment, sound judgment, and appropriate tactical decision making. Instead, uncontrolled stress-induced emotions (i.e. fear and anger), perceptual anomalies (tunnel vision, auditory exclusion, altered sense of space and time), memory loss, and intrusive distractive thoughts may induce behavioral alterations (automatic pilot, dissociation, and freezing) with tragic consequences. In spite of the high risk of stress-induced errors, accidents, or overreaction that can compromise performance, jeopardize public safety, and determine liability, the training of police officers on tactical stress management is still more empirical than based on scientific knowledge. From real-life experience, we have to acknowledge that empirical police training is often insufficient to guarantee operational success and officers’ survival. Thus, an unquestionable mandatory commitment of any modern police institution should be to favor research in the psychophysiology of officers’ behavior under critical tactical stress and to develop more efficient scientifically based training to improve officers’ survival on the street.

During the last decade, only a few attempts have been reported in such direction; however, there could be others that have not been disclosed to the public (as in our case) for institutional classification of the information. Available data are still limited, however, and in most cases rather

empirical. The purpose of this chapter is to summarize present experience and to provide suggestions about how to design more comprehensive investigational protocols to evaluate police tactical stress, using scientific methods and available technologies gathered from experimental and clinical psychophysiology.

## TACTICAL STRESS

AQ1 Police officers know that “when something is going to be wrong” for an unexpected sudden threat occurring during a boring night shift or the best planned SWAT operation, there are immediate, uncontrollable physical reactions (one for all, a marked increase of the heart rate), which alarm the mind about the impending danger and trigger the “oh shit!” statement (Solomon, 1991). At that point, the officer may do the right thing, react and survive, or lose control and be defeated.

The empirical experience of survivors is an inestimable wealth that must be transferred to other officers, to prepare them to prepare for the danger before they run into troubles themselves (Solomon, 1991; Solomon & Horn, 1986). However, besides *fate*, common sense suggests that there have to be critical differences in the *functioning* of officers who performed well and those who failed. In order to inoculate this precious experience into operational efficiency with more efficient training, it is necessary to study and understand such psychophysiological differences. The problem is that acute psychophysiological stress occurring during high-risk police operations is difficult to study and may elude an accurate quantification because it consists of several (interrelated) mechanisms, including psychological, endocrine, immunologic, and physical involvement, which reciprocal interaction is characterized by a pronounced interindividual and situational variability. To achieve a comprehensive understanding, high competence in very different fields and an appropriate interdisciplinary approach are required. Scientists and police officers have to work together to understand the weak points of present knowledge and to design a better training, based on scientific evidence of efficacy. On the contrary, at the moment, the majority of police instructors are highly experienced street veterans, but usually have not had much knowledge about how to use scientific methods in training. On the other hand, scientists skilled in research useful to study police tactical stress are usually closed in psychophysiology laboratories and very far away from the street and from the real-life stress occurring in highly demanding police tactical tasks. Thus, a first mandatory step is to create an appropriate communication between such different professionals, by overcoming the diffidence of police officers who usually don't like to deal with doctors (especially “shrinks”) and to have such people telling them theories about what works (or not) on the street and by pulling the “scientist” out of the laboratory and into the police reality—at least in the training arena where such realm can be realistically reconstructed and studied. An excellent example of such fruitful interaction and integration can be found in the recent book by Matthew J. Sharps titled *Processing under Pressure* (2010), where a lot of scientific knowledge has been provided in an understandable style and has been used to interpret real operational situations.

## EMOTIONS AND COGNITIVE FUNCTION UNDER TACTICAL STRESS

AQ2 Indeed, the relationship between emotion and cognition has been a matter of scientific debate for decades, and a systematic treatment of such a complex matter is obviously beyond the scope of this chapter. Here, we will briefly summarize only basic information useful to understand what happens to police officers when a tactical scenario turns into violence and needs force-on-force action. In such a situation, major emotional reactions to perceived danger trigger the officer's defensive response, mobilizing strength for survival through ANS adaptations, but inducing significant *body dysfunction* (e.g., perceptual distortion and modification of cardiorespiratory function) (Grossman & Siddle, 1998; Honig & Roland, 1998; Solomon & Horn, 1986) with possible derangement of cognitive function and rational control. Initially, cognitive and emotional functions

were viewed as largely separated, with belief that emotion was primary to and independent of cognition (Kunst-Wilson & Zajonc, 1980). Modern research in neuroscience and psychophysiology has significantly modified this interpretation. An important progress in understanding the relationship between cognition and emotion in humans has become possible after the advent of modern neuroimaging, especially the functional MRI, which confirmed that cognitive processes occur in cortical regions of the brain (Gazzaniga, Ivry, & Mangun, 2008) and that brain structures linked to emotion are mostly subcortical. However, there is a more complex network, including anterior cingulate and prefrontal cortex, which provides the mechanism for self-regulation of cognition and emotion (Allman, Hakeem, Erwin, Nimchinsky, & Hof, 2001; Bush, Luu, & Posner, 2000; Posner & Rothbart, 2007; Posner, Rothbart, Rueda, & Tan, 2009). The anterior cingulate cortex also (1) regulates the processing of information from other brain areas, (2) is sensitive to reward and pain (Eisenberger, Lieberman, & Williams, 2003; Hampton & O'Doherty, 2007), and (3) serves as part of a controlling network in coupling cognitive and emotional areas during task performance (Crottaz-Herbette & Menon, 2006; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Posner, Rothbart, Sheese, & Tang, 2007). In addition, subcortical structures (e.g., the amygdala, the ventral striatum, and the hypothalamus), which are considered part of the primitive brain and capable of operating fast and in automatic fashion to evoke survival responses (Whalen et al, 2004), are widely networked to integrate emotion and cognition. In this way, typical cognitive functions, such as perception, attention, and memory, are largely dependent on emotional stimuli. In summary, it is now evident that in the real world, there are situations in which cognition and emotion are acting simultaneously, and it is difficult to separate their reciprocal interaction; therefore, they are now considered as interdependent and integrated functions in controlling human thought and behavior (Duncan & Barret, 2007; Gray, Braver, & Raichle, 2002; Pessoa, 2008; Sergerie, Lepage, & Armony, 2006), especially under high stress situations.

AQ3

AQ4

## THE AMYGDALA AND THE RESPONSE TO THREAT AND FEAR

The key brain structure that coordinates behavioral, immunological, and neuroendocrine responses to environmental threats and fear reaction is the amygdala, a multinuclear structure located deep within the temporal lobes, medial to the hypothalamus, and adjacent to the hippocampus, well situated to integrate and distribute information through widespread projections with the rest of the brain. The amygdala serves in assessing the environment, stores emotional memories within the brain, and compares incoming emotional signals with previous emotional memories in order to make instantaneous decisions about the threat level of new incoming sensory information. The emotional content can change the formation and recollection of a memory event. In animals, the enhancement of memory owing to an emotion is due more to the induced arousal level than to the positive or negative valence of the emotion per se (McGaugh, 2004; Phelps, Ling, & Carrasco, 2006). In humans, the amygdala is known to be a critical structure for the enhancement of emotional memory (Adolphs, Cahill, Schul, & Babinsky, 1997; Phelps, 2004) and to identify new items as opposed to old (Sergerie et al., 2007). The right amygdala is more involved in the formation of emotional memory, whereas the left amygdala is activated by the retrieval of those memories (Sergerie et al., 2006). The amygdala and the associated basal forebrain system play a major role in emotional memory storage (McGaugh, 2004) by modulating activation in a network of brain regions, including the hippocampus, which is centrally involved in memory formation, and in other brain structures (e.g., the nucleus accumbens, caudate nucleus, entorhinal cortex) and cortical regions (McGaugh, 2002). Experiments on fear conditioning have shown that the amygdala participates in the acquisition, storage, and expression of the conditioned fear response (i.e., when an animal learns that a neutral stimulus predicts an aversive event). In humans, integrity of the left amygdala is necessary for physiological reaction to the threat stimulus (Olsson & Phelps, 2007) also in the case of instructed fear (Funayama, Grillon, Davis, & Phelps, 2001; Hugdahl & Ohman, 1977; Phelps et al., 2001) and observational fear (Ohman & Mineka, 2001).

Moreover, the link between perception, attention, and emotion is mediated by the amygdala. In fact, visual responses are stronger when subjects view emotional scenes. It appears that the amygdala may provide a form of emotional attention that enhances visual information under emotional stress (Pessoa, Kastner, & Ungerleider, 2002; Vuilleumier, 2005) and responds to emotional faces of which subjects are not conscious (Whalen et al., 2004). Through its extensive connections to the hypothalamus and other autonomic nervous system centers, the amygdala is able to shortcut neural signals activating the ANS and emotional response before the higher brain centers receive sensory information. In this way, it provides fast and automatic—fight or flight—behavioral responses important for survival, following the “low route” suggested by LeDoux (1996).

To date, little knowledge exists on the molecular basis of stress-induced defense (fight or flight) response underlying the simultaneous coordinated changes in the cardiovascular, respiratory, sensory, and behavioral parameters. To explore neural mechanisms of stress-related adjustments of central autonomic regulation, research has recently focused on several neurotransmitters possibly involved in modulation of the efferent pathways during defense responses. Among them, the orexin system can possibly serve as one essential modulator among many for coordinating circuits controlling autonomic function and behavior. Orexin-containing cells are widely distributed in the hypothalamus, thalamus, cerebral cortex, brain stem, and spinal cord, with widespread connections with other brain regions to control multiple physiological functions, including motivation and regulation of autonomic and neuroendocrine systems (Kuwaki, Zhang, Nakamura, & Deng, 2008). At the perception of a life-threatening attack, the effects of fear, anxiety, and anger are so automatic and rapid so as to preclude analytical thinking of what objectively occurs. In front of a real-life operational danger, the information-processing situation, the officer might unconsciously switch to the *experiential thinking mode* that occurs when a perceived emergency requires a quick response (Artwohl, 2008; Epstein, 1994). As opposed to the deliberative, analytical *rational thinking mode*, experiential thinking is seized by emotions and oriented toward immediate action. This is confirmed by the fact that 74% of the police officers studied by Artwohl (2002, 2008), under a sudden, life-threatening attack, responded “automatically to the perceived threat, giving little or no conscious thought to their actions,” in a way very consistent with the experiential thinking mode. The same author reports also that about 20% of the officers involved in a shooting incident “feel” more real the information provided by “self-evidently valid experiential thinking” than what actually happened during the incident, even when confronted with a videotape proving that they saw things that didn’t happen.

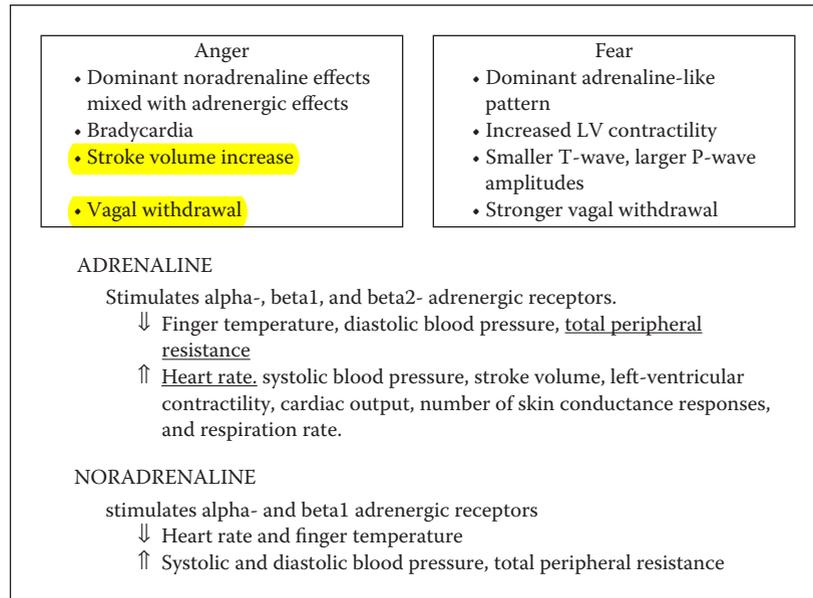
Another cognitive process relevant to police work is the so-called *behavioral (or response) inhibition*—the process required to cancel an intended action. Behavioral inhibition involves several areas of the prefrontal cortex (e.g., dorsolateral prefrontal cortex, anterior cingulate cortex, and inferior frontal cortex) (Aron, Robbins, & Poldrack, 2004; Rubia, Smith, Brammer, & Taylor, 2003) and is usually studied in the laboratory by using the so-called GO/NO-GO tasks in which subjects are asked to execute a motor response when shown the GO stimulus (e.g., press a key as fast as possible when you see a GO stimulus), but to withhold the response to the NO-GO stimulus. An equivalent situation in police work typically occurs in a SHOOT/NO-SHOOT scenario. A recent study investigated the interaction between the processing of emotional words and response inhibition. Response inhibition following negative words engaged in the dorsolateral prefrontal cortex. However, this region was not recruited by negative valence or inhibitory task demands per se while it was sensitive to the explicit interaction between behavioral inhibition and the processing of words with a negative valence (Goldstein et al., 2007). This might suggest a possible mechanism for emotional interference on the officer’s decision-making capability when he is in the empirical thinking mode piloted by the fear and/or anger emotional state. Thus, the experiential thinking mode has obvious advantages in life-threatening situations demanding an immediate response because it rapidly processes information to pilot almost automatically a survival response; however, it doesn’t guarantee that such automatic responses will always be

