

The Structure of Emotion

Psychophysiological, Cognitive and Clinical Aspects

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This book has been written by several of the world's leading experts in the field of research on emotions. The emphasis throughout is on practical psychophysiological approaches, and concrete results.

The authors present an original approach which enables practitioners to differentiate, in an objective psychophysiological manner, positive emotions from negative ones. In this framework emotions are analyzed in the context of response systems. In particular, emotional imagery in normals and behaviorally disturbed individuals, including the relevance of emotional imagery for the treatment of emotional disorders, is combined with the peripheral and central measurement of hedonic tone.

This book is extensively illustrated and presented in a well organized textbook-like format, so that it can be effectively used in graduate courses dealing with clinical and cognitive psychology, as well as behavioral biology. There are four main sections:

[*] Basic Conceptual Issues [*] Organization of Emotions in Memory: Applications to Imagery, Clinical Problems and Experimental Esthetics [*] Acquisition of Fear [*] Emotion and Reflex Modification: Clinical Implications

This material will be highly productive for both clinical and research-oriented psychologists, as well as neuroscientists and behavioral biologists.

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Cardiovascular response to mental and physical tasks as predictors of ambulatory measurements

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Keywords: Blood pressure, heart rate, borderline hypertension, ambulatory monitoring, laboratory-field prediction, cardiovascular reactivity, baselines.

Abstract Cardiovascular responsiveness in the laboratory and in the field was investigated in male students, 40 with borderline hypertensive blood pressure (SBP > 140 mmHg and/or DBP > 90 mmHg), 17 with mildly elevated blood pressure, and 41 with normotensive blood pressure. The behavioral tests and physically demanding tasks in the laboratory included mental arithmetic, free speech condition, the Cold Pressor Test, upright tilt, climbing stairs, and ergometer exercise. Subsequently, subjects participated in a 24-hour psychophysiological ambulatory monitoring. Borderline hypertensive and normotensive subjects differed in baseline, task, and recovery levels of SBP, DBP, and HR. A laboratory-field comparison showed that some laboratory tasks substantially predicted average daytime blood pressure and heart rate. Measures that were obtained during upright tilt and the stairs test were found to explain a higher portion of criterion variance than psychological tasks, e.g., mental arithmetic. The elevated heart rate (baseline and task level) that was evident in borderline hypertensive subjects in the laboratory disappeared during ambulatory monitoring. This finding suggests differential adaptations to the laboratory.

The average daytime and the average nighttime blood pressure which constitute the overall strain for the blood vessels and the heart are relevant parameters for diagnosis and therapy evaluation of hypertension. The methodology of ambulatory monitoring was developed to overcome the obvious sampling bias occurring when measurement is restricted to casual measurement in the physician's office or to the rather specific conditions of the research laboratory. Empirical findings on office hypertension and increasing concern about external validity of "laboratory stressors" underline the utility of ambulatory monitoring as possibly the most important method for assessing the relevant aspects of blood pressure. Psychophysiological approaches that employ certain laboratory tasks to elicit blood pressure responses, obviously, were not adopted as routine methods in this domain, e.g., for diagnosis of essential hypertension or evaluation of therapy. With the development of the ambulatory monitoring methodology, thus, the utility of laboratory measurements concerning such practical decisions and related research issues comes into question, e.g., the generalizability

of the effects of relaxation therapy from one setting to another (Jacob, Shapiro, O'Hara, Portser, Kruger, Gatsonis, & Ding, 1992).

The first aim of the present research was to study the association between laboratory measurements and practically relevant mean daytime levels of blood pressure and heart rate irrespective of etiological concerns. Do laboratory measures – at least – predict the daytime mean substantially? What is the incremental validity of certain laboratory measurements in prediction of the relevant criterion?

