MICHAEL MYRTEK

# Heart and Emotion

## Ambulatory Monitoring Studies in Everyday Life

Hogrefe & Huber

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# Preface

> No pen can describe, no words can express, I say, the strange impression which this thing made upon my spirits; I felt something shoot thro' my blood, my heart flutter'd; my head flash'd, and was dizzy, and all within me, as I thought, turn'd about, and much ado I had, not to abandon myself to an excess of passion at the first sight of her, much more when my lips touch'd her face...(Daniel Defoe, 1724, Roxana, p. 342).

Many poets have described the connection between emotional arousal and bodily changes, especially changes in heart rate. There is no doubt – as we all know from our own experience – that, e.g., there is an increase in heart rate during *acute* anxiety. This common observation is surely the main reason for the assumption of a psychosomatic or psychophysiological covariation. In his famous book entitled "Bodily changes in pain, hunger, fear and race," Cannon (1929) described the physiological basis of this emergency reaction.

In everyday life, these strong emotional reactions are rare events. However, as our studies will show the heart reacts to nearly all stimuli throughout the day and even at night. Interestingly, we are not aware of this ongoing activity, with the exception of the above mentioned strong emotional states. The psychosomatic covariation which is so impressive in an acute emotional state is decoupled by this unawareness.

The studies presented in this book were only possible because of the development of a new ambulatory monitoring method. The essential element of this method is the decomposition of heart rate in a physical and a psychological (emotional, mental) component. This is done by the measurement of physical activity and heart rate and the simultaneous comparison of both parameters. Starting point for the development of this method was a clinical research question on the effects of emotional arousal on myocardial functions. Our method, however, is also fruitful for studies on emotions as well as for research in ergonomics.

Chapter 1 of this book deals with some definitions and models which are relevant in the present context. The literature cited is only part of the bulk of literature in this field and only sets an appropriate frame of reference. This Chapter also describes the foundations of our monitoring method. In Chapter 2 basic physiological principles of the nervous control of the heart and the neurophysiology of emotion are briefly described. Chapter 3 is devoted to the description of the monitoring method used in our studies. Because this method is new, information pertaining to the reliability and validity is important. Chapters 4 to 7 are the main chapters of this book containing the results and the discussion of our studies. Especially relevant is Chapter 4 on interoception because these results form a basis for the perception of emotions (Chapter 5) and for the understanding of stress and strain at the workplace (Chapter 6) and during leisure time (Chapter 7). Chapter 8 deals with monitoring during sleep. In the final Chapter 9, a general discussion of all our findings is given.

In the last 15 years, many studies with more than 1,300 subjects were conducted with our *Freiburg Monitoring System* (FMS; Myrtek, Foerster & Brügner, 2001; Myrtek & Foerster, in press). This enormous task is beyond the work of one individual alone. Therefore, the author would like to acknowledge the assistance of many co-workers. My specials thanks to Prof. Dr. J. Fahrenberg, who created the basis for our research group in the 1960s. His helpful and valued comments accompanied our work. He also organized two very fruitful meetings with other researchers in the field of ambulatory monitoring (Fahrenberg & Myrtek, 1996, 2001). My gratitude should also be expressed to G. Brügner (†) who developed the basic algorithms of our monitoring device. F. Foerster has continued his work and created new algorithms for the detection of posture and motion. My thanks to P. Hüttner who developed algorithms for the recording of behavior and subjective state. W. Müller (†) solved many problems concerning the hardware and V. Höppner contributed to the development of hardware components. G. Jansen is acknowledged for her careful data transfer. The doctoral and graduate students who assisted in conducting the experiments are mentioned as co-authors at the appropriate places in the text. My thanks to M. Cheetham for improving the text. Finally, I wish to acknowledge gratefully the financial support of the German Society for the Advancement of Scientific Research (Deutsche Forschungsgemeinschaft, DFG).

Autumn 2003 Michael Myrtek

*The reader is advised to read first only the shadowed summaries and Chapter 9.5 Conclusions.*

# Contents

# Chapter 1

# Definitions and models

## 1.1 Emotion

According to James (1892), emotions result from the bodily expression: "My theory, on the contrary is that the *bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur* IS *the emotion*" (p. 242). However, James does not describe how the bodily changes are initiated by the perception of the exciting fact (Parkinson, 1988). If this theory were correct, one would have to postulate many different autonomic response patterns to explain the many different emotions. James' theory is called the peripheralist approach and is opposed to the centralist approach proposed by Cannon. According to Cannon (1929) "the responses in the viscera seem too uniform to offer a satisfactory means of distinguishing emotions which are very different in subjective quality" (p. 352). Moreover, visceral changes (with the exception of the heart) are too slow to be a source of emotional feeling. Finally, artificial induction of visceral changes typical of strong emotions by epinephrine does not produce emotions. Cannon argues that activation of central processes in the brain leads to the various symptoms (autonomic responses, motor responses, subjective state) associated with emotion.