the appropriate ones, from both tactical and legal points of view. This fact, in association with stress-induced memory distortion and fragmentation (Grossman & Siddle, 1998), might have serious implications in the postshooting aftermath, especially if officers have to provide justification for the use of deadly force. On the other hand, when officers have to make split-second decisions about the use of force, the automatic processing of the experiential system is dominant over the rational system and becomes the default option. As experiential thinking mode is based on “past experiences” (Epstein, 1994), it seems evident that in order to improve officers’ survival in a force-on-force confrontation, appropriate training should provide “past experiences” of proven efficacy. This cannot be achieved by theoretical teaching of police tactics and skills only, but also requires providing coached repetition under realistic stress, to verify the achievement of emotional control by the trainees and that their “automatic behaviors” under stress will be adaptive and efficient to solve tactical problems, within the law (Artwohl, 2002, 2008; Artwohl & Christensen, 1997; Humes, 1992). Moreover, police training must be redesigned, taking into account modern knowledge in psychophysiology to provide officers with the capability to keep the highest possible degree of emotional and situational control. This is obviously a challenging task because it implies filling the gap between scientific knowledge on psychophysiology gathered in the laboratory and the lack of methods to quantify what extent emotions affect individual tactical behavior in operational scenarios, in order to apply this knowledge in the demanding practice of police work.

## **AUTONOMIC REACTION TO THREAT, FEAR, AND ANGER**

In a life-threatening situation, emotional responses in the brain orchestrate bodily resources in an integrated fashion to secure specific functional adaptations to different and complex demands, finalizing them to survival; however, the debate of whether fear and anger drive specific physiological responses, useful to differentiate them, is still controversial. A first meta-analysis of 22 studies on somatovisceral responses sampled during a variety of emotional states indicated that discrete emotions couldn’t be fully differentiated by visceral activity alone (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). Instead, a meta-analysis of previous research, focusing on the possibility to separate the effects of anger from those of fear, has demonstrated that the simultaneous effects of such emotions and of different behavioral responses (e.g., approach and withdrawal) (Christie & Friedman, 2004) can be at least in part be differentiated by measuring several physiological parameters related to bodily adaptation (Stemmler, 2004). A recent work of the same author has confirmed that anger could be somehow differentiated from fear by measuring bodily reactions (Stemmler, Aue, & Wacker, 2007). In extreme synthesis, the results confirmed that somatovisceral response to anger is characterized by a mixture of adrenaline and noradrenaline effects (Breggin, 1964; Funkenstein, 1955, 1956; Funkenstein, King, & Drolette, 1954; Wagner, 1989) with a relatively larger noradrenergic influence, some vagal withdrawal, and a slight  $\alpha$ -adrenergic activation (Weiss, del-Bo, Reichek, & Engelman, 1980), with resultant bradycardia and peripheral vasoconstriction, without blood pressure increase. Instead, somatovisceral response to fear is characterized by a relatively larger adrenergic influence and comprises vagal withdrawal, slight  $\alpha$ -adrenergic activation, and diverse signs for  $\beta$ 1-adrenergic activation, which are consistent with the action of adrenaline (Fahrenberg & Foerster, 1989; Funkenstein, 1955) (see Figure 14.1).

The dominant autonomic response to threat is characterized by the prevalence of the sympathetic nervous activity over the parasympathetic tone. The enhancement of sympathetic activity generates energy, diverts blood flow away from the gastrointestinal tract and skin via vasoconstriction, enhances blood flow to skeletal muscles (by as much as 1200%) and to the lungs, dilates bronchioles for greater alveolar oxygen exchange, increases heart rate (HR) and contractility, dilates pupils, and relaxes the lens, allowing more light to enter the eye. The prevalence of sympathetic effects and concomitant adrenergic neuroendocrine response are finalized to increase strength, resistance, and attention for survival; however, they induce functional alterations (visual, auditory,



**FIGURE 14.1** Autonomic response to anger and fear, according to the meta-analysis of Stemmler (2004). Relatively stronger noradrenergic effects characterize anger, whereas fear is characterized by relatively dominant adrenergic response. Major physiological effects of adrenaline and noradrenaline are also summarized.

cardiac, and so on), which largely affect the officer's capability to move and act with the same flexibility available during training, in the absence of life-threatening stress (Siddle, 1999).

Now, the question is whether it is possible to objectively quantify the kind and the amount of individual emotional reaction of a police officer involved in a critical operation, by measuring physiological parameters affected by dominant autonomic reactions, and how to do that. Thus, the challenge is to develop reliable, scientifically validated methods to evaluate such psychophysiological response during tactical tasks.

## METHODS TO MEASURE STRESS REACTIONS IN THE LABORATORY

In the psychophysiology laboratory, somatovisceral responses to emotions can be investigated under controlled conditions by monitoring a variety of physiologic signals such as electroencephalogram, electrocardiogram (ECG), electromyogram, impedance cardiogram, blood pressure, skin conductance, skin temperature, pulse volume, and respiration (Kreibig, Wilhelm, Roth, & Gross, 2007; Stemmler et al., 2007). Interestingly, it has also been recently suggested that the amplitude of resting ECG waveform contains information related to emotional personality and brain activity in the amygdala and hippocampus (Koelsch et al., 2007). Most of such recordings are feasible and reliable only when the investigated subject is sitting quietly to prevent movement artifacts, although even in the laboratory the quality of the recordings can be altered by several factors, which might jeopardize the reliability of the result. Such technical difficulty is obviously higher when attempting physiological recordings in the realm of police operational scenarios. For this reason, most parameters usually monitored to measure stress reactions in experimental psychology are not reliably obtainable on the field. Therefore, it is difficult to transfer scientific investigations from the laboratory in the training range and even less in the operational realm. In fact, although the wide experience developed in sports medicine and experimental psychology might help to find some technical solutions, the complexity of the dynamic variables that have to be monitored during realistic police scenarios implying the use of force is too wide to be covered with presently available

technology. It turns out that there is a very limited experience on direct measurement of human physiology during force-on-force encounters by law enforcement and that the only parameter that has been studied so far is the HR obtained with ECG recording or with HR monitoring devices used for sports activity, both methods having pros and cons. In addition to physiological signals, several humoral stress markers can be also measured. Salivary Dehydroepiandrosterone (DHEA), Cortisol, and Secretory Immunoglobulin A (S-IgA) are the most frequently used, because they can be easily sampled without any subject discomfort, even in an outdoor situation. DHEA and its sulfated metabolite DHEA-S are hormones secreted by the adrenal cortex in response to pituitary adrenocorticotrophic hormone (ACTH) production. DHEA-S is the most abundant circulating steroid hormone in humans and its measurement has been of interest, especially because reduced levels of both DHEA and DHEA-S are associated with aging. DHEA is also the precursor to the human sex hormones (estrogen and testosterone) and has been found to be deficient in people suffering from many diseases including obesity, diabetes, hypertension, cancer, Alzheimer's, immune deficiency, coronary artery disease, and various autoimmune disorders. Cortisol, a glucocorticoid hormone, is involved in protein, carbohydrate, and fat metabolism, and it is widely known as the stress hormone because it is secreted in excessive amounts when people are under stress. Cortisol is tightly regulated by feedback mechanisms in both the hypothalamus and the pituitary glands, where the original hormonal signals trigger its production. As in other systems, the hypothalamus begins the process by secreting corticotropin-releasing factor (CRF) in response to a variety of stressors. Then, CRF triggers the anterior pituitary to release ACTH that increases the adrenal cortex secretion of cortisol. Salivary cortisol levels have been compared to serum cortisol levels in a variety of patients, founding a very reliable measurement (Aardal-Eriksson, Karlberg, & Holm, 1998). The advantages of using salivary measurements include noninvasive sample collecting anytime and anywhere without inducing cortisol/stress due to venipuncture for blood sampling. Salivary cortisol levels have been used to measure acute stress induced by consecutive parachute jumps (Deinzer, Kirschbaum, Gresele, & Hellhammer, 1996) or by a psychosocial stress test involving free speech and mental arithmetic in front of an audience for 15 minutes (Kirschbaum, Wust, & Hellhammer, 1992). DHEA/cortisol ratio has been proposed as an important marker of stress and aging. When individuals are under prolonged stress, a divergence in this ratio results, because cortisol levels continue to rise while DHEA levels decrease significantly. The effects of DHEA/cortisol imbalance can be severe and may include elevated blood sugar levels, increased bone loss, compromised immune function, decreased skin repair and regeneration, increased fat accumulation, and brain cell destruction. A significant increase in DHEA/cortisol ratio was found in volunteers who showed a significant reduction in stress, burnout, and negative emotion as a result of stress management intervention. Reduced stress diminishes the system's cortisol demand and can result in the diversion of pregnenolone, a common precursor of DHEA and cortisol, from cortisol production into DHEA synthesis (McCraty, Barrios-Choplin, Rozman, Atkinson, & Watkins, 1998). S-IgA is produced by B-lymphocytes, a major component of the immune system, and it is viewed as the first defending line against pathogens in the upper respiratory tract, the gastrointestinal system, and the urinary tract. Salivary S-IgA levels were inversely correlated to perceived stress in emergency department nurses (Yang et al., 2002). In healthy volunteers, salivary S-IgA levels were measured before and after experiencing the emotional states of either positive feeling of care and compassion or negative feeling of anger. Self-induced positive feeling states produced a significant increase in S-IgA levels, while 5 minutes of self-induced anger feeling produced a significant inhibition of S-IgA lasting from 1 to 5 hours after the emotional experience (Rein, Atkinson, & McCraty, 1995). Thus, salivary S-IgA level can provide information about stress-induced depression of immune defense. Stress-induced activation of mononuclear interleukin  $1\beta$  (IL- $1\beta$ ) is a mechanism potentially linking stress with immune and endocrine status and with heart disease. Regardless of the nature of the stress, the effects of IL- $1\beta$  include the stimulation of ACTH secretion, with a consequent increase in glucocorticoid levels and activation of the sympathetic nervous system, followed by a release of catecholamines. Salivary IL- $1\beta$  concentration is another easily measurable marker of psychological stress (Brydon et al.,

2005; Ilardo et al., 2001). However, costs and organization might be the only limitations in testing the above biomarkers of stress on a large scale. Finally, the degree of individual emotional involvement is usually rated on the basis of self-reports of emotions and motivational approach (Kreibig et al., 2007; Stemmler et al., 2007).