With regard to blood pressure, a multiplicity of empirical studies on ambulatory monitoring exists. However, only recently is a systematic and large scale evaluation of the laboratory-field issue discernible. Findings from such investigations indicate that most correlations between measurements in the laboratory and in the field are significant, but such relationships obviously depend on the selection of tasks that are employed in the laboratory and the choice of response measure, i.e., change scores or task levels (e.g., Fredrikson, Tuomisto, Lundberg, & Melin, 1990; Harshfield, James, Schluskel, Yee, Blank, & Pickering, 1988; Morales-Bal-

lejo, Eliot, Boone, & Hughes, 1988; van Doornen & van Blokland, 1992; van Egeren & Sparrow, 1989). The results of such studies have been discussed in terms of whether enhanced responsiveness in the laboratory predicts a sustained elevation of blood pressure or recurrent peaks of blood pressure throughout the day (see Fredrikson et al., 1990). A few generalizability studies concerning blood pressure and heart rate exist (Fahrenberg, Foerster, Schneider, Müller, & Myrtek, 1984, 1986; Llabre, Ironson, Spitzer, Gellman, Weidler, & Schneiderman, 1988). However, the coefficients of generalizability that are derived from such G-studies are largely dependent on the selection of measurement conditions in the laboratory and field so that further differentiation (e.g., by regression analysis) is desirable.

The predictability issue, of course, needs to be specified with respect to methodological aspects (see Fahrenberg et al., 1986). There are several aspects of laboratory-field prediction that deserve consideration. First, the prediction of individual differences in a habitual disposition, for example, blood pressure responsiveness, requires a sufficient degree of stability of both the predictor and the criterion variable. Second, the kind of behavioral challenge that is employed in the laboratory to elicit blood pressure responses is relevant here. Mirror image tracing, mental arithmetic, or playing a video game may be less suited to represent behavioral challenges in real life. Therefore, such laboratory tasks should be examined in comparison to conventional physical demands like ergometer exercise and upright tilt (orthostatic response). Third, change scores, i.e., task-baseline differences or residual change scores, are generally less reliable than task levels and appear to be biased estimates of responsiveness when initial-value dependencies are present (e.g., Fahrenberg, Foerster, & Wilmers, 1993).

With respect to the criterion variable that should be employed in laboratory-field prediction studies several issues can likewise be raised. The assumption that daytime and nighttime averages constitute the most valid aspects in development of hypertension may be questioned. Other parameters that were suggested in the research literature include spontaneous variability, i.e., total variance of BP measures, the incidence of BP increases exceeding certain limits, the recovery function at night, and

the BP responsiveness (reactivity) that is elicited by emotional episodes or certain tasks (cf. Devereux & Pickering, 1991; Weber & Drayer, 1984). The evaluation of the etiological or prognostic relevance of such indices is beyond the scope of the present investigation.

However, ambulatory monitoring itself would allow for further differentiation of the overall mean daytime BP if the methodology is further developed so that measures of physical activity, protocols on types of behavioral activity and settings, and self-ratings of mood could be obtained simultaneously. Such multimodal assessment was employed in two previous investigations.

The first laboratory-field study was confined to comparing distinct conditions that, by and large, appear to elicit a psychologically and metabolically equivalent response pattern in the laboratory and the field, e.g., ergometry at maximum load compared to 1000m run in the stadium or conditions of active relaxation in both settings (Fahrenberg et al., 1984). This matching of specific tasks and corresponding conditions in daily life may be persuasive, and more recently other researchers have pointed out that fair comparisons should be aimed at in laboratory-field prediction studies (e.g., Matthews, Owens, Allen, & Stoney, 1992; van Doornen & Turner, 1992). However, this matching of complex situations, which was already suggested by Lewin's concept "gleicher Geschehenstyp" (psychological equivalent type of event), is obviously restricted to a few conditions because many laboratory tasks seem to lack ecological validity (for further discussion, see Fahrenberg et al., 1984, 1986).

The confounding of cardiovascular responses with changes in physical activity in ambulatory monitoring was examined in a second study (Fahrenberg, Heger, Foerster, & Müller, 1991). Cross-correlation technique was employed to estimate the common variance between cardiovascular measures, a measure of physical activity, and a self-rating of physical activity. Furthermore, residual scores were derived by partialling out such effects. The conclusion, however, was that such techniques appear to be inadequate to remove the confounding of metabolic and psychological effects in intermittently measured blood pressure. Such methodology may be appropriate with continuously recorded heart rate and physical activity (see Johnston, Anastasiades, & Wood, 1990;

Myrtek, Brügger, Fichtler, König, Müller, Foerster, & Höppner, 1988) or with continuously recorded finger blood pressure (see Schmidt, Steinmetz, Wittenhaus, Piccolo, & Lüpsen, 1992). But "correction" procedures of this kind are questionable in most instances and instead a segmentation of records that relates to simultaneously assessed psychological data is preferable (Fahrenberg et al., 1991). The development and refinement of this methodology is referred to in a recent article (Käppler, Becker, & Fahrenberg, 1993).