As yet no satisfactory definition of what an emotion might be has been given. Plutchik (2003) cites 21 definitions by different authors. Contemporary definitions stress the one or the other aspect proposed by either James or Cannon. The theories by Levenson (1988, 1994) and by Schachter and Singer (1962) are somewhat more closer to James' whereas Pennebaker's view (1982) is more centralistic in pointing out the cognitive aspects. Other authors do not try to define emotion and only list the components involved in an emotional reaction (Lang, 1993; Scherer, 1990, 2000). I hope that our empirical results on the perception of emotions will elucidate the contradictory standpoints.

### *1.1.1 A look at emotion research*

Emotions are an integral part of human life and are of central importance in quite different research questions such as the influence of emotional arousal on clinically important ECG changes (e.g., arrhythmias, ischemic episodes), the degree of emotional work load in comparing differing working places, and the study of emotional arousal producing situations, to mention but a few. However, emotion research has to deal with several problems, the most important of which are the method of emotion induction, the interaction of the different response systems (verbal-cognitive, physiological, behavioral), and the specificity of physiological responses for differing emotions.

The validity of emotion induction is equivocal for both laboratory and field studies. The study of emotional phenomena has been until now typically confined to laboratory situations in which the experimenter tries to elicit different emotional states. As opposed to field studies, subjects in laboratory experiments know that they will be exposed to special situations which may enhance the correlations between physiological activation and self-reported emotional states. On the other hand, field studies also have limitations because they have to rely on self reports of emotion perception. As we will show later, we have to account for subjective hypotheses and schemata as proposed by several authors (Myrtek, 1998a; Pennebaker, 1982; Rimé, Philippot, & Cisamolo, 1990) which distort the perception of an emotion.

A second problem pertains to the interaction of the different response systems. Verbal reports, behavioral responses, and physiological activity are coupled imperfectly (Lang, 1993). Lang (p. 22) states that "it is possible and even usual to generate emotional cognitions without autonomic arousal, aggressive behavior without a hostile motive, or the autonomic and avoidant behavior of fear without insight (proper labeling)." According to Schachter and Singer (1962) physiological changes actually cause the emotion. This emotion perception model assumes that there is activity in different physiological processes which are detected by some higher-order system to generate an emotion report. However, the perception model has been criticized (Reisenzein, 1983).

The third problem deals with the different physiological responses for different emotions. The notion of systematic response profiles associated with various emotions (Levenson, 1988) is still a matter of debate. Levenson (1994) states that the emotions anger, fear, and sadness produce larger increases in heart rate than disgust. The author demonstrated that these differences show consistency across subject populations of different profession, age, culture, and gender. As to happiness, Levenson reports that anger and fear produce larger heart rate accelerations than happiness.

The study of emotional reactions in everyday life relies as yet on self-reported emotional events, mostly assessed by diaries. Naturally, subjects can report only those emotional events they are aware of, leading to the difficult question of to what extent physiological activation of emotional origin is actually perceived. Pennebaker (1982) has shown that emotion perception is not necessarily linked to physiological changes but seems essentially to be a function of cognitive schemas, hypotheses, and so on. Therefore, it would be very important to first detect events with presumably emotionally-induced physiological activation under conditions of daily life and to subsequently acquire time-locked information of the subjective feeling of the individual during such events. Our experience tells us that the method used in our studies is suitable to meet these requirements.

### 1.1.2 Methods in emotion research

In laboratory experiments dependent variables are activities of the autonomic nervous system (ANS), the somatic nervous system, and self-reports of the emotional state. Several autonomic measures have been used such as heart rate, respiration, and electrodermal activity (e.g., Johnsen, Thayer, & Hugdahl, 1995; Stemmler, 1989). Examples for the measurements in the somatic nervous system are the interpretation of facial expressions (Houle & Feldman, 1991; Wilson, 1991) and the measurement of emotional coactivation of facial muscles by EMG (Dimberg, 1997; Fridlund & Izard, 1983; Jäncke, 1994).