## HISTORY OF TACTICAL STRESS AND HEART RATE

In 1984, Massad F. Ayoob, in his book *Stress Fire*, described how survival stress reactions, induced by a deadly force confrontation, could affect defensive efficacy and provided fundamental suggestions for coping with stress, to control physiological symptoms, and to be efficient in an armed confrontation. Since that reading, we started to figure out how to find a way to objectively quantify individual stress in police officers exposed to acute operational pressure implying the use of force and shootings. As cardiologists, we thought the easiest way was to monitor the HR continuously; however, wearable Holter recorders were bulky at that time and much vulnerable to mechanical shock. Thus, we had to wait for the first solid-state recorders to initiate in 1990, the first pilot study evaluating the feasibility to capture the heart rates of law enforcement officers during actual force-on-force scenarios. Bruce Siddle, in *Sharpening the Warrior's Edge: The Psychology & Science of Training* and in a subsequent publication (Siddle, 1995, 1999), reviewed previous research and discussed how survival stress reactions might affect the law enforcement officer when placed in a life or death situation, taking into account the neural basis of survival motor programs, motor skills classification, reaction time, and the psychology of survival training. Most important, he attempted an integration of available information about HR levels, motor skills, and associated cognitive performance, in a model correlating different levels of survival stress reaction, based on the elevation of the HR. In his model, fine motor skills (such as finger dexterity and eye-hand coordination) deteriorate above 115 beats per minute (bpm), whereas complex motor skills (i.e., ability to track and shoot a moving target, which involves eye-hand coordination, timing, and balance) begin to deteriorate when the HR reaches 145 bpm. With HR above 145 bpm, perception begins to be altered, leading to auditory exclusion and narrowing of the visual system (tunnel vision). With further increase of the HR, a progressive deterioration of cognitive control of action can occur, with a sort of functional shut-off of prefrontal cortical areas, and irrational behavior prevails when HR exceeds 175 bpm. The gross motor skill controlling the actions of the large muscle group such as the thighs, chest, back, and arms, are enhanced and maximized with increasing level of stress, although excessive blood reduces flexibility and capability to run well. Siddle as well as other authors (Grossman & Christensen, 2004) suggest that, as in athletic competitions, the optimal tactical HR “zone” should be between 115 and 145 bpm. Instead, when HR raises above 175 bpm, tactical efficiency may be lost because of a progressive trend toward irrationality, favored by perceptual and memory distortion (Klinger, 2001), reduced functioning of the prefrontal cortex, and prevalence of the amygdala signaling under uncontrolled fight-or-flight response (Sharps, 2010). Bruce Siddle’s research about the effects of stress on HR and their physiological consequences on the human body were paramount for police instructors who started to figure out that officers have to receive and practice realistic force-on-force training, because only in that way can they be prepared to deal with the real-life operational stress (Olson, 1998). However, in spite of the unquestionable merit of Siddle’s intuition and attempt to correlate the intensity of operational stress with the HR response, the significance of HR increase is still questionable. In particular, experimental evidence that the absolute value of HR achieved can be an index of individual stress and predictive of operational behavior is lacking at the moment. In 1999, Fenici et al. reported about ECG and blood pressure monitoring in six healthy adult athletes (five were police officers) to evaluate if there was indeed an elevation in the HR and blood pressure of law enforcement officers under the stress of a competitive pistol shooting. Four shooters’ heartbeats reached above 180 bpm and in two cases the HR exceeded 200 bpm, for the occurrence of paroxysmal arrhythmias. The study demonstrated that under competition stress, healthy athletes had elevated heart rates but reported different subjective stress

AQ5

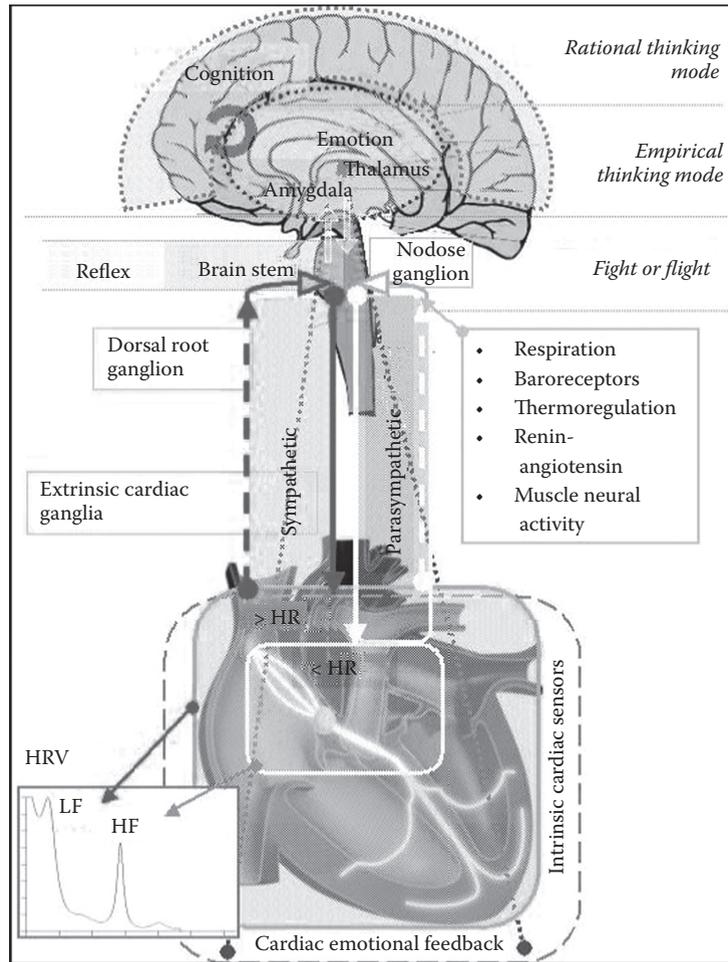
perception. The highest level of stress was achieved during “man versus man” shoot-offs, which better mimic a defensive situation, affecting shooting precision and the outcome of the competition. The authors recommended that further studies were needed to evaluate cardiovascular stress and the coping capabilities of the law enforcement officer in operational scenarios. However, it was also evident that the pure measure of HR increase could be misleading, if not interpreted in the context of the event dynamics. In fact, in action shooting, as in the realm of a police tactical scenario, an overlap can occur of physical effort and psychological strain, both contributing to increase HR. It is possible that the same 175 bpm might have a very different effect on behavioral appropriateness if predominantly generated by physical effort and not by psychological stress. Moreover, the results of few studies, carried out by monitoring the HR during realistic tactical training, seem partially in disagreement with Siddle’s model and suggest the need of a more sophisticated methods to quantify the individual psychological stress during police tactical tasks. At the Federal Law Enforcement Training Centers, Meyerhoff et al. (2004) found a significant elevation in HR and blood pressure during very stressful realistic scenarios simulating highly dangerous situations, created to evaluate the performance of law enforcement personnel with a protocol measuring indices of stress and impact on performance. Differences in HR responsivity were observed between officers who achieved passing scores and those who failed. However, successful officers displayed additional HR acceleration while in the passenger role during a stressful driving episode as well as during the gunfight, whereas officers who received failing scores on those elements had lower HR than the successful ones. Unfortunately, absolute HR values were not reported in this study. Another study, conducted at the Texas State University at San Marcos in connection with the Advanced Law Enforcement Rapid Response Training (ALERRT), was recently presented at the Annual Conference of the Society of Police and Criminal Psychology (SPCP) in 2008. The authors concluded that in the 42 investigated officers (1) there was no significant correlation between the amount of experience and training of the officers and average or maximum HR achieved during force-on-force scenarios, (2) training doesn’t affect management aspect, and (3) there is no relationship between HR and Body Mass Index. However, they also correctly suggested that, as the HR was not measured with continuous ECG recording, some measurements could have been affected by technical limitation of the HR monitor used (Kemp & Diez, 2008). A larger prospective research project, carried out in Italy since 1992 by monitoring ECG and blood pressure of police officers undergoing realistic training in medium to high stress tactical scenarios, including force-on-force and gunfight with Simunitions®, has provided evidence that the resting HR and blood pressure values of the police officers tended to be significantly enhanced already before action. Their HR suddenly increased (even above 150% of the basal state) during life-threatening confrontations. However, the absolute value of HR and the percent of HR increase did not predict the tactical behavior of individual officers or the outcome of their action. In fact, about half of the officers acted properly in spite of very high HRs, whereas half of those who failed had a lower HR increase and their HR was sometime still within the “ideal combat range” (Fenici, 2008; Fenici & Brisinda, 2008b). In summary, the results of previous research could raise doubts about the information that can be gathered with measurements of the HR when the intention is to evaluate the amount of individual stress induced by police tactical operation and/or to predict appropriate tactical behavior as a function of individual HR reaction. Moreover, when tactical tasks implied an amount of physical effort, it was difficult to distinguish to what extent the HR acceleration was due to emotional involvement or to physical activity.

AQ6

In order to separate these two effects, knowledge of mechanisms underlying HR regulation in different physiological and emotional conditions is required.

## HEART RATE REGULATION

Daily life is characterized by alternation of rest and activity, requiring adjustments of the autonomic nervous system (ANS) to adapt cardiorespiratory function for bodily demands. The ANS controls



**FIGURE 14.2** Neural interconnection between brain, cardiac autonomic innervation, and other visceral inputs to the brain stem modulating heart rate (HR) and its variability (HRV). Sympathetic (max effect in 4 s) and parasympathetic (max effect in 0.6 s) “efferent” (solid arrows) and “afferent” (dashed arrows) limbs are shown. The afferent signals from the heart reach the medulla, then travel to the subcortical and cortical areas of the brain, affecting feeling states, mental processes and emotional balance.

body’s visceral functions, including heart activity, gastrointestinal tract movement, and endocrine secretion. The normal sinus rhythm is generated by the intrinsic automaticity of the physiological pacemaker of the heart, which is largely modulated by the ANS through the interplay of sympathetic and vagal outflows (see Figure 14.2). In most physiological conditions, the efferent sympathetic and parasympathetic branches regulate HR, influencing the activity of ion channels involved in the regulation of depolarization of the cardiac pacemaker cells (Piot, Copie, Guize, Lavergne, & Le Heuzey, 1997). The sympathetic system enhances automaticity by increasing the rate of pacemaker depolarization, whereas vagal stimulation causes hyperpolarization and reduces the rate of autodepolarization, with consequent reduction of HR.

### HEART RATE VARIABILITY

Although the heart beating at rest was once believed to be regular, it is actually known that the sinus rhythm of a healthy heart is slightly irregular because of three major physiological originating

factors: (1) a quasi-oscillatory fluctuations in blood-pressure control, (2) respiration, and (3) oscillations due to thermal regulation. This phenomenon is named *HR variability* (HRV). The dynamic modulation of HR is provided by the interaction of the sympathetic system (which has a response time in the order of a few seconds) and of parasympathetic activity (which works much faster: response time 0.2–0.6 seconds) (Berntson et al., 1997). Such continuous modulation by ANS results into HR fluctuation or variability. Whereas the measure of HR is a static index of autonomic input to the sinus node, which doesn't provide direct information on sympathetic or parasympathetic function in a given state, HRV analysis provides a quantitative assessment of cardiac autonomic regulation (ESC and NASPE Task Force on Heart Rate Variability, 1996; Lahiri, Kannankeril, & Goldberger, 2008; Perini & Veicsteinas, 2003). Thus, HRV analysis may be a useful clinical tool to assess the dynamics of sympathovagal balance in a given situation.

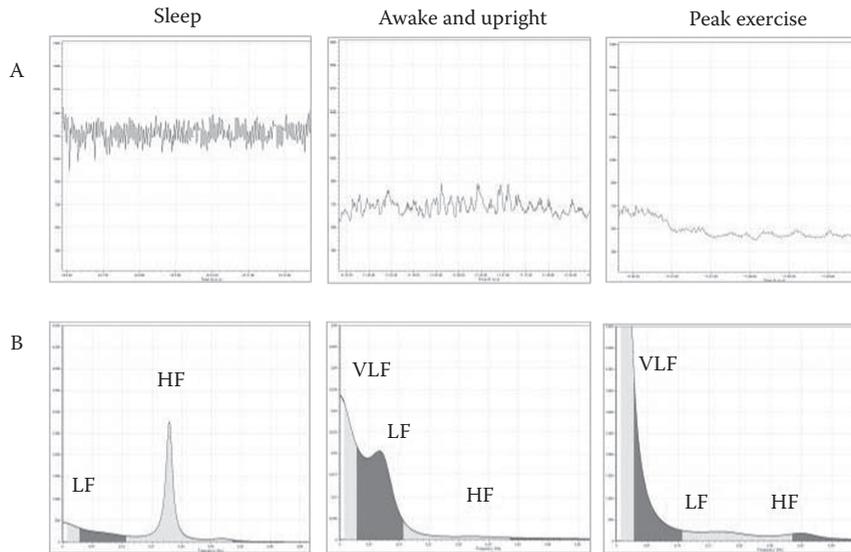
Even though HRV has been extensively studied during the last decades, its clinical application has reached general consensus (ESC and NASPE Task Force on Heart Rate Variability, 1996) only as a predictor of risk after myocardial infarction (Fox et al., 2007, 2008) and as an early warning sign of diabetic neuropathy (Braune & Geisenörfer, 1995; Pagani, 2000). However, HRV analysis is nowadays also increasingly used as a research tool to quantify emotional response in social and psychopathological processes, since theoretical and empirical rationale for its use as an index of individual differences in emotional response has been given recently by Appelhans and Luecken (2006).

