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SPECTRAL ANALYSIS OF THE HUMAN HEARTBEAT

Applications to the detection of potential health risk factors and the measurement of the physiological effects of cognitive workload

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CONTENT

1. INTRODUCTION

This report is concerned with the frequency domain analysis of heart rate data obtained in the research project "Early health effects of stress and the detection of higher risk groups with the aid of provocation tasks" (first and second phases) (Pokorny et al., 1986) which was commissioned by the Director-General of Labour and the Ministry of Social Affairs and Labour. The research was carried out by the Sector of Experimental Psychology and Psychophysiology of the TNO Netherlands Institute of Preventive Health Care, Leiden.
The motivation for this project, prompted by the increasing interest in the effect of stress on employee health, is to be found in the report "Stress in the work situation" by Ekkers and Sanders (1985). The desirability of rendering stress a measurable quantity referred to in that report occupies a central place in the goals of this project as does the need to identify higher risk groups.

As pointed out in the main body of the report of this project ("Vaststelling van vroege gezondheidseffecten van stress en opsporing van risicogroepen met behulp van provocatietests"), a great deal of effort has gone into creating a laboratory environment in which a subject can be presented with standard stimuli, i.e., mental or physical tasks which produce the same response by repeated presentation, assuming that the condition of the subject remains unchanged. [These tasks are also referred to as provocation tests (Pokorny et al., 1986).] Only then can individual differences in response be attributed to differences in the condition of the individual. Particular attention is given not only to the magnitude of the response to the provocation test but also to the time required for the response to return to its pre-task value (recovery time). This latter parameter appears to be an important indicator of, e.g., early hypertension, as will be elucidated in the 'Discussion of results' section.

The aim of this part of the project was to determine, with the aid of the analysis technique described separately (Hyndman, 1986)

1. whether any changes could be detected in the spectrum of the heartbeat with and following the presentation of the provocation tests and, if so, whether such changes are dependent on (a) age, or (b) behavior pattern (type A or B), these two factors often being referred to in the scientific literature (experiment 1) and,
2. whether any changes could be detected in the spectrum of the heartbeat during a cognitive workload, and whether this workload is reflected in the spectral response to a provocation task immediately following the workload (experiment 2).

2. MATERIAL AND METHODS

For both experiment 1 and experiment 2 the measurement blocks (in which the provocation tasks were presented) were divided into three sessions, a five minute pre-task rest session, the task session (two minutes for the cognitive tasks, ten seconds for the physical task) and a five minute post-task rest session.
The time intervals between successive R waves of the ECG were obtained with a precision of 1 msec by electronic event detection. A special computer program for artifact detection and repair, operating under visual control (Van der Hofstede, 1986), ensured that the time intervals produced correspond to actual cardiac events, uncontaminated by spurious electronic triggering caused by, e.g., movement of the subject.

Spectral analysis of the R-R intervals was carried out on a Digital Equipment Corporation PDP11/34 computer with programs which include on-line digitization and simultaneous event recording developed by the Department of Physics of the TNO Institute for Preventive Health Care (NIPG/TNO).

In the first experiment data were analyzed from three separate age groups (20-30 years, average 22.1, s.d. 3.2; 30-40 years, average 34.1, s.d. 2.8; 40-60 years, average 52.8, s.d. 2.5), each of ten male subjects. The youngest group comprised paid university student volunteers solicited via an advertisement in the local university newspaper. The two other groups were made up of employees from a local firm, comprising mainly clerical staff, also solicited on a volunteer basis. These thirty subjects were also divided into the so-called type 'A' and type 'B' personality groups by way of the Jenkins Activity Survey (nine subjects in each group, corresponding to the subjects with the highest and lowest scores, respectively). The average age of these two groups was about the same (approximately 35); the average JAS score for the A's was 153 (s.d. 2.2) and for the B's 74 (s.d. 1.8). All subjects were screened by a routine medical examination and only those subjects who did not display any form of cardiovascular disturbances (e.g. hypertension) were allowed to participate in the experiment.

The experimental design took the form of repeated measurements on three groups of subjects (selected by age) so that statistical analysis was carried out on a total of six groups (3 age groups x 2 repeated measurements). The order in which the tasks were presented was randomized per age group to minimize any systematic carry-over effects.

Statistical analysis took the form of first establishing whether the various tasks were repeatable by calculation of the correlation coefficient between the responses to the first and second task presentations, and then testing for differences in response between (a) age groups and (b) behavior pattern, by way of paired t-tests, carried out via the SSPS-X statistical analysis computer program.