Reference data are available in the literature regarding linear regressions of systolic and diastolic mean daytime blood pressure on the office blood pressure (Baumgart, Walger, Jürgens, & Rahn, 1990). Findings that were obtained by ambulatory monitoring of 1039 normotensive subjects indicated correlation coefficients of .73 (SBP) and .71 (DBP) between office blood pressure (mean of two readings on different days) and mean daytime values, and .59 (SBP) and .57 (DBP) between office and mean nighttime values. A fall in blood pressure values can be expected with serial observations in the laboratory but not in ambulatory monitoring or self-determined measurement (e.g., Marolf, Hany, Bättig, & Vetter, 1987).

The research question of the present study has been whether such predictions could be increased when standardized laboratory tasks that are specifically developed to assess cardiovascular responsiveness are included. The scope of tasks and the number of subjects that are examined allowed for testing the incremental validity of specific laboratory tasks and permitted a comparison of mentally and emotionally challenging tasks with physical tasks (i.e., ergometer exercise, climbing stairs, and upright tilt) in prediction of mean blood pressure and heart rate level in real life. In this investigation, it was particularly important to familiarize subjects with laboratory procedures to adjust for possible differences in apprehensive anticipation and increased levels of activation under rest conditions in the laboratory (Jennings, Kamarck, Stewart, Eddy, & Johnson, 1992). Baseline values from the laboratory and mean nighttime blood pressure values were employed as reference values. A multiple regression model has been employed instead of reporting a large number of correlation coefficients.

Further research questions refer to group

differences among subjects selected according to their normal or borderline hypertensive blood pressure levels under rest conditions. It would, for instance, be interesting to know whether a higher level of heart rate among borderline hypertensives sometimes found by investigators in the laboratory (see Fredrikson & Matthews, 1990) prevails throughout daytime and nighttime ambulatory recordings. The hypothesis concerning recovery functions at night would be that borderline hypertensive subjects exhibit a more sustained level of high blood pressure and heart rate.

To search for valid laboratory-field relationships, it appears to be more appropriate to have comparatively young subjects with mildly elevated or with borderline hypertensive blood pressure levels instead of chronic hypertensives. This should reduce the risk of heterogeneity, and the effect of labeling as hypertensive, increased health concerns, and treatment. Thus a broad screening of potential subjects among a student population was required. This might have the consequence of reducing effect size in comparison with other designs but seemed likely also to enhance validity.

The present communication is part of an extended research project and findings concerning a number of other research questions will be published elsewhere, e.g., issues in response scaling, initial-value dependency of blood pressure measures, group differences in response specificity, and haemodynamic profiles (Fahrenberg et al., 1993).

Method

Subjects

In this study, 98 male university students (none from psychology courses) served as paid voluntary participants. They ranged in age from 19 to 30 years, with a mean age of 23.9 (S.D. = 2.5), and all reported being in good health.

The subjects were recruited by advertisement for the study and via an invitation to have their blood pressure measured. The apparatus (Stavomed BMC 5000, Speidel & Keller) was installed for the public in the University Cafeteria and the University Library. The screening of more than a thousand students led to a selection of subjects with presumably normal, mildly elevated, or borderline hypertensive

blood pressure so that these subjects were invited to come to the laboratory for a more precise examination (for a criteria of blood pressure groupings, see below).

The subjects were informed that the experiment would investigate individual differences in cardiovascular functions under various conditions of mental load and physical exercise. Recordings of blood pressure and the ECG were conducted and psychological questionnaires were administered. The assessment consisted of examination in the laboratory on two days and a 24-hour psychophysiological ambulatory monitoring. Subjects were paid DM 150 for their participation.

Apparatus

The laboratory equipment used were one 16-channel and one 8-channel polygraph (Hellige), a calibrated automatic blood pressure measurement device (Infraton-Tensiomat FIB 4/6, Boucke), two mercury manometers (Erkamed), one impedance cardiograph (Instruments for Medicine Inc., model 400) that was replaced after subject 81 by another (Meddata, Faust), a respiratory function analyzer (Pneumotest, Jaeger), a tilt table, a bicycle ergometer (Mijnhardt), a Hewlett Packard computer 1000/65, and an Amiga 1000 PC for presentation of instructions and tasks. The configuration that was employed in ambulatory monitoring consists of three recorders: a four-channel recorder for blood-pressure, heart rate, respiration rate and activity (Physiport/Tonoport, Par-Natic/Hellige), a pocket-sized computer (PB 1000, Casio) that was programmed to obtain self-ratings at fixed intervals, and a walkman recorder (WM 202, Sony) to record the subject's free comments on the more specific aspects of behavioral settings and events (see Fahrenberg et al., 1991).