## QUANTITATIVE ASSESSMENT OF HRV

HRV is usually measured from changes in heartbeat interval, which is the reciprocal of HR. The starting point for HRV analysis is the ECG recording from which the HRV time series are extracted. The sinus interval is generally defined as the time difference between two successive P-waves. However, as the P-wave is usually a low-amplitude signal, in order to improve the accuracy of detection of the heart rate, the heartbeat period is usually evaluated as the time difference between two consecutive QRS complexes, which are signals 10 times larger in amplitude. After QRS peaks have been properly detected (with a time accuracy of 1–2 ms), the HRV time series (or tachogram) can be derived. Any technical (e.g., errors in QRS detection) or physiological (e.g., arrhythmic events) artifacts in the RR interval time series, which may affect HRV analysis, must be manually removed and only artifact-free sections should be included in the analysis (ESC and NASPE Task Force on Heart Rate Variability, 1996). An example of an HRV tachogram in different physiological conditions is shown in Figure 14.3A.

AQ7

Quantitative assessment of HRV is performed with time-domain, frequency-domain, and nonlinear methods. For a comprehensive description of HRV analysis, the interested reader is addressed to more specific literature (ESC and NASPE Task Force on Heart Rate Variability, 1996; Lahiri et al., 2008; Sztajzel, 2004; Tarvainen, Georgiadis, Ranta-aho, & Karjalainen, 2006). This chapter will mainly describe the fundamentals of frequency domain analysis, because it is the most suitable for short-time analysis and useful to study stress-induced transient fluctuations of autonomic balance potentially affecting tactical behavior of police officers. The time-domain parameters (see Table 14.1) are statistical calculations directly applied to the series of successive RR interval values. Nonlinear methods are increasingly used in clinical studies, but the physiological interpretation of their results is still difficult (Carrasco, Caitan, González, & Yáñez, 2001; Zbilut, Thomasson, & Webber, 2002). Frequency domain analysis describes the periodic oscillations of the HR signal decomposed into different frequencies and amplitudes. It can be performed with nonparametric methods, such as the Fast Fourier Transform (FFT), which is characterized by discrete peaks for the several frequency components, or with parametric methods, such as the autoregressive model estimation (ARMA), resulting in a continuous and smoother spectrum of activity, more suitable for very short-term HRV changes evaluation. The spectral components (see Table 14.2) are evaluated in frequency (Hertz: Hz) and amplitude, the latter assessed by the



**FIGURE 14.3** HRV analysis in different physiological conditions. (A) Tachograms (time variation of RR interval). (B) Power spectral analysis (5' intervals - ARMA model) shows: prevalence of vagal tone (HF) during sleep; clear-cut increase in LF power (and LF/HF ratio) occurs when awake and upright, predominantly due to an increase in direct neural stimulation of sympathetic tone. At the peak of exercise, the HRV total power decreases, with dominance of the VLF component.

area below each component (power spectral density). Short-term (5 minutes) spectral recordings are mainly characterized by two components: the low frequency (LF: 0.04–0.15 Hz) and the high frequency (HF: 0.15–0.4 Hz). The most relevant periodic determinant of HRV is the respiratory sinus arrhythmia due to the physiological influence of breathing, which is measured by the HF component and generally believed to be of parasympathetic origin. The frequency components within the LF band are considered of both sympathetic and parasympathetic origin (Berntson et al., 1997) even though some researchers have suggested them to be mainly of sympathetic genesis (Malliani, Pagani, Lombardi, & Cerutti, 1991). Furthermore, there are also feedback mechanisms providing quick reflexes. The most relevant is the arterial baroreflex, based on specialized stretching sensors (baroreceptors) located on the walls of some large vessels and activated by blood pressure increase. Baroreceptors activation is known to inhibit sympathetic outflow from the brain to peripheral vascular bed, whereas psychological stress enhances sympathetic outflow by inhibition baroreflex activity (Eckberg et al., 1988). Within the LF band, the frequency range around 0.1 Hz (named also middle frequency or MF band) is considered as due to baroreceptor activity

**TABLE 14.1**  
**Time Domain HRV Parameters**

Variable	Units	Description
SDNN	msec	Standard deviation of all NN intervals
SDANN	msec	Standard deviation of average of NN intervals in all 5-minute segments of entire recording
rMSSD	msec	Square root of the mean of the sum of the squares of differences between adjacent NN intervals
SDNN index	msec	Mean of the standard deviations of all NN intervals for all 5-minute segments of the entire recording
NN50		Numbers of pairs of adjacent NN intervals differing by more than 50 msec in the entire recording
pNN50	%	NN50 count divided by the total number of all NN intervals

**TABLE 14.2**  
**Frequency Domain HR Parameters**

**Absolute values** (expressed in ms<sup>2</sup>)

• Total power	= variance of all NN intervals	<0.4 Hz
• ULF (24h)	ultra low frequency	<0.003 Hz
• VLF	very low frequency	<0.003–0.04 Hz
• LF	low frequency power	0.04–0.15 Hz
• MF	middle frequency power	0.08–0.1 Hz
• HF	high frequency power	0.15–0.4 Hz
• LF/HF	ratio of low-high frequency power	

**Normalization** of LF and HF (in n.u.) by subtracting VLF component:

$$\text{LF or HF norm (nu)} = \frac{\text{LF or HF (ms}^2\text{)}}{\text{total power (ms}^2\text{)} - \text{VLF(ms}^2\text{)}} \times 100$$

**Relative values** (in %) of each component (LF and HF) in proportion to total power

and reflecting the blood pressure feedback signals sent from the heart back to the brain (Aguirre, Wodicka, Maayan, & Shannon, 1990; Pitzalis et al., 1997; Robbe et al., 1987; Tiller, McCraty, & Atkinson, 1996). On the other hand, HR fluctuations below 0.04 Hz have not been studied as much as higher frequencies. They are usually divided into very low frequency (VLF: 0.003–0.04 Hz) and ultra-low frequency (ULF: 0–0.003 Hz) bands, the latter generally omitted in case of short-term recordings (ESC and NASPE Task Force on Heart Rate Variability, 1996). These lowest frequency components of HRV have been related to humoral factors such as thermoregulatory processes and renin-angiotensin system (Berntson et al., 1997). The power of spectral densities can be expressed in absolute values (ms<sup>2</sup>/Hz) and in normalized units (n.u.). The normalization is performed by subtracting the VLF component from the total power, to minimize the effects of the changes in total power on the LF and HF components (Sztajzel, 2008). The total power of HRV is the total variance RR intervals and corresponds to the sum of the four spectral bands, ULF, VLF, LF, and HF. The power of the single spectral peaks is not a direct measure of the autonomic activities (Kamath & Fallen, 1993), but can be accepted as a quantifier of autonomic responsiveness (Saul, Rea, Eckberg, Berger, & Cohen, 1990). In particular, the LF/HF ratio is generally accepted as an index of instantaneous sympatho-vagal balance (ESC and NASPE Task Force on Heart Rate Variability, 1996; Lahiri et al., 2008; Perini & Veicsteinas, 2003; Sztajzel, 2004). Therefore, relative (%) changes in LF and HF powers and variations of in LF/HF ratio indicate a shift from the vagal to sympathetic dominance and vice versa, induced by situational changes or stimuli (e.g., awakeness, sleep, and moving from supine to upright position) (see Figure 14.3B). Besides HRV, other markers of autonomic activity are HR recovery after exercise, (Lahiri et al., 2008), HR turbulence, QT interval, and baroreflex sensitivity (Sztajzel, 2004).

## HRV AND PHYSICAL EFFORT

Power spectral analysis of HRV has been also used to evaluate the respective sympathetic and vagal roles in controlling HR during and after muscular work (Buchheit, Laursen, & Ahmaidii, 2007; Perini & Veicsteinas, 2003; Pichon, de Bisschop, Roulaud, & Papelier, 2004). Interestingly, although HRV analysis is reliable to highlight modifications in autonomic activities induced by different physiological conditions at rest (e.g., hypoxia exposure, training, water immersion), changes in HF and LF powers and in LF/HF ratio during exercise don't reflect the withdrawal of vagal activity and the sympathetic activation occurring at increasing loads. In fact, Perini and Veicsteinas (2003) have shown that LF power doesn't change during low-intensity exercise and decreases to

negligible values at medium–high intensity albeit an enhancement of sympathetic activity. The same authors suggest that changes in LF power observed at medium–high intensity might be the expression of the modifications in arterial pressure control mechanisms occurring with exercise and that LF changes are affected also by body position. In fact, the LF component increases at medium–high intensities when exercise is performed in the supine position but has an opposite trend in the sitting position, maybe in relation to different muscular inputs in the two conditions. In the same study, the HF component was appreciable in the entire range of relatively intensive exercise, and it was accounting for the most part of the total power, which usually decreases at maximal load. This peculiar finding was interpreted by Perini and Veicsteinas (2003) as possibly due to a modulation of the HF component by a direct mechanical effect of the increased respiratory activity induced by exercise.

### HRV AND EMOTIONAL STRESS

As noted earlier in the chapter, normal HR variability is due to the synergic action of the two branches of the ANS with other neural, humoral, and physiological reflexes finalized to keep cardiovascular adaptation in the optimal range for appropriate reaction to changes of external or internal conditions. These changes are also influenced by emotional reactions (Berntson et al., 1997). In fact, several studies carried out in the controlled laboratory environment have shown the relationship between exposure to acute psychological stress and alteration of cardiovascular ANS response (Delaney & Brodie, 2000; Orsila et al., 2008; Pagani et al., 1991; Salahuddin, Cho, GiJeong, & Kim, 2007; Shapiro et al., 2000). The acute effects of short-term psychological stress on time and frequency domains of HRV has been mainly investigated in the laboratory using different kinds of mental stress (e.g., stroop conflict color test, arithmetic calculation, computer controlled mental tasks, or stressful interview).

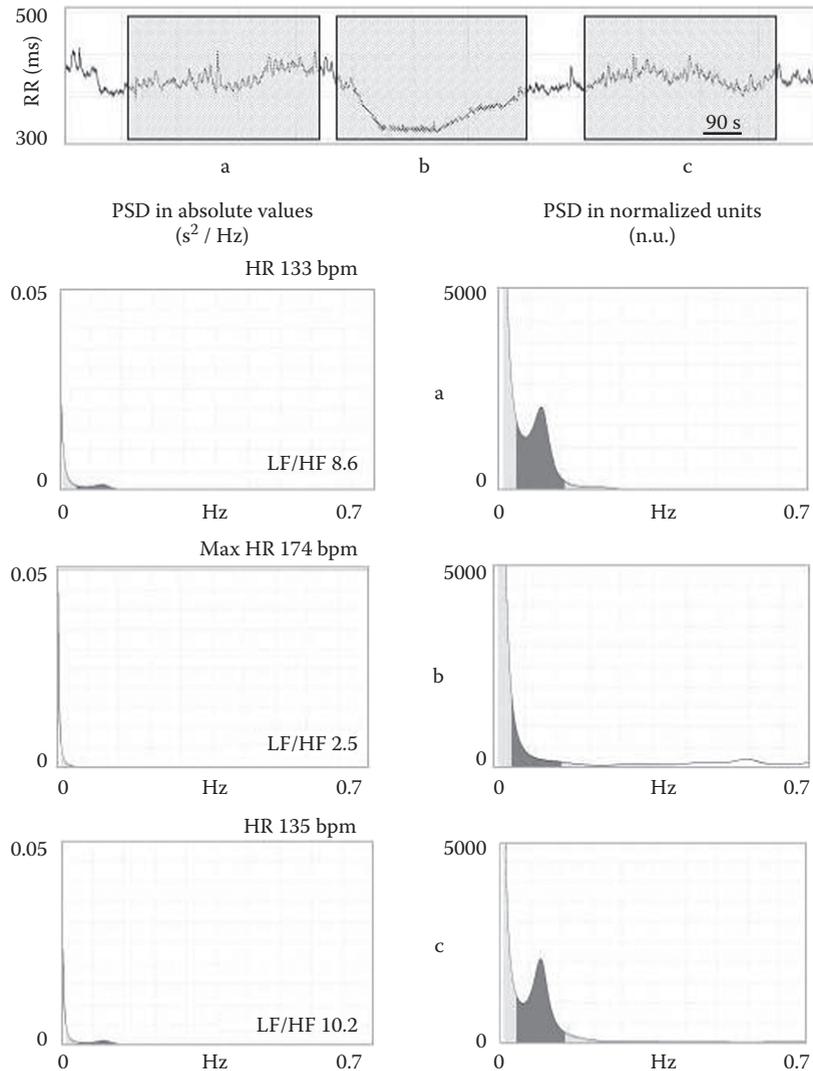
Three main stress-induced adaptations have been described: (1) a significant enhancement of HR indicating a shift toward sympathetic predominance, which is also evidenced by increase of skin conductance and decrease of skin temperature; (2) enhancement of the LF component with consequent increase of the LF/HF ratio (Orsila et al., 2008; Salahuddin et al., 2007); and (3) vagal withdrawal demonstrated by the reduction of total power (RR variance). It was also shown that additional stress (e.g., that induced by painful stimulation during mental stress) increases HR without significant changes of HRV parameters, probably because of a compensatory sympathoadrenal activation releasing catecholamine into the circulation (Terkelsen, Mølgaard, Hansen, Andersen, & Jensen, 2005).