Four different mental tasks were presented to the subject, viz.,

- the mental arithmetic task, which consists of a multiplication of two numbers being displayed, an answer then being displayed and the subject, within a given time limit, then responding by pressing a button marked "correct" or "incorrect", accordingly;
- the memory task, which consists of the subject memorizing a displayed six-digit number, performing an intermediate subtraction task, and then, within a given time limit, indicating which one of the digits of a displayed number differs from the original memorized number;
- the unstable tracking task, a one-dimensional compensatory tracking task which consists of the subject manipulating a joystick in such a way as to keep a lightspot at the centre of a LED-bar, the difficulty of doing so increasing the further the lightspot has been allowed to travel from the centre of the LED-bar;
- the memory search task, which consists of the subject indicating, by pressing a button marked "Yes" or "No" within a given time limit, whether either one of two pre-specified letters appears in a group of letters which are made to appear before him on a TV screen.

A physical task was presented in the form of a handgrip task which consists of the subject squeezing a handgrip for ten seconds at 85% of maximal voluntary force.

To test the reliability of the responses to the various tasks, each of the tasks was presented twice (at least one hour apart) to each subject.

In the second experiment a group of 8 male subjects was chosen. Specifically, the ages were between 46 and 51 years, and all subjects had clerical-type positions. As before, all subjects underwent a routine medical screening and signed an informed consent. The experiment consisted of two sessions, each of 90 minutes duration, a 'work period', carried out on one day, and a 'relaxation period', carried out on the other. Provocation tests (two mental perception tasks, one physical task) were presented directly before and directly after each of the two sessions, the mental tasks for a duration of two minutes, the physical task, for ten seconds.

In addition to the memory search task, described earlier, the binary choice task was presented to the subjects as a provocation task. This task makes use of the same TV screen and buttons employed by the memory search task and consists of the discrimination betwee a high tone and a low tone, generated in random sequence at one tone per second, presented binaurally to the subject on headphones. The occurrence of the high tone requires the subject to press the button on the right, and the low tone, the button to the left, accuracy of response being more important than speed. Only one error per 20 seconds is permitted, two successive errors causing the screen to become completely red. Each correct response results in the screen becomingly increasingly green (or less red) until after ten successive correct responses, the screen is completely green. The occurrence of an error when the screen is partially red results in it becoming completely red.

The physical task comprised the handgrip task, described earlier. To minimize any systematic carry-over effects, half of the subjects were presented the memory task first and then the binary choice task, and the other half received the reverse order. Each task was accompanied by a pre- and post-task rest session, both five minutes duration.

The 'work period' comprised the following sequence of activities. The subjects were financially rewarded to enhance their motivation (*f* 5,- per task with a bonus of *f* 10,- for every task which they performed satisfactorily provided that the reaction task in the difficult setting was performed satisfactorily):

- the tracking task (2 x 14 minutes duration), an eye-hand coordination task, in which a cursor on a TV screen is horizontally positioned by means of a joystick in such a way that an upward moving sawtooth-shaped track passes through the gap in the cursor. The second presentation of this task was made more difficult than the first by decreasing the amount of upcoming track displayed in advance ('preview'). The bonus was awarded only if the subject improved on this (already satisfactory) score in the first presentation;
- the correction task (7 minutes duration) consists of finding typing errors in a technical report, the content of which is unlikely to distract the subject from the task at hand. A bonus was awarded if a sufficient number of errors were correctly designated;
- the arithmetic task (7 minutes duration) comprises 40 different arithmetic problems, each with a choice of five answers, for which the subject must indicate the correct one;
- the reaction task (16 + 12 minutes duration) comprises eight different stimuli which appear on the TV screen: 2, 3, 4, 5 left on the screen, and 2, 3, 4, 5 right on the screen, all occurring with equal frequency. There are four response buttons, operated with the two hands. A finger of the left hand is to be used in response to stimuli presented left on the screen, and a finger of the right hand is to be used in response to stimuli presented right on the screen. Each button is associated with two particular digits. The second presentation of the task is made more difficult by making the digits appear more obscurely on the screen. A bonus was rewarded only if the subject improved on his (already satisfactory) score in the first presenta-

tion. Moreover, all bonuses could be lost by unsatisfactory performance on this task;

- the speed and accuracy task (7 minutes duration) comprises 75 problems, each designatiing five combinations of two letters and/or digits. The subject must indicate which one of the five combinations on the answer card does not correspond to the five combinations on the question card, speed and accuracy being equally important;
- the Bourdon-Wiersma test (7 minutes duration) comprises a form on which 25 groups of 3, 4 or 5 dots in various configuration appear randomly on each of the 50 lines. The subject must cross out all groups of 4 dots, speed and accuracy being equally important.

