DIFFERENT AUTONOMIC RESPONSES TO ORTHOSTATIC AND TO MENTAL STRESS IN YOUNG NORMALS

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Different autonomic responses to orthostatic and to mental stress in young normals – C.A. Swenne, M. Bootsma, H. H. van Bolhuis – Homeostasis 36, 5–6, 1995 – We compared the cardiovascular responses (heart rate, heart rate variability, blood pressure) to comparable amounts of orthostatic and mental stress. Twenty young healthy males were subjected to incremental head–up tilt (angles: 0°, 10°, 20°, 30°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75°, and 80°), and to mental stress in the form of a computer game. Heart rate (HR) appeared to be equal at 40° tilt, and while passively looking at the computer screen. Both states served from then on as control states for orthostatic and mental stress, respectively. Under mental stress, the rate–pressure product increased with 7.5 %. A similar increase of the rate–pressure product was found at a tilt angle of 50°. Hence, the extra 10° of tilt and the computer game were stressors of equal magnitude. The increase in rate–pressure product with tilt was caused by an increase in heart rate (HR). Also the low–frequency power (LF) in the heart rate variability spectrum increased. Blood pressure did not change. Under mental stress, the rate–pressure product increased due to an increase in blood pressure, while HR remained unchanged, and LF decreased. These typical responses can be explained by cardiopulmonary baroreceptor unloading with orthostatic stress, versus increased central command and arterial baroreceptor loading under mental stress.

Key Words: arterial baroreflex; autonomic nervous system; blood pressure; cardiopulmonary baroreflex; central command; heart rate; heart rate variability; mental stress; orthostatic stress; sympathovagal balance

INTRODUCTION

Heart rate and heart rate variability may be indexes for the sympathovagal balance. Assessment of the sympathovagal balance is important in cardiology, because cardiac autonomic outflow is the main modulator of cardiac performance, and, in the diseased heart, of paroxysmal function disturbances, like ischemia and arrhythmias.

Physical and mental stress both influence autonomic outflow, and elicit changes in heart rate, heart rate variability, and blood pressure. In daily life, mental and physical stress cannot be separated. Both stressors play a role in, e.g., Holter electrocardiography. In these ambulatory recordings, blood pressure typically remains unknown. We asked ourselves whether heart rate and heart rate variability are sufficient for estimating autonomic outflow. Perhaps, hnowing the blood pressure is also essential. To find an answer to this question, we designed an experiment in which it was attempted to oppose an equal amount of either physical or mental stress to a number of individuals, and compare the responses in heart rate, heart rate variability, and blood pressure.

SUBJECTS AND METHODS

Twenty health males (mean ± SD ages 25.3 ± 4.1 years) were, in one session, first subjected to a physical stress protocol, and then to a mental stress protocol. Sessions were held in a quiet, climatized room (22 °C), between 9 and 12 AM. No other persons but the subject and one or two experimenters were present. The subjects had eaten a light breakfast. They did not smoke or consume any caffeine in the morning, or alcohol after the dinner of the day before. During the measurements, the subjects did not speak. Respiration was free. The ECG was recorded on a Marquette Holter recorder with time track.

Physical stress was applied in the form of orthostatic stress (slow incremental tilting). Each tilting angle was maintained during 6 minutes. Of each 6–minute episode, minute 1 was used to wait for adaptation to the new tilting angle. The ECG of minutes 2–3–4–5 was used for the computation of the heart rate (HR) and the low–frequency heart rate variability power (LF). LF was computed by dividing the 0.07–0.14 HZ power in the Fourier spectrum of the inter–beat interval series by the 0.07–0.40 Hz power, and multiplying this by 100. Minute 6 was used for blood pressure measurement (Dinamap).

A conditioning tilting protocl, consisting of tilting angles of 0, –5, –10, –15, –10, and –5 ° head–down tilt, preceded the measurement tilting protocl, consisting of tilting angles of 0, 10, 20, 30, 40, 45, 50, 55, 60, 65, 70, 75, and 80 ° head–up tilt. The conditioning protocol served not only autonomic, hemodynamic and humoral, but also mental adaptation, because it familiarized the subject with the sensation of tilting angle increments before the first measurement angle of 0 ° was reached.

In total, the conditioning and the measurement protocols casted for 114 minutes (36 minutes of conditioning; 78 minutes of measurement). In order to prevent either falling asleep or mental arousal (in our experience both may happen without active prevention by the experimenter), the subjects were slightly distracted with a "neutral" videotape (wildlife, arts). With this slight distraction we attempted to reach a state of low mental activity. As any unpleasant sensation would introduce mental stress or hemodynamic instability (e.g., by restless legs that have a hemodynamic effect because of the muscle pupm effect), the protocol was terminated at any sign of discomfort.