The most important variable in psychophysiological research is heart rate, because heart rate is a sensitive indicator of the arousal of the ANS. Heart rate increases during all emotions, possibly with the exception of disgust (Levenson, 1988), during mental activation, during psychosocial stress, and during many motivational states such as thirst and hunger. However, heart rate increases are also caused to a much larger extent by physical exercise, postural changes, changes in temperature, and changes in altitude, to mention only the most important factors. Therefore, a mere heart rate increase cannot be interpreted as a part of an emotional state without further information. In our field studies, heart rate and physical activity play the most dominant role (see below).

### 1.1.3 Evolutionary aspects

Cannon (1929) described the increase in “adrenin” and the increase of blood sugar (as a source of muscular energy) following strong emotional experiences. He pointed to the “reflex character” (p. 196) of these reactions and argued that reflexes as a rule are useful responses because they are very quick. The reactions “render the organism more efficient in the physical struggle for existence” (p. 206). Therefore, emotions have a protective function. Levenson (1988) argues that emotions are an efficient mechanism to mobilize and organize disparate response systems to events that pose a threat to survival.

An increase in heart rate is a sign of emotion in humans, mammals, and some other vertebrates, and obviously this is rooted in evolution. Cabanac (1999) was interested in the phylogenesis of emotion and conducted some experiments with rats, lizards, and frogs. In lizards, heart rate increased after 1 minute of gentle handling from 70 bpm (beats/min) to 110 bpm and gradually decreased thereafter in the next five minutes. The same was true for a rat in which heart rate increased from about 360 bpm to 460 bpm in the first minute. The duration of tachycardia was longer in the rat than in the lizards and significant differences to the control period were observed till the $14^{th}$ minute after handling. No significant differences during handling were observed in frogs.

These findings suggest that emotional stress was present in lizards and absent in frogs. Cabanac argues that emotion is a mental feeling and animals possessing emotion have consciousness. Therefore, it can be assumed that emotion might have emerged phylogenetically in reptiles. Emotion as indicated by emotional tachycardia and emotional fever (elevation of the core temperature by emotional arousal) is present in reptiles, birds, and mammals but not in amphibians and fish.

Another evolutionary aspect is the facial expression of emotional reactions in the context of social behavior. A number of emotions, such as anger, fear, and happiness are manifested as different facial expressions and are obviously inborn (Dimberg, 1988). Human subjects, and primates too, are biologically prepared for emotional communication in a face-to-face interaction. This emotional communication in social interaction is accompanied by the appropriate reactions of the ANS. Aureli, Preston, and de Waal (1999) studied the heart rates of two middle-ranking adult females living in a group of rhesus macaques by heart rate telemetry under natural conditions. The behavior of the subjects and a spoken commentary were videotaped while time markers were inserted in the heart rate data file. Two types of social interactions were investigated, while controlling for the effects of posture and activity of the subjects. The first interaction consisted of the mere approach of a dominant individual causing anxiety-like emotion in the approachee. Heart rate changes following approaches by kin and by subordinate individuals were used as control measures. The second type of social interaction was allogrooming. Heart rate changes during grooming were compared to matched control periods. As expected, the approach by a dominant individual was sufficient to provoke a significant heart rate acceleration. The approach of the subject's kin or a subordinate nonrelative did not cause consistent heart rate responses. It was hypothesized that allogrooming has a tension-reduction function. In both subjects, heart rate deceleration was significantly more prominent while receiving grooming than in matched control periods.

## 1.2 Concepts related to emotion

Two concepts, motivation and stress, are closely related to emotion and should be mentioned briefly. Hunger, thirst, and pain, as described by Cannon, are motivational states, they can elicit a stress response, and are surely accompanied by emotions. Stress is defined by Averill, Opton, and Lazarus (1971) as a negatively toned emotional response. Indeed, all three terms, that is emotion, motivation, and stress, are only different aspects of the same phenomenon.

### *1.2.1 Motivation*

According to Hamburg, Hamburg, and Barchas (1975), "emotion has several components: a subjective component, an action component, and a physiologic component appropriate to the action. The term emotion usually emphasizes the subjective component, but this is in fact the subjective aspect of a motivational pattern" (p. 237). Therefore, an emotion is an expression of a motivational state and this emotion helps to meet the adaptive tasks which are necessary for survival. A similar definition is given by Buck (1989): "emotion can be regarded as a process by which motivational potential built in to the organism is actualized when activated by a challenging stimulus. Emotion is thus a *readout* of motivational potential" (pp. 201–202). The author postulates a biologically based hierarchy of "primary motivational-emotional systems." These systems comprise reflexes, instincts or fixed action patterns, drives, affects, and effectance motivation.