In the 'relaxation period' the subject had the choice of watching a videofilm from a selection of light entertainment films, reading comics and/or listening to light music, while reclining in an easy chair.

The design of experiment 2 took the form of a one-factor experiment with two conditions, viz., the 90 minute relaxation condition and the 90 minute exertion condition. All eight subjects participated in both conditions. The spectral response to a given standard stimulus (i.e., provocation test) after the relaxation condition was compared to that to the same stimulus after the exertion condition by way of paired t-tests. The spectral responses to the standard stimuli just before the onset of these conditions serve as control measurements.

3. RESULTS

The spectra of the low-pass filtered cardiac event sequence (LPFCES) of individual subjects is depicted as a relative power distribution of 0.05 Hz-wide spectral bands expressed as a fraction of total (pre-task rest) spectral power. This characterization considerably reduces inter-subject variance while retaining the essential features of the spectrum.

Particular attention was given to the effect of the different tasks on band 2 and 3 which correspond to the frequency range between .05 Hz and .15 Hz, the frequency range associated with the baroreflex regulation of blood pressure (Hyndman et al., 1971), hereafter referred to as the b.p. band. Figure 1 depicts for each of the three different age groups the relative power distribution of the LPFCES. It can be seen that the spectrum of the older group is significantly smaller than the two other groups for all bands ($p<.001$). Similarly, as figure 2 shows, the spectra of the type A group of subjects is significantly larger than the type B group, for bands 1, 2 and 3 ($p<.01$). From these plots it can be appreciated that the effects of a task on the spectra of different groups can be only meaningfully compared by expressing these effects as percentages of the reference spectra, i.e., the pre-task rest spectra.

The effect of the different tasks on the spectra can be summarized as follows:

a. with regard to the provocation tests used in the first experiment, only the memory search task produced a consistent (reproducible) effect on the spectra and did this for all of the groups (correlation between response to 1st and 2nd task presentation, 0.6-0.8);

b. in particular, the b.p. band was found to decrease by 35% in the youngest group ($p<.05$), 60% in the middle group ($p<.01$) and 55% in the oldest group ($p<.01$), these differences not being significant. Moreover, the b.p. band remained depressed by 40% ($p<.02$) of its pre-task rest value in the middle group in the post-task rest period (see fig. 3). The handgrip task produced a consistent (reproducible) effect only on the spectra of the middle group. Here, the b.p. band increased by 45% ($p<.05$) after this task (correlation between response to 1st and 2nd task presentation, 0.8) (see fig. 4);

c. both the type A and the type B groups displayed a 55% decrease in the b.p. band with the memory search task;

d. with regard to the <u>second</u> experiment, although both the binary choice task and memory search task produced the expected (significant) decreases in the blood pressure band, the spectral responses to the provocation tasks after the exertion condition were not found to differ from the responses after the relaxation condition. The spectra immediately following the exertion condition, prior to the presentation of the standard stimuli, were found to be significantly larger than those following the relaxation condition ($p<.05$).

4. DISCUSSION OF RESULTS

The reduction in spectral power with increasing age which is depicted in figure 1 can likely be attributed to the reduction in baroreflex sensitivity with age reported by Gribbin et al. (1971), which causes homeostatic blood pressure fluctuations to be less reflected in the heart rate.
The larger low-frequency spectral power of the type A subjects compared to the type B subjects seen in figure 2 is consistent with the increasing evidence that type A's display a more labile regulation of blood pressure than their type B counterparts (Dembroski et al., 1983). As already pointed out, Akselrod and co-workers (1981; 1985) have shown that malfunction of the renin-angiotensin system for regulating blood pressure is accompanied by increases in the low frequency spectral power of the heartbeat, similar to those displayed by our type A subjects.

Moving on to the effect of the memory search task on the spectra, it should be noted that the experimental design was specifically made to include a post-task rest measurement session so that response recovery could be studied. The importance of physiological recovery from a stressor is obvious because the maintenance of the defense alarm reaction beyond the time required for coping responses is maladaptive and may promote disease. To quote Zanchetti and Bartorelli (1977) in their studies on the etiology of essential hypertension, "The real issues, however, are ... if these pressor reactions can outlive the stimuli, as the very concept of a chronic disease like hypertension implies a self-perpetuating mechanism".