The effects of specific emotions have been also investigated in the psychology laboratory, monitoring multiple physiological and behavioral parameters during exposure to standardized video clips inducing discrete emotions, with evidence that the simultaneous effects of different emotions and motivational direction (approach and withdrawal) can be separated with HRV analysis (Kreibig et al., 2007; Stemmler et al., 2007) (no data on spectral parameters are available from those studies). Relatively few studies have addressed the association between real-life stress and cardiac autonomic response in humans (Lucini, Di Fede, Parati, & Pagani, 2005; Lucini, Norbiato, Clerici, & Pagani, 2002). Even less is known about acute autonomic adaptations in police officers exposed to threat-induced stress, because a systematic investigation of autonomic reactions induced by dangerous tactical tasks is still lacking. We believe research should be carried out to fill this lack of knowledge and that HRV evaluation might be a powerful, objective, and noninvasive tool to explore dynamic interactions between physiological, mental, emotional, and behavioral processes. In fact, previous work showed that changes in heart rhythms affect not only heart function but also brain ability to process information, including decision making, problem solving, and creativity (McCraty, 2002) and that real-time assessment of HRV fluctuation is a reliable method to differentiate positive and negative emotional changes (McCraty, Atkinson, Tiller, Rein, & Watkins, 1995). For almost a decade, Fenici and colleagues have shown that simple HR

AQ8

analysis was not sufficient to validate Siddle's model, because the level of stress-induced HR increase, although statistically significant (Fenici, 1999; Fenici, Brisinda, & Fenici, 2002), has a wide interindividual variability and a that a lower level of tachycardia is not univocally a predictor of individual tactical efficiency (Fenici, & Brisinda, 2004). More recently, the same authors have applied spectral analysis of HR variability from the same dataset to attempt a dynamic imaging of the interplay between sympathetic and parasympathetic control on the HR, timed and correlated with situational monitoring of individual tactical behavior during threat-induced stress reactions (Fenici & Brisinda, 2008a; Fenici & Brisinda, 2008b). One hundred and ten police officers volunteered for that study, all of whom were previously evaluated to exclude any cardiac and/or psychological abnormalities. 12-lead ECG was continuously recorded (Mortara-Rangoni H-Scribe Holter System), along a realistic training session. At the beginning, after a preliminary 10-minute rest period in supine position, allowed for stabilization, ECG was recorded over a 10-minute supine baseline, over a 5-minute of controlled breathing, and over a subsequent 10-minute period of active standing. Blood pressure was measured in both postures. After about 2 hours of normal low-stress daily activity, each subject participated in a briefing, describing the high-stress police tactical tasks to be performed during realistic training. At the end of the scenario, all subjects underwent a debriefing session where their performance was discussed and confronted with instructors, using video recordings as objective reference. ECG Holter recording was continued until at least 1 hour after the end of the training session. The high-stress realistic training session consisted of active participation in scenarios simulating risky police tactical operations including a building search, intervention for domestic violence, and force-on-force confrontations with professional role players. The officers' behavior during the scenarios was continuously monitored with multiple video cameras synchronized with the Holter recorder's timer, for off-line evaluation by police instructors. Power spectral analysis of HRV was performed with a parametric autoregressive model (ARMA model) estimation, which provides a continuous, smooth spectrum of different components and quantification of their relative intensity (Tarvainen, Geogiadis, Ranta-aho, & Karjalainen, 2006), from standard time intervals of 5 minutes (ESC and NASPE Task Force on Heart Rate Variability, 1996) and from ultra-short time intervals (30–50 seconds) during the phases of highest stress (Salahuddin et al., 2007). One relevant finding of the study is the observation that ultra-short term analysis of HRV is necessary to quantify acute perturbations of cardiovascular autonomic balance induced by acute stress response. In fact, standard HRV power spectral analysis, calculated from 5-minute intervals (see Figure 15.4), was inadequate to evidence sudden, short-lasting changes of the HRV pattern correlated with the phases of maximum tactical stress. In fact, the 5-minutes analysis at peak stress showed a sudden decrease of total power characterized by prevalence of the VLF component, with a time-averaging effect of rapidly changing events impairing the evaluation accuracy of peak HR and of the LF/HF ratio (see values in Figure 14.4 and Figure 14.5).

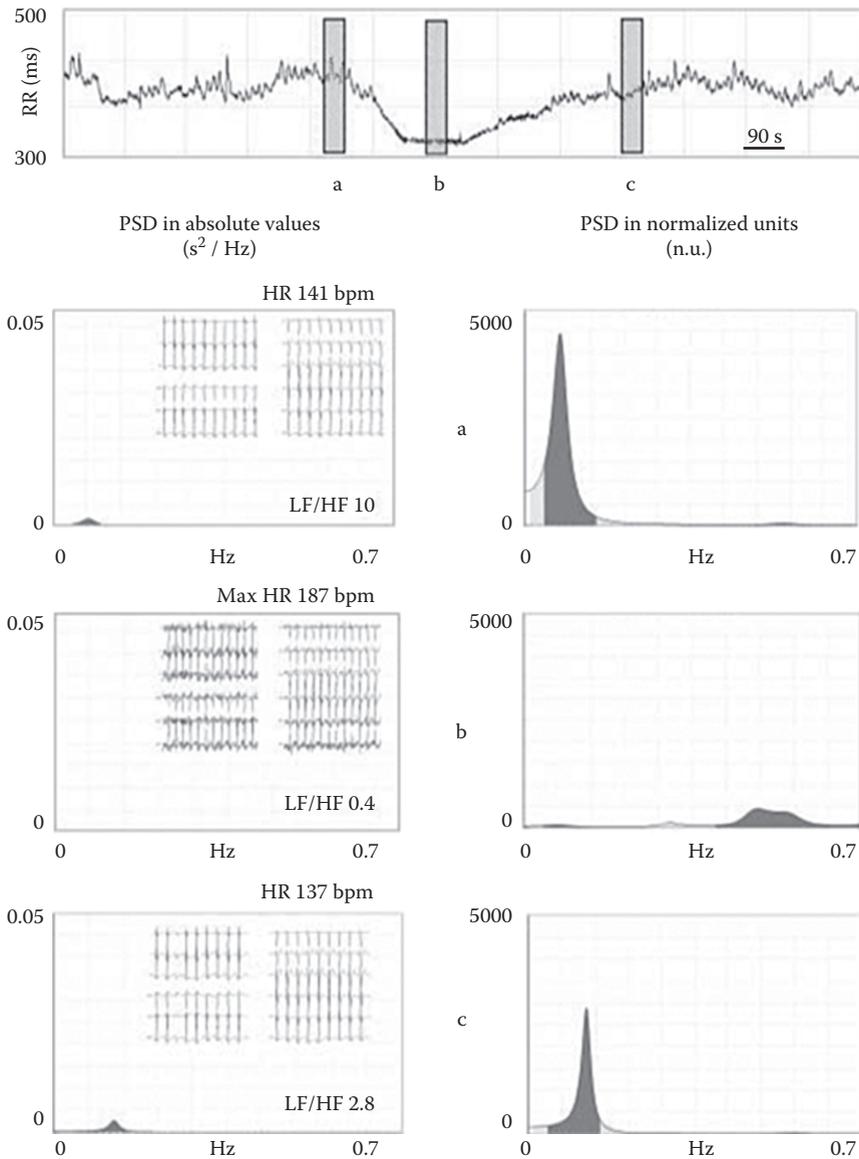
Instead, in the 50-second analysis, the VLF component was absent, whereas the LF components were well evident before (Figure 14.5A) and after (Figure 14.5C) peaks of danger, but disappeared at the nadir of HR, when one or more HF components became appreciable, usually with inversion of the LF/HF ratio (Figure 14.5B). Such a kind of transient fluctuation of LF and HF relative power was highly reproducible in the same subject, as a function of the onset/offset of subsequent bursts of threat. Each time the level of threat decreased, HRV was reproducibly characterized by the reappearance and progressive increase of the LF component (Figure 14.5C). The same pattern was observed in the majority of the investigated subjects during similar events, thus only ultra-short term analysis identifies fluctuations of HRV spectral components, at the onset/offset of sudden threat. This study represents a first attempt to image the dynamicity of cardiovascular autonomic fluctuation in a model of human acute psychophysiological reaction induced by real-life police tactical stress. The main new finding is that, under the fight-or-flight response grip, fast dynamic changes in cardiovascular autonomic regulation occur, inducing rapid changes of HRV parameters within seconds. To attempt an interpretation of such peculiar transient fluctuations in HRV power



**FIGURE 14.4** HRV spectral analysis from 5' intervals (shaded rectangles on the tachogram) (a) before, (b) during, and (c) after an episode of transient increase of HR caused by a sudden threat. Power spectral densities (PSD) are expressed in  $s^2/Hz$  (left panels) and in normalized units (right panels). LF/HF ratio is also shown. The averaging effect of 5' analysis determines underestimation of the peak HR (174 bpm whereas the real was 190 bpm). At peak stress PSD shows dominance of the VLF, reduced LF power and LF/HF ratio (2.5).

spectral components during defense-arousal, it must be realized that spectral analysis of HRV can only give a partial estimate of autonomic function (because this method does not measure nervous activity directly) and that other mechanisms, such as circulating epinephrine or saturation kinetics of the sympathetic and vagal efferent nerve activity on the sinus node, might contribute to induce extreme tachycardia during acute stress (Ahmed, Kadish, Parker, & Goldberger, 1994; Malik & Camm, 1993; Tulen et al., 1994).

The reproducible pattern characterized by a marked decrease of HRV total power, LF component disappearance, and VLF dominance suggests an “adrenaline-like pattern of fear” (Stemmler et al., 2007) rather than enhanced neurosympathetic drive as the most relevant mechanism of threat-induced sudden burst of tachycardia. The relative dominance and fluctuations of HF component evidenced by ultra-short term analysis at peak-stress (Figure 14.5B) could be due



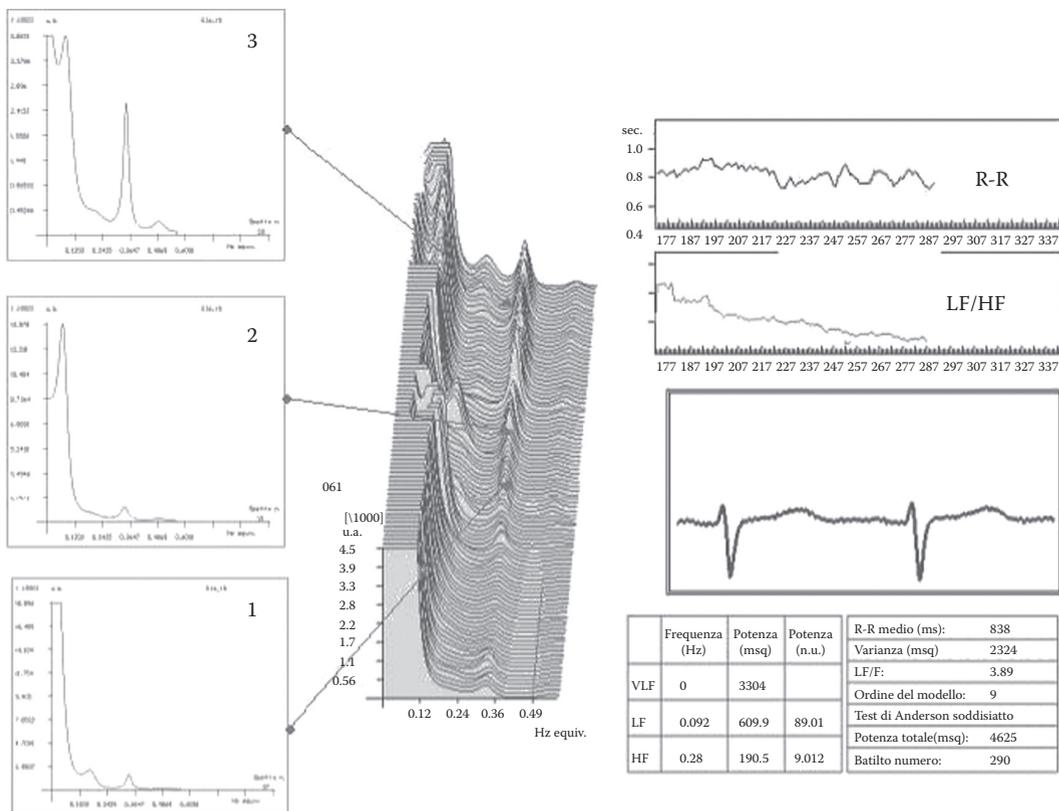
**FIGURE 14.5** Same subject, situation and layout as in Figure 4. HRV spectral analysis (50 sec intervals) shows: dominance of the LF component in (a) and marked drop of the TP with a delayed HF component in (b - sudden threat). In (c), recovery of HRV is sustained by reappearance of a delayed LF peak. No VLF in all phases. Compared to 5' intervals, ultra-short term analysis estimates more appropriately peak HR (187 bpm) and evidences an inversion of LF/HF ratio, not appreciable in Figure 14.4.12-lead ECG is also shown.

to stress-induced alteration of the respiratory rate and rhythm (Perini & Veicsteinas, 2003). The above provides evidence that, as happens during high-intensity physical exercise (Perini & Veicsteinas, 2003; Casadei, Cochrane, Johnston, Conway, & Sleight, 1995), HRV analysis might suggest mechanisms different from simple sympathovagal interaction as the cause of HR increase (Perini & Veicsteinas, 2003). As blood pressure cannot be continuously monitored during realistic scenarios, we cannot exclude that the modification of LF components could be also related to arterial pressure fluctuations, via baroreceptorial mechanisms (Perini & Veicsteinas, 2003; Saul et al., 1990).