### *1.2.2 Stress*

We have already described the emergency reaction proposed by Cannon (1929) which is surely characteristic of a severe stress situation. This reaction is characterized by a general sympathetic discharge of the autonomic nervous system resulting in an increase of heart rate, rapid breathing, increased systolic blood pressure, vasodilatation in the skeletal muscle, and release of glucose from the liver. Many of these effects are at least caused partly by the discharge of epinephrine or adrenine (as called by Cannon) from the adrenal glands. According to Cannon, epinephrine "not only aids in bringing out sugar from the liver's store of glycogen, but also has a remarkable influence in quickly restoring to fatigued muscles, which have lost their original irritability, the same readiness for response which they had when fresh... (*This*) would give to the animal in which these mechanisms are most efficient the best possible conditions for putting forth supreme muscular efforts" (pp. 204–205). Especially relevant for our purpose is a footnote by Cannon in this context (p. 205): "If these results of emotion and pain are not "worked off" by action, it is conceivable that the excessive adrenin and sugar in the blood may have pathological effects."

During the late 1930s, Selye (1976) reported a nonspecific response in laboratory animals to different agents such as heat, cold, trauma, etc. This response which Selye called *stress* consisted in heightened activity of the anterior pituitary gland and the adrenal cortex with a heightened level of cortisol. The damaging agents eliciting the response were called *stressors*. Contrary to the definition by Selye, in engineering stress denotes all objective environmental factors acting upon the person without consideration of the resulting effects (Rohmert & Rutenfranz, 1975). Given a stress factor, the effects of stress, which will be individually different, are called strain.

The assessment of the stress factors is often possible with physical or technical measurements, whereas strain can only be assessed by physiological indicators and subjective ratings made by the individual. The following stress factors are important (Strasser, 1982): (1) Informational-mental, (2) social-emotional, (3) physical-situational (e.g., temperature), and (4) energetical factors (e.g., physical activity). The informational-mental and social-emotional factors represent psychological stress, whereas the physical-situational and energetical factors are classified as physical stress.

## 1.3 Work load: Theoretical background

According to the foregoing paragraph, there are four factors relevant in work resulting in four work load components: Total work load, physical work load, emotional work load, and mental work load. In contemporary workplaces the psychological components (emotional, mental) seem to be the most important. All components can be identified instantaneously by the joint on-line analysis of heart rate and physical activity.

### *1.3.1 Total work load*

Heart rate is the parameter most often used to assess total work load in the laboratory and in the field. The electrocardiogram (ECG), which is used for the measurement of heart rate, is a very strong biological signal and, therefore, can be easily detected.