Procedure and Methods

Laboratory First Day

After obtaining informed consent from the participants in this study, several psychological questionnaires were administered. Then in another room, two measures of systolic and diastolic (phase 5) blood pressure were taken after 5 min in reclining position employing a mercury manometer (Erkamed). The subjects were next led to the polygraph laboratory and then to the cardiovascular laboratory. The rel-

evant tasks were demonstrated and practised to familiarize the subjects, for example, with the mental arithmetic test and orthostatic reactions using the tilt table. Furthermore, ECG recordings and blood pressure measurements were conducted during a short psychological interview to facilitate habituation.

Laboratory Second Day

Subjects could choose between an 8 a.m. or 11 a.m. appointment. Subsequent to an adaptation phase that was also used for a short questionnaire and a further 5 min rest, blood pressure was measured twice in reclining position. Then, subjects were seated in a semi-reclining padded chair in a sound-dampened and air-conditioned room adjacent to the polygraph laboratory. After electrodes and transducers were fastened and checked, general instructions were given concerning the initial rest phase, and specific instructions were presented via tape recorder, slide, or computer display prior to each subsequent condition. The following conditions were employed in fixed order to assess individual differences:

- *Initial rest*: to establish the baseline Laboratory 1 (duration of 210 s).
- *Mental arithmetic*: Subjects were requested to perform the continuous addition of one- and two-digit numbers as quickly and accurately as possible while distracted by noise sequences of realistic content (music, air plane, traffic, football stadium) at maximum level of 80 dBA (duration of 180 s, recovery for 60 s).
- *Concentration task*: Subjects performed a multiple reaction tracking task that required the inspection of matrices of two-digit numbers. An increase in number of correct responses automatically reduced the given inspection time so that the algorithm provided a constant level, e.g., 30% hit rate. The subject could not exceed this criterion, although additionally motivated by visual and acoustic feedback, as well as by monetary incentive (duration of 300 s, recovery for 60 s).
- *Handgrip exercise*: Subjects were asked to press a handgrip with their left hand exerting maximal pressure (duration of 55 s, recovery of 45 s).
- *Free speech*: Subjects were instructed to give a speech containing critical comments on the present investigation and to frankly rate the

present investigators (preparation of the free speech of 60 s, delivering the speech for 90 s, recovery for 60 s).

- *Cold Pressor Test*: Subjects were instructed to immerse their left hand in cold water that was kept at a steady temperature of 4°C by continuous cooling (duration of 55 s + 55 s, recovery for 50 s).
 - *Concluding rest*: (duration of 120 s).
- Multiple recordings of cardiovascular and other physiological functions were obtained. However, in the present context, only blood pressure and heart rate are relevant and the other recordings are not referred to. The software system BIO 14 developed by Foerster was employed for parameterization (Fahrenberg & Foerster, 1989, 1991).
- *Heart rate* (HR, bpm) was derived from the ECG using standard lead II.
 - *Blood pressure* (SBP, DBP, MBP, mmHg) was recorded intermittently by a non-invasive automatic procedure (Boucke Infraton Tensiomat) that provides Korotkov sounds on the first channel and the calibrated cuff pressure signal on the second channel. The software algorithm for parameterization of these signals to obtain blood pressure values was developed by Foerster (see Fahrenberg & Foerster, 1989). Thirty measures of blood pressure were obtained during rest, task, and recovery phases of the experiment.
- After the assessment in the polygraph laboratory was concluded, the subject had time to relax and subsequently the assessment was confined to Laboratory 2, i.e., the cardiovascular laboratory.
- *Rest*: The subject rested in reclining position on the tilt table to establish baseline Laboratory 2 (duration of 240 s).
 - *Upright tilt*: After tilting the subject in upright (75°) position within four seconds the registration was continued (duration of 420 s).
 - *Exercise 100 Watt*: Subjects exercised on the bicycle ergometer in reclining position cycling at 50 to 60 revolutions per minute (duration of 240 s at 50 watt; 240 s at 100 watt; the last 60 s of a 300 s recovery period were used as recovery level).
 - *Heart rate* (HR, bpm) was obtained from the ECG using Nehb anterior leads.
 - *Blood pressure* (SBP, DBP, MBP, mmHg) was measured at 1 min intervals employing the mercury manometer.