**METHODOLOGICAL PROBLEMS WITH HRV MEASUREMENTS**

The Italian study has demonstrated that spectral analysis of HRV from ECG data is feasible and reliable to discover transient changes of cardiac sympathovagal modulation induced by acute real-life police stress, and provided that ultra-short term analysis is used. In fact, we found that transient and fast changes of autonomic balance were evidenced only using intervals of 30 to 50 seconds, which, according to Salahudin et al. (2007), are the minimum required for an adequate estimation of HF and LF components and LF/HF ratio and represent a validated method for assessing acute stress-induced HRV variations. However, a better way to image acute changes of HRV spectral density during nonstationary events could be the use of time-frequency and time-variant methods (Mainardi, Bianchi, & Cerutti, 2002; Martinmäki & Rusko, 2008), which provide quantitative beat-to-beat evaluation of HRV parameters fluctuation (Petrucci et al., 1996) (see Figure 14.6).

AQ9 Furthermore, more advanced mathematical algorithms seem promising to achieve a more selective quantification and separation of cardiac sympathetic and parasympathetic activities useful to improve the assessment of acute stress by HRV measuring of the autonomic response (Zhong, Jan, Hwan Ju, & Chon, 2006; Chen & Mukkumala, 2008). Another relevant point is that presently available hardware for digital Holter ECG recording, although reliable for clinical purposes, is too bulky, expensive, and fragile to be extensively used in tactical situations. For that purpose,



**FIGURE 14.6** Example of dynamic beat-to-beat imaging of acute changes of HRV spectral density, in a healthy 18-year-old subject during postural change, from upright (1) to supine (3) position. In the middle: sequence of beat to beat spectral densities. On the left: selected instantaneous spectral images are shown, with prevalence of LF in the upright (1 and 2) and of HF in the supine (3). On the right: windows monitoring the dynamics of RR interval, of LF/HF ratio, and of the ECG waveform.

commercial HR/RR interval recorders developed for sports activity may offer a simple, inexpensive alternative to standard ECG recording (Kemp & Diets, 2008). However, the reliability of such devices for short-term HRV measurements under heavy-duty dynamic conditions has not been validated so far. In fact, only a few studies assessing the agreement with standard ECG recordings are available at the moment (Nunan et al., 2008, 2009; Salahuddin et al., 2007) but performed in quiet resting laboratory conditions. In the latter two studies, carried out to assess the reliability of short-term resting HRV measured from Polar S810 heart-rate data, it was shown that the number of RR intervals obtained with the S810 showed excellent and interchangeable agreement with ECG recordings, but that some of the HRV parameters derived from the RR interval recorder did not agree with those derived from standard ECG, when the two data sets were processed in the same way. Thus, the authors concluded that users should be aware that HRV measures, derived from factory default settings of different systems, might yield widely varying outcomes (Nunan et al., 2008). In the most recent study, only marginal differences between the mean measures of HRV with the Polar S810 and with reference ECG recording were found, except for the LF and HF normalized units (Nunan et al., 2009). However, in both studies, prior to HRV analysis, raw RR intervals derived from both equipments had to be edited and compared to discriminate error caused by S810 acquisition or by artifacts. Manual editing before HRV analysis is at the moment unavoidable, especially when dealing with data acquired during heavy and uncontrollable tactical dynamicity. Thus, to optimize monitoring of personnel exposed to high-stress activity and to evaluate their performance under heavy-duty conditions, such as during police tactical training or even real operational deployment, a robust miniaturized personal monitoring device (i.e., a digital ECG recorder with a sampling frequency of 1 KHz), compatible with tactical equipment and with wireless connection to wearable low-noise ECG electrode systems (such as Quasar, Smartshirt, Sensotex, and so on), should be manufactured. The next step of technological development should be the inclusion of on-board capability for real-time HRV evaluation and wireless data transmission for Web remote monitoring (Salahuddin et al., 2007; Salahudin & Kim, 2006). Obviously, for a more accurate dynamic evaluation of police stress-related ANS adaptation, other physiological parameters such as blood pressure, posture, respiration rate, skin conductance, and temperature also should be monitored simultaneously with ECG, but again such recordings are difficult and poorly reliable under dynamic action. Especially a continuous noninvasive blood pressure monitoring is impossible at the moment because of the high sensitivity to movement artifacts, even with the most recent technology (Nair et al., 2008).



### HRV MONITORING TO FAVOR HEART–BRAIN COHERENCE

Research suggests that HRV monitoring during tactical training can be useful to improve the operational efficiency and success of police officers. In fact, it might help to increase insight into the complexity of human cognition/emotion interaction under threat-induced fear and to study how heart–brain interaction might affect officers' behavior when they automatically switch to the empirical thinking mode. Furthermore, HRV can be used as a sort of biofeedback tool to train people to improve emotional control.

It has been shown that cardiac oscillators involved in HRV modulation, besides regulating cardiac function, also send messages to the brain that affect perceptions, mental processes, feeling states and human performance (see Figure 14.2). Other biological oscillators—located in the brain, intestinal walls, lungs, and smooth muscles of the vascular system—are strictly involved in psychophysiological modulation. It is well known that, by intentionally focusing on one or more of these systems, it is possible to alter their rhythm and indirectly affect the cardiac activity and the cognitive and emotional functions of brain. This has been empirically achieved for hundreds of years, with meditation (affecting directly the brain), yoga (working on lungs), chi-kung (affecting the gut), and in several martial arts. Recently, research has investigated mechanisms underlying the positive effects of such traditional methods by spectral analysis of HRV. Experiments

combining HRV indexes and observation of animals' behavior in a rat model of severe cardiac failure has demonstrated that abnormal sensory messages from the periphery (the failing heart) to the central nervous structures produces an abnormal cardiovascular autonomic regulation and favor an abnormally anxious response and behavior (Henze et al., 2008). Conversely, if the heart sends positive messages to the brain, as in a deliberate feeling of positive affection, the modification of cardiac sympatovagal balance might induce better heart–brain coherence in humans (Tiller et al., 1996), with resultant enhancement of mental clarity, emotional balance, and personal efficiency (McCraty et al., 1995). Thus, HRV is a simple noninvasive method to measure in humans the reflex feedback of the primitive brain stem to the afferent information sent by the heart to the brain and the complex psychophysiological reactions to activation of the upper-emotional and cognitive brain centers critical for decision making and integration of reason and feelings under stress (see Figure 14.2). From a clinical point of view, all of the above can be used to cure patients affected by cardiac disease, improving their rehabilitation in order to reduce future adverse cardiac events (Pagani & Lucini, 2008). Similarly, the same knowledge and methods might be utilized to design more appropriate training programs and preventive interventions for police officers exposed to demanding tactical stress. In fact, it is well known that relaxation training programs may significantly improve cardiac autonomic nervous tone. For example, relaxation by yoga training is associated with a significant increase of cardiac vagal modulation (Khattab et al., 2007). More interestingly, 5 days of integrative body–mind training (IBMT) improve attention and self-regulation in comparison with the same amount of relaxation training, with significantly better physiological reactions evidenced by HRV, EEG, and brain imaging data (Tang, 2008; Tang et al., 2007, 2009). An additional confirmation suggesting the need of a more holistic approach to police training can be found in the positive results obtained by teaching methods for self-induction of better heart–brain coherence in police officers McCraty, Tomasino, Atkinson, & Sundram, 1999) and in correctional officers McCraty, Atkinson, & Tomasino, 2003).

## REFERENCES

- Aardal-Eriksson, E., Karlberg, B. E., & Holm, A. C. (1998). Salivary cortisol: An alternative to serum cortisol determinations in dynamic function tests. *Clin Chem Lab Med*, 36(4), 215–222.
- AQ10 Adolphs, R., Cahill, L., Schul, R., & Babinsky, R. (1997). Impaired declarative memory for emotional material following bilateral amygdala damage in humans. *Learn Mem*, 4, 291–300.
- Aguirre, A., Wodicka, G. R., Maayan, C., & Shannon, D. C. (1990). Interaction between respiratory and RR interval oscillations at low frequencies. *J Auton Nerv Syst*, 29, 241–246.
- Ahmed, M. W., Kadish, A. H., Parker, M. A., & Goldberger, J. J. (1994). Effect of physiologic and pharmacologic adrenergic stimulation on heart rate variability. *J Am Coll Cardiol*, 24(4), 1082–1090.
- Allman, J. M., Hakeem, A., Erwin, J. M., Nimchinsky, E., & Hof, P. (2001). The anterior cingulate cortex: The evolution of an interface between emotion and cognition. *Ann NY Acad Sci*, 935, 107–117.
- Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology*, 10(3), 229–240.
- Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends Cogn Sci*, 8, 170–177.
- Artwohl, A. (2002, October). Perceptual and memory distortions during officer involved shootings. *FBI Law Enforcement Bulletin*.
- Artwohl, A. (2008). *Perceptual and memory distortions during officer involved shootings*. AELE Lethal & Less Lethal Force Workshop.
- Artwohl, A., & Christensen, L. (1997). *Deadly force encounters: What cops need to know to mentally and physically prepare for and win a gunfight*. Boulder, CO: Paladin.
- AQ11 Ayoob, M. F. (1986). *Stress fire*. (Volume 1 of *Gunfighting for police: Advanced tactics and techniques*. Police Bookshelf.
- Berntson, G. G., Bigger, J. T. Jr, Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., et al. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiol*, 34, 623–648.