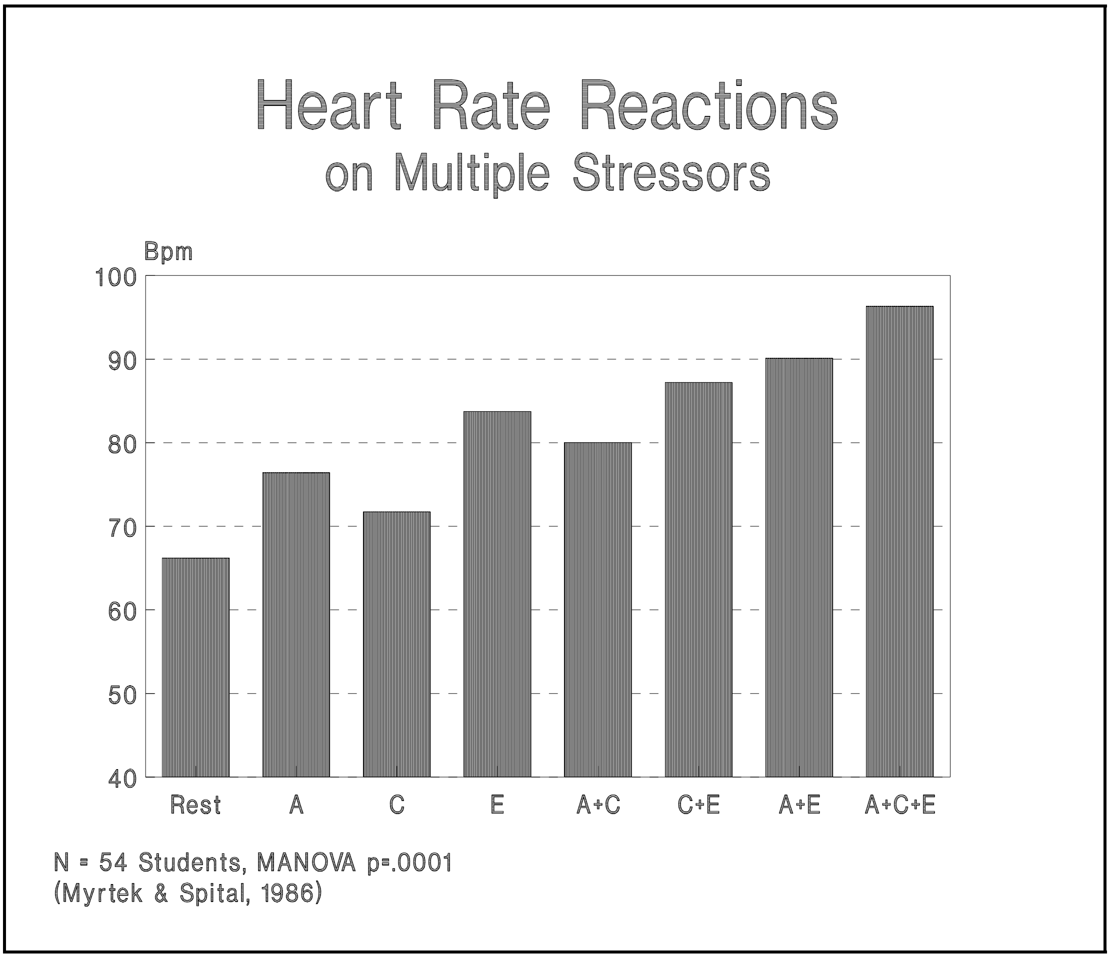


**Figure 1.** Heart rate reactions on multiple stressors: Mental arithmetic (A), cold pressor test (C), ergometric exercise with 25 watts (E), and combinations of all stressors. From Myrtek, Brügner, & Müller, 1996a. Reproduced with permission from *Ambulatory Assessment* by Fahrenberg & Myrtek, ISBN 0-88937-167-9, p. 116. Copyright 1996 by Hogrefe & Huber Publishers, Seattle, Toronto, Göttingen, Bern.

Several authors have demonstrated that heart rate reactivity in a stressor combination, for example, work on a bicycle ergometer (physical stress) and mental arithmetic (psychological stress), was higher than heart rate reactivity either in the ergometer or in the arithmetic condition (Bartenwerfer, 1963; Blix, Stromme, & Ursin, 1974; Roth, Bachtler, & Fillingim, 1990; Turner, Carroll, Hanson, & Sims, 1988). In an own laboratory study, we used the stressors mental arithmetic, cold pressor, and low grade ergometric exercise (Myrtek & Spital, 1986). Heart rate reactivity was significantly higher for all stressor combinations as compared to heart rate reactivity of the single stressors (see Figure 1). The combination of all three stressors yielded the highest heart rate reactivity which was significantly higher than each double stressor combination. Generally, heart rate reactivity elicited by a stressor combination was nearly an additive combination of the respective reactivity elicited by the single stressors. This experiment shows that heart rate reflects both psychological and physical work load.

### *1.3.2 Physical work load*

Physiologically, there is a linear relation between physical work load and oxygen uptake (Mellerowicz, 1975). The latter is linearly related to cardiac output. On the other hand, cardiac output is widely dependent on heart rate. Therefore, heart rate is a measure of physical work load, when emotional or mental work load are absent. During psychological work load, heart rate increases above the level indicated by the oxygen uptake. This phenomenon is called *additional heart rate* (e.g., Turner et al., 1988). Compared to physical activity during which any increase in activity increases oxygen consumption in a monotone fashion, oxygen uptake during an increase in psychological work load is only slightly higher than without this increase (caused by an increase of muscle tone).

Figure 2 shows the relation between physical exercise on a bicycle ergometer and heart rate for three subjects. Subjects worked for six minutes with a load of 100 watt, two minutes with 150 watt, two minutes with 175 watt and so on, with an increase of 25 watt every two minutes (Myrtek & Nahrwold, 1974). Heart rate was taken in the last minute of each stage. As can be seen from the Figure, heart rate is indeed linearly correlated with physical work load. There are also differences in the physical capacity of the subjects. Subject #3 reveals a heart rate of 60.5 bpm at rest and of 174.0 bpm at 250 watt. For subject #1 the figures are 70.0 and 193.0 bpm, respectively. The lowest physical capacity shows subject #2 with a heart rate of 73.5 bpm at rest and 208.0 bpm at 250 watt.