Bands 2 and 3 (the 'b.p. band'), as already mentioned, correspond to spectral components between .05 Hz and .15 Hz, the frequency range associated with blood pressure homeostasis (Hyndman et al., 1971). That this regulating activity is depressed in the post-task rest session of the middle group (fig. 3) suggests the involvement of task-activated and persisting hormone increases, such as circulating adrenaline, as reported by Johansson and Frankenhauser (1973). As Levi (1971) has pointed out, the neurendocrine reactions can influence nearly all physiological variables. Moreover, adrenaline has frequently been implicated in the pathogenis of essential hypertension (Cuche et al., 1976; Saavedra et al., 1976; Brod, 1971). However, Johansson and Frankenhauser (1973) have shown that the ability to raise adrenaline secretion during mental work is positively related to performance. Their subjects could be separated into two groups - those whose adrenaline returned rapidly to control values and those whose adrenaline recovery was much slower - and the faster group performed significantly better on the task and scored lower in a neuroticism personality test. These researchers suggested that a slower recovery of adrenaline means either that the organism keeps secreting adrenaline when it is no longer required, or that it is less efficient in biochemically dissipating the substance, either one of which is indicative of poor adjustment. As they put it "It is reasonable to assume that the rate at which adrenaline secretion returns to baseline levels after the cessation of the stressor may determine the relative potency of harmful and beneficial adrenaline effects".

Further evidence of the potential deleterious effects of prolonged cardiovascular recovery from stressors can be found in Brod's theory of stress-induced hypertension, in which the frequent mobilization of the defence response produces a protracted and eventually chronic blood pressure elevation (as can be observed experimentally in animals), suggesting that individuals with abnormally long recovery periods to a standard cognitive task might be more inclined to develop hypertension, particularly if they are frequently required to cope with situations which for them are mentally/emotionally demanding. As Brod put it "... a new blood pressure rise may be started by another stimulus before the previous one has subsided completely. The pressor reactions would then eventually fuse". Indeed Brod (1963) and Baumann (1973) found that early hypertensives display a more protracted recovery to a cognitive task than normotensives. The latter group attributed this prolonged recovery to uneconomic biochemical reactions since a number of biochemical parameters displayed a similar prolonged task recovery. Particularly impressive is the more recent work of Falkner et al. (1979) who showed that labile hypertensives are characterized by a much more prolonged blood pressure recovery to a cognitive task than normotensives (see fig. 5).

It is interesting to note that similar personality characteristics are associated with individuals who exhibit slower physiological recovery to psychological effort (Katkin, 1966; Freeman, 1939) and individuals who develop essential hypertension (Benson & Gutman, 1974; Weiner, 1974). The suggestion that anxious or neurotic people may have little opportunity to recover from the constant stream of stimulation characteristic of contemporary life (Malmo, 1957), may be the clue relating personality, recovery, and hypertension. As Malmo pointed out, slow recovery may be due to an inherited deficiency in certain physiological inhibitory mechanisms and/or a weakening of such mechanism due to an individual constantly operating at physiological levels which are higher than normal. The obvious connection between personality and hypertension susceptibility has prompted Bauman to refer to this illness as a 'cerebro-visceral regulation disease' in which the pathogenic efficiency of stress depends largely on personality structure and stress sensitivity.

The more recent trend to classify subjects as type 'A' or type 'B' (Dembroski et al., 1983) has shown that the type A personality exhibits a more prolonged blood pressure recovery to stressors (Van Schijndel et al., 1984). In our experiments, the type A subjects also showed a prolonged recovery in the b.p. band to the memory search task, albeit only in one of the task presentations ($p<.05$).

It is interesting to note that the very group that displays a protracted depression of the b.p. band following the execution of the memory search task - the middle group - also displays an enhanced b.p. band following the handgrip task (fig. 4). Since isometric exercise causes a considerable increase in arterial blood pressure (Astrand et al., 1965), this short but powerful disturbance obviously requires more time in this group to be compensated by the blood pressure mechanisms. The type A group also displayed this enhanced b.p. band following the handgrip task, albeit, as was the case for the memory search task, only in one of the task presentations ($p<.05$).