- Braune, H. J., & Geisenörfer, U. (1995). Measurement of heart rate variations: influencing factors, normal values and diagnostic impact on diabetic autonomic neuropathy. *Diabetes Res Clin Practice*, *29*, 179–187.
- Breggin, P. R. (1964). The psychophysiology of anxiety. *Journal of Nervous and Mental Disease*, *139*, 558–568.
- Brydon, L., Edwards, S., Jia, H., Mohamed-Ali, V., Zachary, I., Martin, J. F., & Steptoe, A. (2005). Psychological stress activates interleukin-1 $\beta$  gene expression in human mononuclear cells. *Brain, Behavior, and Immunity*, *19*, 540–554.
- Buchheit, M., Laursen, P. B., & Ahmaidii, S. (2007). Parasympathetic reactivation after repeated sprint exercise. *Am J Physiol Heart CircPhysiol*, *293*, 133–141.
- Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends CognSci*, *4*, 215–222.
- Cacioppo, J. T., Berntson, G. G., Larsen, J. T., Poehlmann, K. M., & Ito, T. A., (2000). The psychophysiology of emotion. In M. Lewis & J. M. Haviland-Jones (Eds.), *Handbook of emotions* (2nd ed., pp. 173–191). New York: Guilford.
- Carrasco, S., Caitan, M. J., González, R., & Yáñez, O. (2001). Correlation among Poincaré plot indexes and time and frequency domain measures of heart rate variability. *J Med EngTechnol*, *25*(6), 240–248.
- Casadei, B., Cochrane, S., Johnston, J., Conway, J., & Sleight, P. (1995). Pitfalls in the interpretation of spectral analysis of the heart rate variability during exercise in humans. *ActaPhysiolScand*, *153*(2), 125–131.
- Chen, X., & Mukkamala, R. (2008). Selective quantification of the cardiac sympathetic and parasympathetic nervous systems by multisignal analysis of cardiorespiratory variability. *Am J Physiol Heart CircPhysiol*, *294*(1), 362–371.
- Christie, I. C., & Friedman, B. H. (2004). Autonomic specificity of discrete emotion and dimensions of affective space: a multivariate approach. *Int J Psychophysiol*, *51*(2), 143–153.
- Crottaz-Herbette, S., & Menon, V. (2006). Where and when the anterior cingulate cortex modulates attentional response: Combined fMRI and ERP evidence. *J Cogn Neurosci*, *18*, 766–780.
- Deinzer, R., Kirschbaum, C., Gresele, C., & Hellhammer, D. H. (1996). Adrenocortical responses to repeated parachute jumping and subsequent h-CRH challenge in inexperienced healthy subjects. *Physiology and Behavior*, *61*(4), 507–511.
- Delaney, J. P., & Brodie, D. A. (2000). Effects of short-term psychological stress on the time and frequency domains of heart-rate variability. *Percept Mot Skills*, *91*(2), 515–524.
- Duncan, S., & Barrett, L. F. (2007). Affect is a form of cognition: A neurobiological analysis. *Cognition and Emotion*, *21*, 1184–1211.
- Eckberg, D. L., Rea, R. F., Andersson, O. K., Hedner, T., Pernow, J., Lundberg, J. M., et al. (1988). Baroreflex modulation of sympathetic activity and sympathetic neurotransmitters in humans. *ActaPhysiolScand*, *133*(2), 221–231.
- Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, *302*, 290–292.
- Epstein, S. (1994). The integration of the cognitive and psychodynamic unconscious. *American Psychologist*, *49*, 709–723.
- Etkin, A., Egner, T., Peraza, D. M., Kandel, E. R., & Hirsch, J. (2006). Resolving emotional conflict: A role for the rostral anterior cingulate cortex in modulating activity in the amygdala. *Neuron*, *51*, 871–882.
- Fahrenberg, J., & Foerster, F. (1989). *Nicht-invasive Methodik für die kardiovaskuläre Psychophysiologie* [Non-invasive methods for cardiovascular psychophysiology]. Frankfurt: Lang.
- Fenici, R. (1999). Cardiac factors in critical incidents. 27th Annual Conference of the SPCP, Port Jefferson, New York.
- Fenici, R., & Brisinda, D. (2004). Cardiac and psycho-physiological reactions induced by police tactical tasks and combat shooting. Presented at the 32nd Annual Conference of the Society for Police and Criminal Psychology, Rome, October 11–15.
- Fenici, R., & Brisinda, D. (2008a). Evaluation of stress-related heart-rate variability in police officers during operational training for high-risk tactical tasks. Edward Shaeffer Award at the 34th Annual Conference of the Society for Police and Criminal Psychology, Walnut Creek, CA, October 16–18.
- Fenici, R., & Brisinda, D. (2008b). Stress-induced changes of heart rate variability in police officers during operational training for demanding tactical tasks. *Eur Heart J*, Suppl. 29, Abs 4424, 750.
- Fenici, R., Brisinda, D., & Fenici, P. (2002). Cardiovascular and psycho-physiological reaction during police action and combat shooting. Proceedings of XIV World Congress of Cardiology.
- Fenici, R., Ruggieri, M. P., Brisinda, D., & Fenici, P. (1999). Cardiovascular adaptation during action pistol shooting. *Journal of Sports Medicine and Physical Fitness*, *39*(3), 259–266.

- Fox, K., Borer, J. S., Camm, A. J., Danchin, N., Ferrari, R., Lopez Sendon, J. L., et al. (2007). Heart rate working group: Resting heart rate in cardiovascular disease. *J Am CollCardiol*, *50*(9), 823–830.
- Fox, K., Ford, I., Steg, P. G., Tendera, M., Robertson, M., & Ferrari, R. (2008). Heart rate as a prognostic risk factor in patients with coronary artery disease and left-ventricular systolic dysfunction (BEAUTIFUL): A subgroup analysis of a randomized controlled trial. *Lancet*, *372*(9641), 817–821.
- Funayama, E. S., Grillon, C., Davis, M., & Phelps, E. A. (2001). A double dissociation in the affective modulation of startle in humans: effects of unilateral temporal lobectomy. *J Cogn Neurosci*, *13*, 721–729.
- Funkenstein, D. H. (1955). The physiology of fear and anger. *Scientific American*, *192*, 74–80.
- Funkenstein, D. H. (1956). Nor-epinephrine-like and epinephrine-like substances in relation to human behavior. *Journal of Nervous and Mental Disease*, *124*, 58–68.
- Funkenstein, D. H., King, S. H., & Drolette, M. (1954). The direction of anger during a laboratory stress-inducing situation. *Psychosomatic Medicine*, *16*, 404–413.
- Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2008). *Cognitive neuroscience* (3rd ed.). New York: W. W. Norton.
- Goldstein, M., Brendel, G., Tuescher, O., Pan, H., Epstein, J., Beutel, M., & Silbersweig, D. (2007). Neural substrates of the interaction of emotional stimulus processing and motor inhibitory control: an emotional linguistic go/no-go fMRI study. *Neuroimage*, *36*, 1026–1040.
- Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences*, *99*, 4115–4120.
- AQ12 Grossman, D., & Siddle, B. K. (1998). The physiological basis and implications of memory loss during extreme survival stress situations. Critical Incident Amnesia. Millstadt, IL: PPCT Management Systems.
- AQ13 Grossman, D., & Christensen, L. W. (2004). On combat: The psychology and physiology of deadly conflict in war and peace. WSG Research Publications.
- Hampton, A. N., & O'Doherty, J. P. (2007). Decoding the neural substrates of reward-related decision making with functional MRI. *Proceedings of the National Academy of Sciences*, *104*, 1377–1382.
- Henze, M., Hart, D., Samarel, A., Barakat, J., Eckert, L., & Scrogin, K. (2008). Persistent alterations in heart rate variability, baroreflex sensitivity, and anxiety-like behaviors during development of heart failure in the rat. *Am J Physiol Heart Circ Physiol*, *295*, 29–38.
- Honig, A. L., & Roland, J. E. (1998, October). Shots fired: Officer involved. *The Police Chief*.
- Hugdahl, K., & Ohman, A. (1977). Effects of instruction on acquisition and extinction of electrodermal responses to fear-relevant stimuli. *J Exp Psychol [Hum Learn]*, *3*, 608–618.
- AQ14 Humes, C. (1992). The flashlight dilemma. *Tactical Edge*.
- Ilardo, C., Toniolo, A. M., Aimone-Gastin, I., Abdelmoutaleb, I., Guéant, J. L., & Desor, D. (2001). Effects of psycho-physical stress (competitive rafting) on saliva interleukin-1 beta. *Stress and Health*, *17*, 9–15.
- Kamath, M. V., & Fallen, E. L. (1993). Power spectral analysis of heart rate variability: Non invasive signature of cardiac autonomic function. *Crit Rev Biomed Eng*, *21*, 245–311.
- Kemp, M., & Diets, A. S. (2008). "And the beat goes on": Heart rates of law enforcement officers during deadly force scenarios). Presented at the 34th Annual Conference of the Society for Police and Criminal Psychology, Walnut Creek, CA, October 16–18.
- AQ15 Khattab, K., Khattab, A. A., Ortak, J., Richardt, G., & Bonnemeier, H. (2007). Iyengar yoga increases cardiac parasympathetic nervous modulation among healthy yoga practitioners. *Evid Based Complement Altern Med*, 4511–4517.
- Kirschbaum, C., Wust, S., & Hellhammer, D. H. (1992). Consistent sex differences in cortisol responses to psychological stress. *Psychosom Med*, *54*(6), 648–657.
- Klinger, D. (2001). *Police responses to officer-involved shootings*. Washington, DC: U.S. Government Printing Office.
- Koelsch, S., Rempis, A., Sammler, D., Jentschke, S., Mietschen, D., Fritz, T., & Siebel, W. A. (2007). A cardiac signature of emotionality. *Eur J Neurosci*, *26*(11), 3328–3338.
- Kreibig, S. D., Wilhelm, F. H., Roth, W. T., & Gross, J. J. (2007). Cardiovascular, electrodermal, and respiratory response patterns to fear- and sadness-inducing films. *Psychophysiology*, *44*(5), 787–806.
- Kunst-Wilson, W. R., & Zajonc, R. B. (1980). Affective discrimination of stimuli that cannot be recognized. *Science*, *207*, 557–558.
- Kuwaki, T., Zhang, W., Nakamura, A., & Deng, B. S. (2008). Emotional and state-dependent modification of cardiorespiratory function: Role of orexinergic neurons. *Auton Neurosci*, *142*(1–2), 11–16.
- Lahiri, M. K., Kannankeril, P. J., & Goldberger, J. J. (2008). Assessment of autonomic function in cardiovascular disease physiological basis and prognostic implications. *J Am CollCardiol*, *51*, 1725–1733.
- LeDoux, J. E. (1996). *The emotional brain*. New York: Simon & Schuster.
- Lucini, D., Di Fede, G., Parati, G., & Pagani, M. (2005). Impact of chronic psychosocial stress on autonomic cardiovascular regulation in otherwise healthy subjects. *Hypertension*, *46*(5), 1201–1206.

- Lucini, D., Norbiato, G., Clerici, M., & Pagani, M. (2002). Hemodynamic and autonomic adjustments to real life stress conditions in humans. *Hypertension*, *39*(1), 184–188.
- Mainardi, L. T., Bianchi, A. M., & Cerutti, S. (2002). Time-frequency and time varying analysis for assessing the dynamic responses of cardiovascular control. *Crit Rev Biomed Eng*, *30*(1–3), 175–217.
- Malik, M., & Camm, A. J. (1993). Components of heart rate variability: What they really mean and what we really measure. *Am J Cardiol*, *72*(11), 821–822.
- Malliani, A., Pagani, M., Lombardi, F., & Cerutti, S. (1991). Cardiovascular neural regulation explored in the frequency domain. *Circulation*, *84*(2), 482–492.
- Martinmäki, K., & Rusko, H. (2008). Time-frequency analysis of heart rate variability during immediate recovery from low and high intensity exercise. *Eur J Appl Physiol*, *102*(3), 353–360.
- McCraty, R. (2002). Influence of cardiac afferent input on heart–brain synchronization and cognitive performance. *International Journal of Psychophysiology*, *45*(1–2), 72–73.
- McCraty, R., Atkinson, M., Tiller, W. A., Rein, G., & Watkins, A. D. (1995). The effects of emotions on short-term power spectrum analysis of heart rate variability. *American Journal of Cardiology*, *76*(14), 1089–1093.
- McCraty, R., Barrios-Choplin, B., Rozman, D., Atkinson, M., & Watkins, A. D. (1998). The impact of a new emotional self-management program on stress, emotions, heart-rate variability, DHEA and cortisol. *Integrative Physiological and Behavioral Science*, *33*(2), 151–170.
- McCraty, R., Tomasino, D., Atkinson, M., & Sundram, J. (1999). Impact of the HeartMath Self-Management Skills Program on physiological and psychological stress in police officers (Publication no. 99-075). Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath.
- McCraty, R., Atkinson, M., & Tomasino, D. (2003). Impact of a workplace stress reduction program on blood pressure and emotional health in hypertensive employees. *Journal of Alternative and Complementary Medicine*, *9*(3), 355–369.
- McGaugh, J. L. (2002). Memory consolidation and the amygdala: A systems perspective. *Trends Neurosci*, *25*, 456.
- McGaugh, J. L. (2004). The amygdala modulates the consolidation of memories of emotionally arousing experiences. *Annu Rev Neurosci*, *27*, 1–28.
- Meyerhoff, J. L., Norris, W., Saviolakis, G. A., Wollert, T., Burge, B., Atkins, V., & Spielberger, C. (2004). Evaluating performance of law enforcement personnel during a stressful training scenario. *Ann NY Acad Sci*, *1032*, 250–253.
- Nair, D., Tan, S. Y., Gan, H. W., Lim, S. F., Tan, J., Zhu, M., et al. (2008). The use of ambulatory tonometric radial arterial wave capture to measure ambulatory blood pressure: The validation of a novel wrist-bound device in adults. *Journal of Human Hypertension*, *22*, 220–222.
- Nunan, D., Donovan, G., Jakovljevic, D. G., Hodges, L. D., Sandercock, G. R., & Brodie, D. A. (2009). Validity and reliability of short-term heart-rate variability from the Polar S810. *Med Sci Sports Exerc*, *41*(1), 243–250.
- Nunan, D., Jakovljevic, D. G., Donovan, G., Hodges, L. D., Sandercock, G. R., & Brodie, D. A. (2008). Levels of agreement for RR intervals and short-term heart rate variability obtained from the Polar S810 and an alternative system. *Eur J Appl Physiol*, *103*(5), 529–537.
- Ohman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychol Rev*, *108*, 483–522.
- Olson, D. T. (1998). Improving deadly force decision-making. *FBI Law Enforcement Bulletin*, *67*, 1–9.
- Olsson, A., & Phelps, E. A. (2007). Social learning of fear. *Nat. Neurosci*, *10*, 1095–1102.
- Orsila, R., Virtanen, M., Luukkala, T., Tarvainen, M., Karjalainen, P., Viik, J., & Nygård, C. H. (2008). Perceived mental stress and reactions in heart rate variability: A pilot study among employees of an electronics company. *Int J Occup Safety Ergonomics*, *14*(3), 275–283.
- Pagani, M. (2000). Heart rate variability and autonomic diabetic neuropathy. *Diabetes Nutrition & Metabolism*, *13*(6), 341–346.
- Pagani, M., & Lucini, D. (2008). Cardiovascular physiology, emotions, and clinical applications: Are we ready for prime time? *Am J Physiol Heart Circ Physiol*, *295*(1), H1–3.
- Pagani, M., Mazzuero, G., Ferrari, A., Liberati, D., Cerutti, S., Vaitl, D., et al. (1991). Sympathovagal interaction during mental stress: A study using spectral analysis of heart rate variability in healthy control subjects and patients with a prior myocardial infarction. *Circulation*, *83*(2), 43–51.
- Perini, R., & Veicsteinas, A. (2003). Heart rate variability and autonomic activity at rest and during exercise in various physiological conditions. *Eur J Appl Physiol*, *90*(3–4), 317–325.
- Pessoa, L. (2008). On the relationship between emotion and cognition. *Nat Rev Neurosci*, *9*, 148–158.
- Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research*, *15*, 31–45.