Ambulatory Monitoring

A 24-hour ambulatory monitoring was subsequently conducted to obtain records of physiological and psychological variables in real life. After electrodes and transducers were attached subjects were instructed and trained in the use of the monitoring system and the pocket-sized computer to obtain concurrent self-reports on setting variables and mood. Blood pressure measurement was carefully checked. Climbing stairs (42 steps) in the laboratory building as fast as possible was used as an initial behavioral test. Then subjects left the laboratory and continued their normal daily activities. After returning the next day subjects were thoroughly interviewed regarding the recorded profiles of changes in heart rate, blood pressure, activity, and concurrent self-ratings.

- *Blood pressure* (SBP, DBP, MBP, mmHg) was recorded intermittently (a daytime interval of 15 min and 60 min at night). The Physiport employs the ECG to define a window for detecting Korotkov sounds that are transmitted by a microphone attached over the brachial artery (for further technical information, see Kiparski & Steffens, 1985). The calibration certificate (Landesamt für Mess- und Eichwesen, Berlin) states a measurement precision $\pm .5$ mmHg for the pressure transducer. However, precision of blood pressure measurement depends on careful checks of equipment, positioning, and initial readings.
- *Heart rate* (HR, bpm) was automatically derived from the continuous ECG recordings from Nehb anterior leads.
- *Activity* (units/minute) was derived from continuous registration of physical activity by means of a three-dimensional piezoelectric transducer (Par) that was attached to the left lower arm (above flexor digitorum muscle). In the study's second part from subject 53 onward, the transducer was attached to the left upper thigh because physical activity during climbing stairs test had not been assessed satisfactorily, i.e., as a maximum value, in all subjects prior to this. The signal was filtered, rectified, smoothed, sampled at 100 Hz and, finally, integrated per minute. The maximum value that is obtained from each individual is referred to as a reference value of 100 so that an intraindividually calibrated range from 0 to 100% of activity is

defined. This index provides a rough estimate of gross physical activity and within-subject changes in activity which involve limb movements. For 46 subjects, who had the transducer attached to their upper thigh, a segmentation of daytime recordings was conducted. BP and heart rate measures were grouped according to high (>30%) and low (≤30%) physical activity as recorded during the 5 min prior to the measurement.

Measurement and Classification of Blood Pressure

Blood pressure in this study was always measured according to Riva Rocci's method, i.e., employing an arm cuff (pressure release at a rate of 2 to 3 mm per second), a calibrated manometer, and detecting Korotkov sounds. However, different strategies had to be used, i.e., auscultation or automatic measurement by means of the Boucke system or the Physiport. Therefore, a measurement reliability study appeared to be mandatory although all manometer systems were recently calibrated and the three investigators who made the auscultatory measurements had been thoroughly trained employing a double stethoscope. Correlation coefficients were computed within and between methods of blood pressure measurement. Such consistency coefficients obviously must be conservative estimates of the true instrumental reliability since these coefficients also reflect temporal (in-)stability of blood pressure level.

Blood pressure measurements that are obtained at an interval of about one minute under rest conditions are highly correlated within methods. The obtained correlation coefficients concerning the sphygmomanometer method range between .96 and .97 for SBP ($df = 96$, $P < .01$) and between .86 and .95 for DBP; concerning the Boucke method .92 for SBP and .86 for DBP. Stability coefficients within methods between two rest conditions are: sphygmomanometer method .61 for SBP and .56 for DBP (interval approx. 120 min), Boucke method .73 for SBP and .62 for DBP (interval approx. 90 min). The coefficient of consistency between sphygmomanometer and Boucke method appear to be of the same order, namely .71 for SBP and .63 for DBP (interval approx. 30 min). However, between methods and conditions the coefficients are smaller: Physiport meth-

od (night mean) with sphygmomanometer method during rest conditions in the laboratory between .54 and .57 for SBP and between .31 and .45 for DBP; Physiport method (night mean) with Boucke method during rest between .32 and .39 for SBP and between .33 and .34 for DBP.