Evidence suggesting that hypertensives have overactive or even fused defense reactions can be found in the results of Takeshita et al. (1975) who found that hypertensives have significantly lower baroreflex gain in heart rate control. These workers ascribed such a gain reduction to changes in the central nervous system. The reduction in spectral power with mental load produced in all subjects by the memory search task is also a result of this gain reduction (Sleight et al., 1978; Conway et al., 1983). Djojosugito et al. (1970) found such baroreflex gain decreases to be a major feature of the defence reaction, by which hypothalamically activated increases in heart rate are prevented from being diminished by reflex inhibition via the baroreflex.

It is generally accepted that short-term blood pressure regulation is neurogenically achieved by the baroreceptor reflexes, whereas long-term regulation is exercised by the fluid balance system of the kidney (Guyton et al., 1970). Episodes of stress-induced blood pressure elevation may well be neurogenically mediated but, in some manner, their repeated occurrence often eventually leads to a sustained increased pressure which is not necessarily neurally mediated. Indeed, most experimental evidence favours the view that the role of the baroreceptor reflexes is to buffer short term changes of pressure but that over the long term they exert a permissive role by virtue of their resetting (adaptation). This short-term blood pressure control syustem appears then to act as a protective mechanism for the long-term pressure control system (kidney). However, activation of the defense reflex can override the baroreflex for the purpose of providing the body with the critical means to take defensive physical action. If the resulting increase in blood pressure is not only acute but prolonged, as a result of the concomitant release of hormones into the blood remaining undisipated due to insufficient metabolic activity or a malfunctioning of biochemical inhibitory mechanisms, the result may be an accumulating damage to the kidney ultrastructure. Indeed, renal vascular resistence has been reported to increase with advancing hypertension (Birkenhäger & Schalekamp, 1976). This need only be slightly out of proportion to the overall resistance increase to cancel the effects of an increased blood pressure on fluid excretion. As a result of the action of whole body autoregulation, the resulting increase in cardiac output will be returned to normal by widespread constriction of the resistance vessels (evidenced by the reported progressive non-autonomic reduction in vascular calibre). In such a way the arterial pressure will be sustained at a higher than normal value, which in turn, produces more damage to the kidney, the kidney being thus the 'culprit' and 'victim' in this model of hypertension.

An alternative view is found in Folkow's 'structural vascular adaptation' model of hypertension (1973) which, to quote the author "seems to be a phenomenon that can occur in all individuals as a fairly rapid response to a pressure load, and it appears to be crucial for both creating and maintaining true hypertension". In this model, when resistance vessels are exposed to frequent (and prolonged) neurohumoral pressure rises, they adapt structurally within a few weeks with a thickening of the media which surrounds the wall lumen. This structural adaptation implies both a raised resistance even at complete smooth muscle relaxation and potentiated resistance increases to given smooth muscle activation. Implicit to this model of hypertension is a self-perpetuating nature since, once the process is started through too frequent activation of the defense reflex, the resistance increases create the very pressure loads which serve to cause further structural adaptation, and so on. Moreover, the thereby potentiated resistance (and thus pressor) responses to stress further exacerbate the situation.

Even before chronic elevation in blood pressure sets in, long-recovery individuals exposed to an environment comprising any particular sequence of stressors would evidence a greater mean blood pressure elevation - possibility to the extent of damaging the kidney ultrastructure or provoking structural vascular adaptation - over the period, and thus load on the heart as well, than would their normal recovery counterparts exposed to the same environment (stressors). Frequent prolonged episodes of elevated blood pressure may thus have ultimate consequences for long-term blood pressure homeostasis. Indeed, Birkenhäger (1976) has found such prolonged stress-induced blood pressure elevations to be associated with higher mean values of blood pressure months after the stressful episode.

The results of experiment 2, in which the spectra immediately following the exertion condition (prior to the presentation of the standard stimuli) were found to be significantly larger than those following the relaxation condition, are in agreement with earlier findings reported by Hyndman and Gregory (1975) in which the degree of post-task spectral 'overshoot' reflected the difficulty of a tracking task. In that work it was put forward that baroreflex control of heart rate increased after the cessation of the task. This phenomenon could also explain the results presented in the main body of the report of this project (Pokorny et al., 1986, part 1) in which the heart rate response to the binary choice task and memory search task is significantly smaller after the exertion condition than after the relaxation condition. The (presumed) increase in baroreflex control of heart rate after the exertion condition would then act to buffer any provocation-task-initiated increase in heart rate.