- Petrucci, E., Mainardi, L. T., Balian, V., Ghiringhelli S., Bianchi A. M., Bertinelli M., et al. (1996). Assessment of heart rate variability changes during dipyridamole infusion and dipyridamole-induced myocardial ischemia: A time variant spectral approach. *J Am CollCardiol*, 28(4), 924–934.
- Phelps, E. A. (2004). Human emotion and memory: Interactions of the amygdala and hippocampal complex. *Curr Opin Neurobiol*, 14, 198–202.
- Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *PsycholSci*, 17, 292–299.
- AQ16 Phelps, E. A., O'Connor, K. J., Gatenby, J. C., Gore, J. C., Grillon, C., & Davis, M. (2001). Activation of the left amygdala to a cognitive representation of fear. *Nature Neuroscience*, 4437–4441.
- Pichon, A. P., de Bisschop, C., Roulaud, A., & Papelier, Y. (2004). Spectral analysis of heart rate variability during exercise in trained subjects. *Med Sci Sports Exerc*, 36, 1702–1708.
- Piot, O., Copie, X., Guize, L., Lavergne, T., & Le Heuzey, J. Y. (1997). Variabilité de la fréquence cardiaque: physiologie et méthodologie. *Réalités cardiologiques*, 120, 8–14.
- Pitzalis, M. V., Mastropasqua, F., Massari, F., Passantino, A., Colombo, R., Mannarini, A., et al. (1998). Effect of respiratory rate on the relationships between RR interval and systolic blood pressure fluctuations: A frequency-dependent phenomenon. *Cardiovascular Research*, 38, 332–339.
- Posner, M. I., & Rothbart, M. K. (2007). *Educating the human brain*. Washington, DC: American Psychological Association.
- Posner, M. I., Rothbart, M. K., Rueda, M. R., & Tang, Y. Y. (2009). Training effortless attention. In B. Bruya (Ed.), *Effortless attention: A new perspective in the cognitive science of attention and action*. Cambridge, MA: MIT Press.
- AQ17 Posner, M. I., Rothbart, M. K., Sheese, B. E., & Tang, Y. (2007). The anterior cingulate gyrus and the mechanism of self-regulation. *Cogn Affect Behav Neurosci*, 7391–7395.
- Rein, G., Atkinson, M., & McCraty, R. (1995). Physiological and psychological effects of compassion and anger. *Journal of Advancement in Medicine*, 8(2), 87–105.
- Robbe, H. W. J., Mulder, L. J. M., Ruddle, H., Langewitz, W. A., Veldman, J. B. P., & Mulder, G. (1987). Assessment of baroreceptor reflex sensitivity by means of spectral analysis. *Hypertension*, 10, 538–543.
- Rubia, K., Smith, A. B., Brammer, M. J., & Taylor, E. (2003). Right inferior prefrontal cortex mediates response inhibition while mesial prefrontal cortex is responsible for error detection. *Neuroimage*, 20, 351–358.
- Salahuddin, L., Cho, J., GiJeong, M., & Kim, D. (2007). Ultra short term analysis of heart rate variability for monitoring mental stress in mobile settings. *ConfProc IEEE Eng Med Biol Soc*, 1, 4656–4659.
- Salahuddin, L., & Kim, D. (2006). Detection of acute stress by heart rate variability using a prototype of a mobile ECG Sensor. International Conference on Hybrid Information Technology (ICHIT06, IEEE CS), vol. 2, 453–459.
- Saul, J. P., Rea, R. F., Eckberg, D. L., Berger, R. D., & Cohen, R. J. (1990). Heart rate and muscle sympathetic nerve variability during reflex changes of autonomic activity. *Am J Physiol*, 258(3), H713–721.
- Sergerie, K., Lepage, M., & Armony, J. L. (2006). A process-specific functional dissociation of the amygdala in emotional memory. *J Cogn Neurosci*, 18, 1359–1367.
- Sergerie, K., Lepage, M., & Armony, J. L. (2007). Influence of emotional expression on memory recognition bias: a functional magnetic resonance imaging study. *Biol Psychiatry*, 62, 1126–1133.
- Shapiro, P. A., Sloan, R. P., Bagiella, E., Kuhl, J. P., Anjilvel, S., Mann, J. J. (2000). Cerebral activation, hostility and cardiovascular control during mental stress. *J Psychosom Res*, 48, 485–491.
- Sharps, M. J. (2010). *Processing under pressure: Stress, memory and decision-making in law enforcement*. New York: Looselaf Law Publications.
- Siddle, B. K. (1995). *Sharpening the warrior's edge: The psychology & science of training*. Millstadt, IL: PPCT Research Publications.
- Siddle, B. K. (1999). *The impact of the sympathetic nervous system on use of force investigation*. Millstadt, IL: PPCT Research Publications.
- Solomon, R. (1991). The dynamics of fear in critical incidents: Implications for training and treatment. In J. T. Reese, J. M. Horn, J. M. & C. Dunning (Eds.), *Critical incidents in policing* (pp. 347–358). Washington, DC: U.S. Department of Justice.
- Solomon, R. M., & Horn, J. M. (1986). Post-shooting traumatic reactions: A pilot study. In J. T. Reese & A. H. Goldstein (Eds), *Psychological services for law enforcement*. Washington, DC: U.S. Government Printing Office.
- Stemmler, G. (2004). Physiological processes during emotion. In P. Philippot & R. S. Feldman (Eds.), *The regulation of emotion* (pp. 33–70). Mahwah, NJ: Lawrence Erlbaum.
- Stemmler, G., Aue, T., & Wacker, J. (2007). Anger and fear: Separable effects of emotion and motivational direction on somatovisceral responses. *Int J Psychophysiol*, 66(2), 141–153.

- Sztajzel, J. (2004). Heart rate variability: a non-invasive method to measure the autonomic nervous system. *Swiss Med Wkly*, *134*, 514–522.
- Tang, Y. Y. (2008). *Exploring the brain, optimizing the life*. Beijing: Science Press.
- Tang, Y. Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., et al. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences*, *104*, 17152–17156.
- Tang, Y. Y., Ma, Y., Fan, Y., Feng, H., Wang, J., Feng, S., et al. (2009). Central and autonomic nervous system interaction is altered by short-term meditation. *Proceedings of the National Academy of Sciences*, *106*(22), 8865–8870.
- Tarvainen, M. P., Georgiadis, S. D., Ranta-aho, P. O., & Karjalainen, P. A. (2006). Time-varying analysis of heart rate variability signals with Kalman smoother algorithm. *PhysiolMeas*, *27*(3), 225–239.
- Task Force of the European Society of Cardiology and the North American Society of Pacing and Heart Rate Variability. (1996). Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*, 354–381.
- Terkelsen, A. J., Mølgaard, H., Hansen, J., Andersen, O. K., & Jensen, T. S. (2005). Acute pain increases heart rate: differential mechanisms during rest and mental stress. *AutonNeurosci*, *121*(1–2), 101–109.
- Tiller, W. A., McCraty, R., & Atkinson, M. (1996). Cardiac coherence: a new non invasive measure of autonomic nervous system order. *Alternative Therapies*, *2*(1), 52–65.
- Tulen, J. H., Man int 'Veld, A. J., VanRoon, A. M., Moleman, P., Van Steenis, H. G., Blankestijn, P. J., et al. (1994). Spectral analysis of hemodynamics during infusions of epinephrine and norepinephrine in men. *J ApplPhysiol*, *76*(5), 1914–1921.
- Vuilleumier, P. (2005). How brains beware: neural mechanisms of emotional attention. *Trends CognSci*, *9*, 585–594.
- Wagner, H. (1989). The peripheral physiological differentiation of emotions. In H. Wagner & A. Manstead (Eds.), *Handbook of social psychophysiology* (pp. 77–98). Chichester, UK: Wiley.
- Weiss, T., del-Bo, A., Reichek, N., & Engelman, K. (1980). Pulse transit time in the analysis of autonomic nervous system effects on the cardiovascular system. *Psychophysiology*, *17*, 202–207.
- Whalen, P. J., Kagan, J., Cook, R. G., Davis, F. C., Kim, H., Polis, S., et al. (2004). Human amygdala responsiveness to masked fearful eye whites. *Science*, *306*, 2061.
- Yang, Y., Koh, D., Ng, V., Lee, C. Y., Chan, G., Dong, F., & Chia, S. E. (2002). Self-perceived work related stress and the relation with salivary IgA and lysozyme among emergency department nurses. *Occup Environ Med*, *59*, 836–841.
- Zbilut, J. P., Thomasson, N., & Webber, C. L. (2002). Recurrence quantification analysis as a tool for the non-linear exploration of nonstationary cardiac signals. *Med EngPhys*, *24*, 53–60.
- Zhong, Y., Jan, K. M., Hwan Ju, K., & Chon, K. H. (2006). Quantifying cardiac sympathetic and parasympathetic nervous activities using principal dynamic modes analysis of heart rate variability. *Am J Physiol Heart CircPhysiol*, *291*, 1475–1483.

### Author Queries

- AQ1: Please revise the sentence beginning “Police officers know...” for clarity.
- AQ2: Please spell out ANS on first mention.
- AQ3: In the Posner et al. citation, Tan is Tang in the reference list. Please check.
- AQ4: Barret is spelled Barrett in the reference list. Please check.
- AQ5: Please clarify the phrase “signaling under uncontrolled fight-or-flight response.”
- AQ6: Kemp & Diez 2008 is Kemp & Diets in the reference list. Please check.
- AQ7: Please spell out RR on first mention.
- AQ8: Please clarify “We.” You’re writing as a single author.
- AQ9: Mukkumala has a different spelling in the reference list. Please check.
- AQ10: Please spell out all abbreviated journal titles throughout the reference list.
- AQ11: Please provide a publisher location for Massad 1986.
- AQ12: In Grossman & Siddle, is Critical Incident Amnesia the name of the journal? If so, please provide the issue number and page numbers.
- AQ13: Please provide a location for WSG Research Publications.
- AQ14: Please provide the complete reference information for Humes 1992.
- AQ15: Please provide a volume number for Khattab et al.
- AQ16: Please provide a volume number for the Phelps et al. 2001 article.
- AQ17: Please provide a volume number for the Posner et al. article.