After the orthostatic stress protocol, mental stress was applied in the form of a computer game (BEAST). This computer game can be played with the right hand, because it uses only the cursor keys on the keyboard. During the mental stress protocol, the subjects were sitting, while the blood–pressure was continuously non–invasively measured with the Finapres blood pressure measurement device (Wesseling 1982), the cuff being attached to the left middle finger. Blood pressure measurement was done as naturally as possible by letting the left hand rest on the table besides the keyboard of the computer. After having installed the subject in this way, 5 minutes were used to instruct the subject, and to let the subject adapt to the situation. The measurements consisted of a 5 minutes control episode during which the subjects were watching the BEAST start screen, and of a 5 minutes episode of intense playing. The last 4 minutes of the control and the stress episodes were used for computation of HR, LF, and blood pressure.

RESULTS

The highest tilting angles reached were 50 ° (1 subject), 55 ° (1 subject), 60 ° (3 subjects), 65 ° (3 subjects), 70 ° (1 subject), and 80 ° (11 subjects). All subjects completed the mental stress protocol.

The relevant results of the orthostatic and physical stress protocols are given in Table 1 and in Figure 1. It appeared that the heart rate in the control state of the mental stress protocol was equal to the heart rate at 40 ° of tilt. For this study, this tilt angle was considered to be the control state of the orthostatic stress protocol.

The rate–pressure products of the control states differed due to the different methods of blood pressure measurement (in pilot measurements, we tried to use the Finapres device during the tilt sessions as well, however, the required fixed position of the hand during the long tilt session was experienced as unpleasant by some subjects). The increase in the rate–pressure product with mental stress was 7.5 %. The best orthostatic match was the 50 ° tilt state, which had a 7.6 % larger rate–pressure product than the 40 ° tilt state. Hence, the extra 10 ° of tilt and the computer game were stressors of equal magnitude.

Our measurements showed that orthostatic stress caused increases in HR, LF, and in the rate–pressure product. Contrastingly, mental stress caused a decrease of LF, and an increase in the rate–pressure product, the mean blood pressure and the pulse pressure, while HR did not change.

Tab. 1 Rate and pressure values during control and stress (N = 20). Mean SD values of heart rate (HR), normalized low–frequency power (LF), rate–pressure–product (RPP), mean blood pressure (MBP), and pulse pressure (PP), during control (40 ° tilt) and orthostatic stress (an extra 10 ° tilt), and during control (sitting, and watching the computer screen) and mental stress (playing a computer game in the sitting position). P–values < 0.05 have been marked with and asterisk, and are considered to signal statistically significant differences (2–sided paired t–tests). RPP increases with orthostatic and mental stress are 7.6 and 7.5 %, respectively.

Orthostatic Stress Parameter	Control	Stress	P-value
HR (bpm)	68.0±10.2	73.5±10.6	0.000*
LF (nu)	63.4±11.1	70.4±11.4	0.002*
RPP (mmHg/min)	8019±1617	8630±1782	0.000*
MBP (mmHg)	88.2±8.4	89.8±9.6	0.364
PP (mmHg)	49.6±6.3	45.8±13.4	0.250

Mental Stres Parameter	Control	Stresss	P-value
HR (bpm)	67.1±9.9	66.1±9.9	0.344
LF (nu)	65.8±11.0	58.4±13.2	0.024*
RPP (mmHg/min)	8833±2095	9498±2574	0.013*
MBP (mmHg)	90.5±16.8	98.7±16.2	0.000*
PP (mmHg)	56.4±9.2	61.4±7.4	0.013*

Parameter	40° Tilt Control	Siting Control	P-value
HR (bpm)	68.0±10.2	67.1±8.1	0.445
LF (nu)	63.4±11.1	65.8±11.8	0.431

DISCUSSION

The autonomic outflow (Fig. 2) is governed by the vasomotor center, involving, a.o., specific areas of the medulla oblongata (Karemaker 1987), where multiple afferents that provide the central nervous system with information about the periphery are integrated with central command (Herd 1991). For our experiment, we consider the arterial baroreflex, the cardiopulmonary baroreflex and the central command of primary importance. We assume that these inputs to the vasomotor center were identical during the orthostatic and mental stress control states of 40° and of passive watching of the computer screen while being seated, respectively.