Another finding of the Hyndman and Gregory study was that over longer periods of tracking task execution, the spectral power of the blood pressure band began to drift upwards, which they suggested might be indicative of fatigue. In 1982 Egelund investigated this phenomenon in long-distance truck drivers and found that, indeed, spectral power began to increase around the same time that the drivers reported feeling fatigued. We attempted to apply these findings to the data of experiment 2 but, unfortunately, the data was unsuitable for spectral analysis owing to its nonstationary nature. [Recall that the 'work period' comprised a mixture of many different types of tasks and problem-solving exercises, thus lacking the orderly structure of the standard stimuli battery.] This practical limitation underlines the merit of the design philosophy developed by this group of measuring the cumulative effects of exertion *a posteriori* (Pokorny et al., 1981).

5. CONCLUSIONS

It should be emphasized that although the spectral power of the heartbeat in the range corresponding to blood pressure homeostasis (.05-.15 Hz) in the middle group, and albeit not consistently, in the type A personality group, was found to display a protracted recovery to both a mental stressor (the memory search task) and a physical stressor (the handgrip task), and although prolonged cardiovascular recovery to stressors is often referred to in the scientific literature as a 'potential risk factor' for cardiovascular disease, there is as yet no hard evidence that prolonged recovery ultimately translates into such disease.

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Figure 1. Average relative spectral power of the 0.5 Hz low-pass filtered RR-interval series. All rest periods, absolute powers in A.U.

✪= age under 30 years; average total power (abs.): 18656 s.e. 933 spectral bands are averaged over 120 spectra

●= age between 30 and 40; average total power (abs.): 17093 s.e. 1446; spectral bands are averaged over 120 spectra

○= age over 40 years; average total power (abs.): 6339 s.e. 498 spectral bands are averaged over 94 spectra

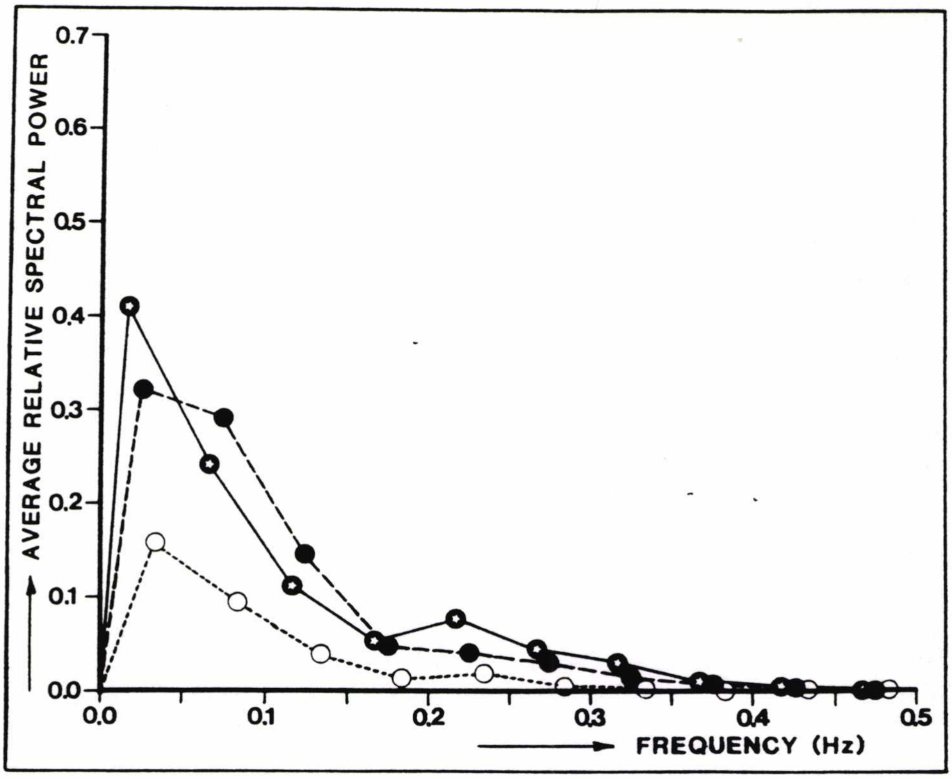

Figure 2. Average relative spectral power of the 0.5 Hz low-pass filtered RR-interval series. All rest periods, absolute powers in A.U.
● = types A; average total power (abs.): 19969 s.e. 1624 spectral bands are averaged over 107 spectra
✪ = types B; average total power (abs.): 13836 s.e. 1070 spectral bands are averaged over 107 spectra