We have already stated that heart rate reflects both psychological and physical work load. The greatest part of heart rate reactivity in a given situation, however, is due to the physical and not to the psychological work load component. During strenuous physical exercise, the amount of heart rate increase due to psychological work load is negligible compared to the amount due to physical work load. The linear relationship between physical activity and oxygen uptake, whereby this uptake is hardly influenced by psychological work load components, enables the estimation of the true physical work load by the measurement of oxygen uptake. This method is called indirect calorimetry.

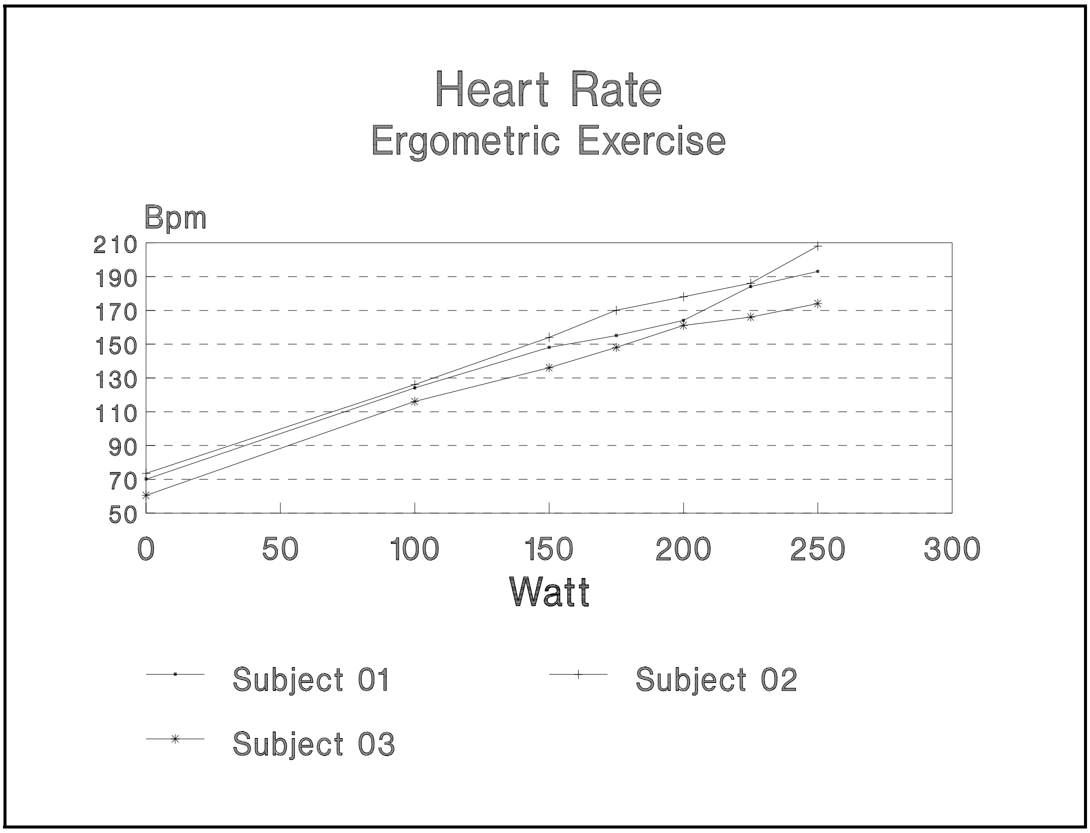


**Figure 2.** Heart rate (beats/min) and physical activity (watt) during ergometric exercise on a bicycle ergometer for three male students.

Under field conditions, however, measurements of oxygen uptake are difficult to obtain because subjects are forced to wear a mask. Therefore, several authors tried to assess physical work load by the subjects' physical activity. Avons, Garthwaite, Davies, Murgatroyd, and James (1988) demonstrated that physical activity assessed with very simple actometers already showed significant correlations with oxygen uptake. LaPorte and coworkers (1979, 1982; LaPorte, Montoye, & Caspersen, 1985) used relative simple motion detectors capable of detecting motion but not the intensity of motion. Using several samples, significant correlations between physical activity and energy expenditure were demonstrated. These methods are somewhat simple but with the use of more sophisticated measurement concepts it is possible to strongly enhance the correlation between physical activity and energy expenditure. With the use of accelerative sensors, very high correlations between oxygen uptake and physical activity were observed under laboratory conditions using treadmill ergometry (Tryon, 1991).