During orthostatic stress (50 ° tilt) the arterial blood pressure did not change (Tab. 1, Fig. 1). Going from 40 ° to 50 ° tilt was only a small part of the extensive tilting protocol; therefore, it is unlikely that central command changed. Hence, cardiopulmonary baroreceptor unloading, by a decrease in central venous pressure, is the most probable cause of the modified sympathovagal balance, which became manifest in an increase in HR and LF. This is a reasonable supposition, because with orthostatic stress, blood is pooling in the lower extremities, which reduces central venous pressure (Mark 1983). Kollai and colleagues (Kollai 1978) have shown that, with varying atrial pressure, the sympathetic and vagal systems behave reciprocally. Consequently, this orthostatic stress induced an increase in sympathetic, and a decrease in parasympathetic tone.

Muscle sympathetic activity increases under mental stress (Anderson 1991). Although we could not find explicit evidence of this, it is reasonable to assume that this increase of sympathetic outflow is primarily caused by central command. When this induces changes in arterial and/or venous pressure, the increased firing rate of the arterial and/or the cardiopulmonary baroreceptors add to the central command causing modification of the sympathovagal balance. It remains

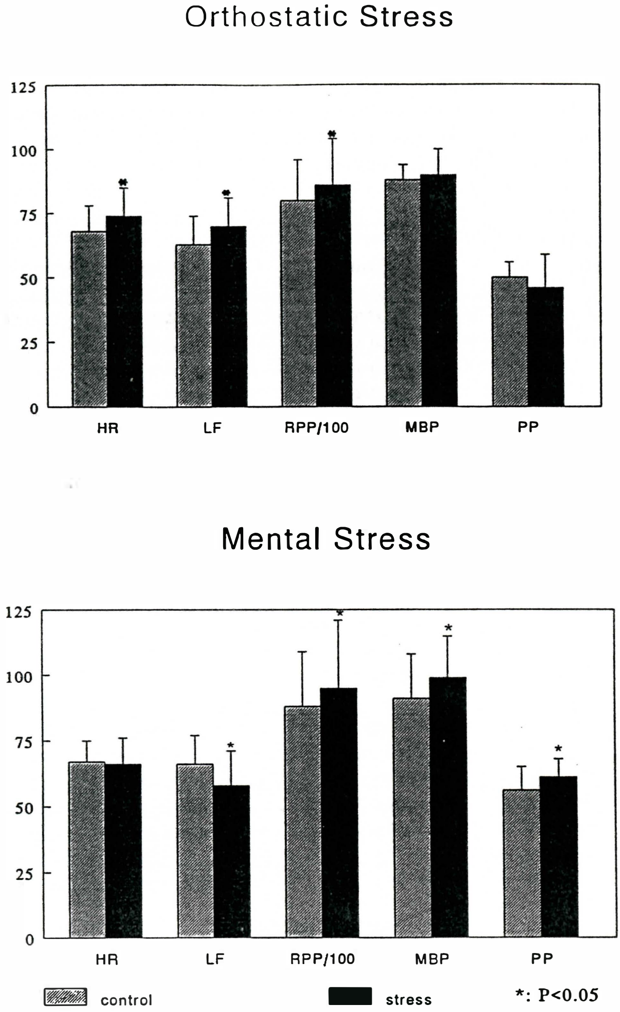

Fig. 1 Bar graphs of heart rate (HR), low–frequency power (LF), rate–pressure product (RPP), mean blood pressure (MBP), and pulse pressure (PP), during control and orthostatic stress (upper panel), and during control and mental stress (lower panel). The error markers indicate standard deviations. Asterisks indicate statistically significant differences (2–sided paired t–tests, $P < 0.05$). Numerical values of the depicted data can be looked up in Tab. 1.

unknown what happened in our experiment to the central venous pressure, but our data show that mean arterial blood pressure and pulse pressure clearly increased. This may very well explain that HR and LF did not increase during mental stress (LF decreases even): the baroreflex(es) hay have increased vagal outflow as well.

In their review, Steptoe and Vögele (Steptoe 1991) mention five types of mental stress: 1) problem–solving tasks (e.g., mental arithmetic); 2) information–processing tasks (e.g., color–word conflict task); 3) psychomotor tasks (e.g., computer/video game); 4) affective conditions (e.g., stressful interview); 5) aversive or painful conditions (e.g., loud noise, cold pressor). Our test was a psychomotor task with minimal motor response requirements (cursor keys). In the literature, mental stress reportedly increases both heart rate and blood pressure. This qualitative difference may be due to differences in the studied population, the stress test, and the intensity of the stressor.

The reported increase of the rate–pressure product is generally larger than in our study. E.g., Zotti and colleagues (Zotti 1991) measured in post–infarction patients, aged 39–69 years, an increase of the rate–pressure product of 38 % with mental arithmetic, and of 22 % with an interactive concentration taks; Saab and colleagues (Saab 1991) measured in normotensive whites, aged 25–44 years, an increase of the rate–pressure product of 28 % with a cold pressor test, 36 % with an interview, and 68 % with a video game. Pagani and colleagues (Pagani 1991) measured in healthy subjects, aged 38±2 years, an increase of the rate–pressure product of 36 % with an interactive concentration task, and also 36 % with an interview. There is experimental evidence that baroreceptor reflex control of heart rate is concerned, there was complete vagal compensation for the increase in sympathetic outflow.