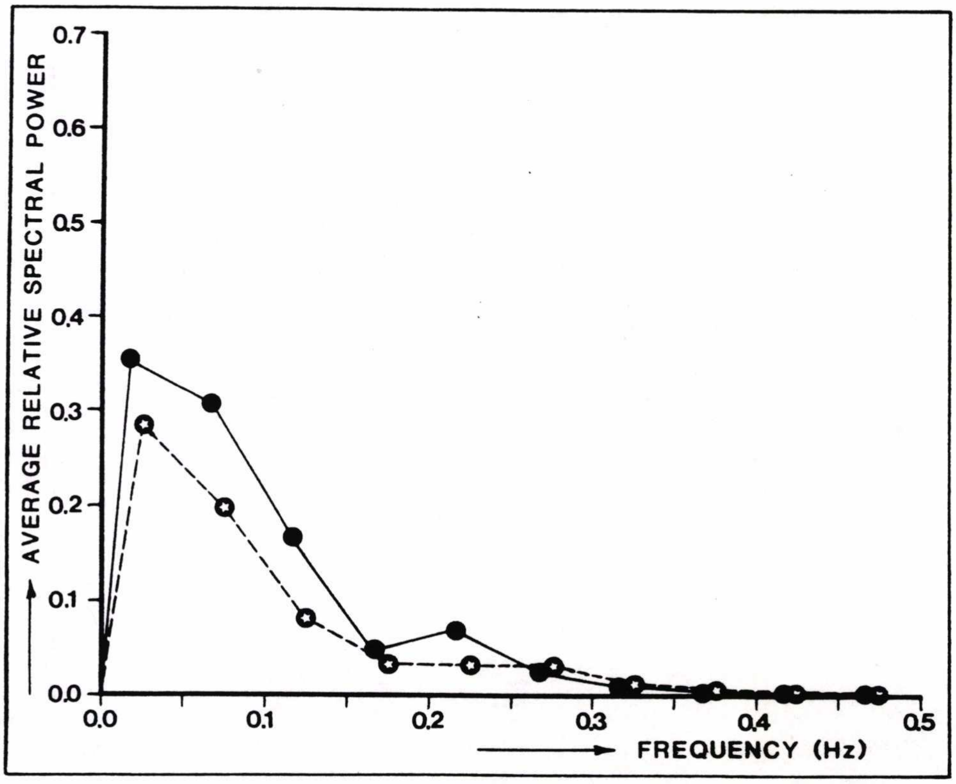

Figure 3. Average relative spectral power of the 0.5 Hz low-pass filtered RR-interval series. Memory search task, middle group. Spectral bands are averaged over 8 spectra (Band 1 is set to zero)