### *1.3.3 Emotional work load*

The essence of this book deals with the measurement of the emotional work load component in everyday life. This assessment is more complicated than the measurement of the other components. A special monitoring device, the *Freiburg Monitoring System* (FMS; Myrtek et al., 2001) was developed by the Psychophysiological Research Group in Freiburg. As already mentioned in the Preface, the method is based on the simultaneous on-line comparison of heart rate and physical activity in order to assess heart rate increases which are not caused by physical activity, i.e., the *additional heart rate* (AHR). The on-line algorithms used for AHR are described in detail in Chapter 3 (Methods).

### 1.3.4 Mental work load

Many authors claim that a decrease in heart rate variability is an indicator of mental work load (Meshkati, 1988; Strasser, 1982; Wilson, 1988). We have shown in the above cited laboratory study (Myrtek & Spital, 1985) that the decrease of heart rate variability (operationalized by the mean squared successive differences, MSSD) during mental arithmetic was higher than during a cold pressor test. Attenuation of the T-wave amplitude of the ECG is also claimed to be an indicator of mental work load. However, our extensive studies with many different samples have shown that T-wave amplitude is not a valid indicator (Myrtek, Brügner, & Müller, 1996b). The question whether our emotional work load component will perhaps embrace the mental work load component, too, will be discussed later on.

## 1.4 Summary

The first chapter deals with definitions and models relevant for this book. There is as yet no satisfactory definition of what an emotion might be. Emotion research has to deal with several problems such as emotion induction, the interaction of the response systems (verbal-cognitive, physiological, behavioral), and the question of different physiological responses for different emotions. An important aspect is that emotional reactions in everyday life rely on self-reported emotional events. This implies that subjects can only report emotions they are aware of. It has been shown, however, that emotion perception is not always linked to physiological changes but seems to be essentially a function of cognitive schemas.

From an evolutionary point of view emotions have a protective function. Emotions mobilize disparate response systems to events that pose a threat to survival. Results show that emotional tachycardia is present in reptiles, birds, and mammals but not in amphibians and fish. The facial expression of emotions are obviously inborn and serve emotional communication.

Closely related to emotion are the concepts of motivation and stress. These terms seem to only refer to different aspects of the same phenomenon. Some authors claim that an emotion is an expression of a motivational state in which the emotion helps to activate adaptive tasks necessary for survival. The emergency reaction described by Cannon is a strong stress situation but represents a way of coping with a threatening sítuation. Whereas Cannon points to the sympathetic autonomic nervous system and the discharge of epinephrine, Selye focused on the anterior pituitary gland and the adrenal cortex. According to Selye, stress means a nonspecific response of the organism elicited by a stressor. In engineering, however, stress denotes the objective environmental factors acting upon the person. Stress elicits organismic responses which are called strain. We prefer this latter definition.

In the present book, a break down of the different work load components will be given. Heart rate is at the same time a sensitive parameter of both physical (energetical) and psychological (emotional, mental) work load and by this represents an indicator of total work load. In the absence of a psychological work load component, physical work load is linearly related to heart rate and oxygen consumption. However, if psychological work load is also present during physical work load, heart rate increases above the level indicated by the oxygen uptake resulting in the so-called *additional heart rate* (AHR). It has been shown that physical activity measured with a system of accelerative sensors is highly correlated with oxygen uptake. Therefore, physical activity represents the physical or energetical work load component. Many authors have claimed that a decrease of heart rate variability might be an indicator of mental work load. Whether there is truth in this will be discussed in Chapter 3.

# Chapter 2

# Basic physiological principles

## 2.1 Nervous control of the heart

Heart activity is regulated by both the sympathetic and parasympathetic division of the autonomic nervous system (ANS). Under normal conditions both divisions exhibit tonic activity, whereby the parasympathetic supply is inhibitory in its action and the sympathetic supply is stimulatory.

### *2.1.1 Parasympathetic fibers (nervus vagus)*

The preganglionic fibers arise from the vagal motor nuclei and the nucleus ambiguus (nA) in the medulla oblongata and pass via the vagus to the cardiac ganglia. After transmission across the synapses, postganglionic fibers go out to the cells in the sino-atrial and atrioventicular nodes. Within the ventricular muscle no vagal fibers have been found.