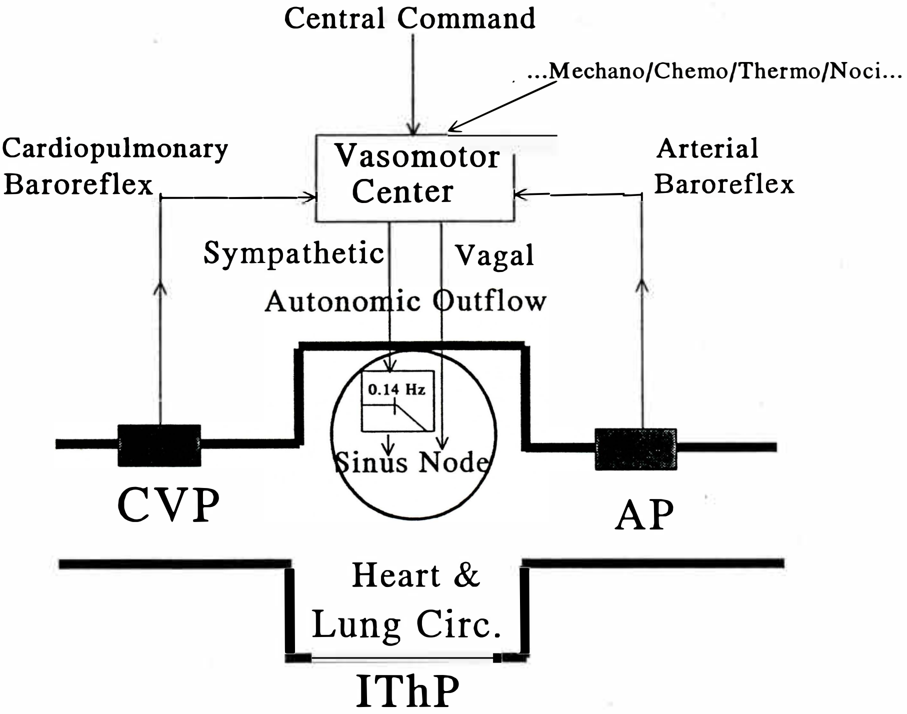

Fig. 2 Schematic representation of autonomic control. Transmural pressure differences between the central venous pressure (CVP), arterial blood pressure (AP), and the (respiration dependent) intra–thoracic pressure (IThP) constitute the time dependent cardiopulmonary and arterial baroreceptor loading. Sympathetic and vagal outflow result from integration of all central and peripheral information in the vasomotor center, located, a.o., in the medulla oblongata. Fast sympathetic fluctuations cannot be followed by the sinus node due to diffusion problems at the synapses. This characteristic is represented in the Figure by a low–pass filter.

Comparison of the spectral responses with those of other studies is difficult, because the algorithms for the computation of, e.g., LF, have not been standardized. In the study of Pagani and colleagues (Pagani 1991), LF seems to increase with the concentration task and the interview. Moriguchi (Moriguchi 1991) reports an increase in LF with mental arithmetic in young normotensives, aged 29 4 years. Hence, besides our observation that HR did not change under mental stress, also our finding that LF decreased under mental stress contrasts with the findings of others. From mental tasks that present an attention signal some seconds before the real stimulus is presented, it is known that, during anticipation, an initial heart rate increase is followed by a heart rate decrease (McCanne 1990). Within subjects, the percentage of correct responses correlates with the amount of decrease, suggesting that this heart rate decrease measures concentration. However, the anticipation periods were short (10s). Hence, to our knowledge, we are the first to report the absence of heart rate increases and the decrease in low–frequency power with mental stress.

Our findings have an important practical consequence, namely, that both the electrocardiogram and the blood pressure should be recorded when studying the dynamics of the sympathovagal balance. The electrocardiogram alone does not, or not fully, reveal those autonomic responses that become only, or partly, apparent in blood pressure. While the continuous peripheral arterial blood pressure is also suited for heart rate determination, it is not ideal for heart rate variability analysis (Swenne 1991). Happily enough, with the ambulatory Portapres measurement device (Imholtz 1993), like the stationary Finapres device (Wesseling 1982) based on your principle of continuous non–invasive arterial pressure measurement (Peňáz 1973) simultaneous recording of the electrocardiogram and the arterial blood pressure has become feasible!

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