✪ = first 5 minutes; average total power (abs.): 21933 s.e. 6444

● = task 2 minutes; average total power (abs.): 29186 s.e. 8319

○ = last 5 minutes; average total power (abs.): 19625 s.e. 5618

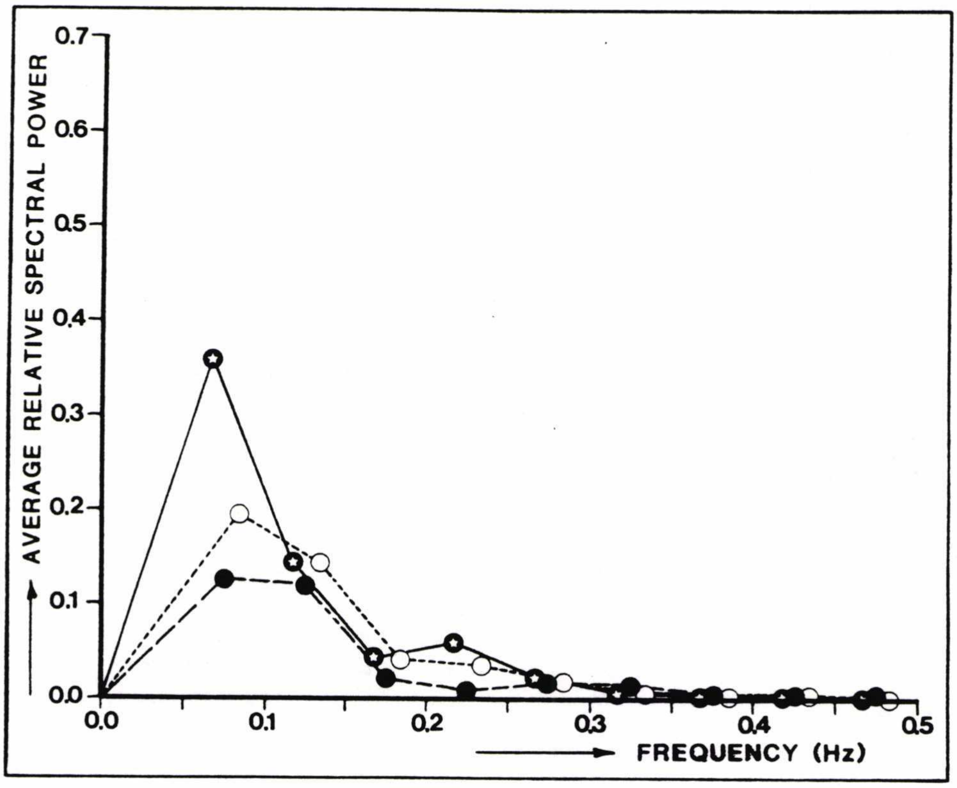

Figure 4. Average relative spectral power of the 0.5 Hz low-pass filtered RR-interval series. Handgrip task, middle group. Spectral bands are averaged over 20 spectra
✪= first 5 minutes; average total power (abs.): 14152 s.e. 2121
○= last 5 minutes; average total power (abs.): 18238 s.e. 2796

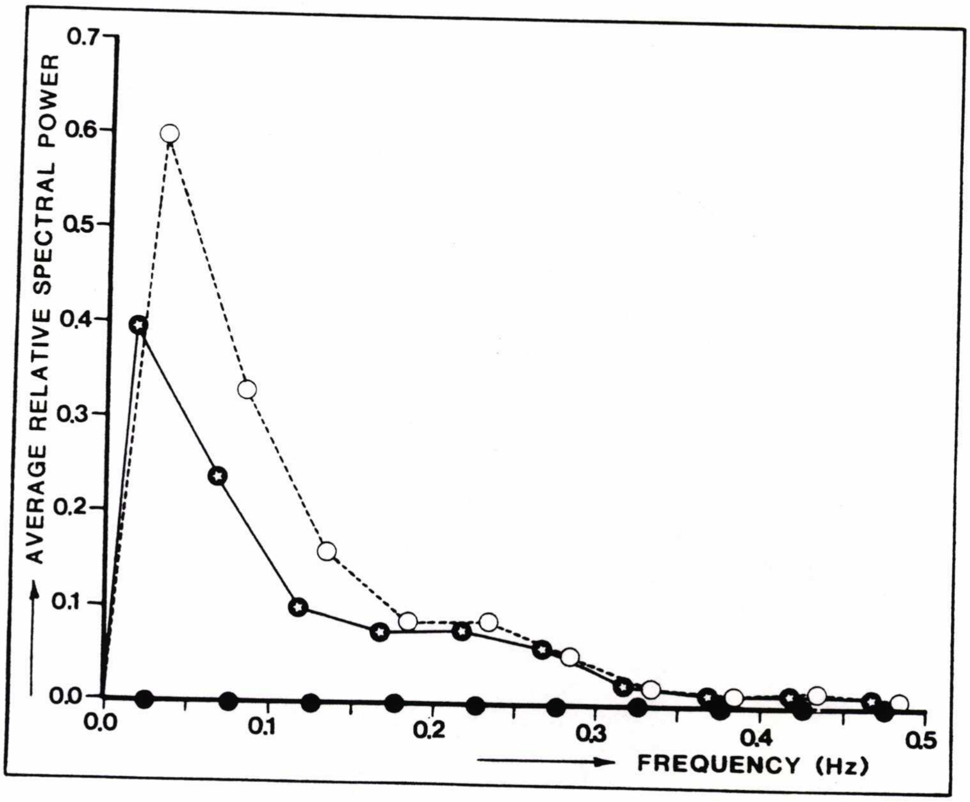

Figure 5. Diastolic pressure response to mental stress for the three study groups is depicted as mean pressure in mm Hg ± SE from baseline, during 10 min of mental stress and in the recovery period. Labile subjects have a significantly greater response than control ($p < .001$). Additionally, the genetic group also has a diastolic pressure response greater than control ($p < .001$). (Reprinted, by permission of the American Heart Association, from B. Falkner, G. Onesti, E.T. Angelakos, M. Fernandez & C. Lonagman. Cardiovascular response to mental stress in normal adolescents with hypertensive parents. Hypertension 1 (1979) 23)