Stimulation of the vagus (electrically or by the administration of acetylcholine) results in a decrease of heart rate, a diminution in the strength of the atrial contraction, and in a reduction in the conduction velocity through the AV node. Vagus nerve stimulation suppresses the development of the pacemaker potential in the sinus node through an increase of the permeability of the cell membrane to potassium ions (Antoni, 1997; Marshall, 1968).

Vagal tone of the heart derives from ongoing activity in peripheral sensory receptors (arterial baroreceptors, arterial chemoreceptors) and from other groups of central neurons. Stimulation of the arterial baroreceptors by rises in arterial blood pressure increases cardiac vagal outflow. Denervation of the baroreceptor reduces but does not abolish cardiac vagal discharge. Hypocapnia produced by hyperventilation causes tachycardia and reduction in cardiac vagal efferent activity. Vagal tone is also reduced by anesthetics presumably by reduction of tonic influences from other parts of the nervous system. Decerebration produces a vagally mediated fall in heart rate. Lesions in the hypothalamus (hypothalamic defense area) also produce cardiac slowing, whereas stimulation in this area inhibits cardiac vagal activity (Taylor, Jordan, & Coote, 1999).

### *2.1.2 Sympathetic nerves*

Preganglionic fibers originate from the lateral horn cells of the thoracic spinal cord. These fibers synapse in the lateral sympathetic chains and the postganglionic fibers run to the sinoatrial and atrioventricular nodes and bundle of His. Fibers accompanying the branches of the bundle of His innervate the ventricular muscle. The lateral horn neurons themselves are controlled by neurons from the ventral medulla oblongata.

Stimulation of the sympathetic nerves (electrically or by administration of epinephrine or norepinephrine) causes an opposite effect than stimulation of the vagus: heart rate, force of contraction, and conduction velocity through the AV node are increased. Sympathetic nerve stimulation causes an increased rate of membrane depolarization during diastole in the pacemaker cells (Antoni, 1997; Marshall, 1968). Stimulation of the right sympathetic nerves especially causes increased heart rate and augments atrial force of contraction. The left sympathetic cardiac nerves augment ventricular contractions and also increases conductance and rate via the AV node (Taylor et al., 1999).

### *2.1.3 Central control of the cardiovascular and respiratory systems*

The effectiveness of respiratory gas exchange is determined by the rates and patterns of lung ventilation and blood perfusion. Therefore, respiratory and cardiac rhythms are related to guarantee an optimal oxygen uptake. The neural substrate for respiratory rhythm generation lies in the medulla oblongata. Afferent fibers transmitting sensory information arises from the heart (mechano- and chemoreceptors in the walls of the atria and ventricles), vascular, and ventilatory systems (mechano- and chemosensitive sensory afferents throughout the respiratory tract). These circulatory and respiratory afferents are located in the trigeminal, glossopharyngeal, and vagus nerves. The arterial baroreceptors are located in the walls of the carotid sinus and aortic arch. Arterial chemoreceptors are located in the carotid and aortic bodies. The cardiorespiratory afferents terminate in the brain stem, in the nucleus of the solitary tract (NTS), and in the trigeminal nucleus. Vagal afferents terminate predominantly in the caudal two-thirds of the NTS and glossopharyngeal afferents in the rostral two-thirds (Taylor et al., 1999).

Any acute rise in arterial pressure increases the baroreceptor discharge rate and this enhances the vagal output to the heart and inhibits the sympathetic outflow to the heart and the vasculature (baroreceptor reflex). The baroreflex is very rapid with a latency between baroreceptor stimulation and onset of vagal bradycardia of 0.5 s or less. The latency for changes in sympathetic vasomotor nerve activity is about 1.5 s. A fall in blood pressure causes baroreceptor unloading and reduces the baroreceptor input to the brain stem. This results in tachycardia due to reduced vagal inhibition and increased sympathetic activity. Myocardial contractility increases due to the sympathetic activity. Furthermore, in most laboratory animals the baroreflex elicits a sympathetically mediated vasoconstriction involving the skeletal muscle, skin, kidneys, and the splanchnic vasculature. By this peripheral resistance is raised (Levick, 1995).

The ventilatory and vascular control systems are centrally coupled. The modification of cardiovascular control by the respiratory system dominates but stimulation of