The blood pressure measurements by means of the ambulatory monitoring system Physiport generally appear to be satisfactory (Langewitz, Dähnert, & Rüddel, 1987). The Boucke method that was employed in the polygraph laboratory still has some problematic aspects in precisely detecting diastolic (phase 5) values (see Fahrenberg & Foerster, 1989). The reliability coefficients and the stability coefficients within each method may be considered satisfactory. The consistency (generalizability) coefficients between methods or across methods and conditions, as expected, are much lower. The conclusion was to only employ sphygmomanometric measures for the classification of subjects into blood pressure groups.

Six blood pressure measurements were used for the classification: two measures obtained on the first day in the laboratory, two measures obtained at the beginning of the assessment on the second day (before conducting the polygraph recordings), and the first and second reading from the rest condition preceding the tilt test in the cardiovascular laboratory. All measurements were taken after a 5 min rest in the reclining position. Mildly elevated blood pressure was assumed when *one or more* values met the criterion SBP > 140 mmHg and/or DBP > 90 mmHg; borderline hypertensive blood pressure was assumed when the *mean* of these six measurements met this criterion. According to this definition 40 subjects were classified as "borderline," 17 subjects as "mildly elevated," and 41 subjects as "normotensive."

This classification is needed when differences between blood pressure groups in a laboratory-field comparison are investigated, but the classification, at present, is not relevant for the regression analysis concerning prediction of ambulatory blood pressure.

Data Analysis

A number of data were missing due to recording artifacts; however, the missing data rate for blood pressure and heart rate was on the order of less than 3% and appeared to be negligible.

An exception was the handgrip task which was, therefore, excluded, from the analyses.

With respect to the multivariate statistical procedures, missing data were replaced by an estimate that takes into account not only the sample mean (\bar{x}_i) but also the individual's mean across tasks (\bar{x}_i) and the mean for the specific task (\bar{x}_{ij}):

$$\bar{x}'_{ij} = \bar{x}_i + (\bar{x}_i - \bar{x}_i) + (\bar{x}_j - \bar{x}_i)$$

Multiple regression analyses were employed to evaluate the relationship between laboratory task levels and daytime means of blood pressure and heart rate. The incremental validity of specific tasks in prediction of daytime measures was of particular interest here. The ambulatory monitoring and the laboratory assessment were combined to evaluate group differences between subjects with borderline hypertensive, mildly elevated, and normotensive blood pressure. A multivariate analysis was conducted for 12 conditions and 98 subjects. The MANOVA was also computed across four subsets of conditions.

Tentatively, a recovery index was defined to represent individual differences in the decrease of blood pressure level and heart rate after sleep onset. Sleep onset appears to be suf-

ficiently well established from ambulatory monitoring of heart rate and activity and by referring to protocol entries and a retrospective interview. Pre-sleep baseline is defined as the minimum value of SBP, DBP, and HR within the two-hour interval before sleep onset. Based on nightly measurements (interval of 60 min) the shape of the recovery function was defined by the average successive difference of measures y_{D1} (slope), the average successive difference of differences y_{D2} (flexure or curvature of slope), and the ratio y_{D1}/y_{D2} = (exponential deceleration). Within subjects the indices, on the average, are based on seven measures. Univariate t-tests were applied to test the hypothesis concerning group differences in recovery functions at night.

Results

Laboratory-field comparison

From Table 1, it is evident that blood pressure and heart rate manifest a large range and variability across the screening and baseline conditions and across the mental and physical tasks, as well as from daytime to nighttime averages during ambulatory monitoring. Multiple re-

Table 1 SBP, DBP, and HR during rest and task conditions in the laboratory and during 24-hour ambulatory monitoring for 98 subjects.

Conditions/ Tasks	Systolic Blood Pressure mmHg		Diastolic Blood Pressure mmHg		Heart Rate bpm	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Screening ^a	154.0	17.4	79.3	14.9	—	—
Rest (mean)	134.3	12.3	77.8	8.6	65.7	13.0
Baseline interview	125.9	14.5	65.3	10.0	75.9	13.1
Interview question 4	138.4	16.4	76.8	13.6	—	—
Baseline laboratory 1	124.1	13.4	65.8	10.3	66.2	10.5
Mental arithmetic	138.9	18.3	70.7	13.1	85.8	17.2
Concentration task	135.0	17.4	72.4	12.0	72.7	12.5
Handgrip ^b	137.5	17.9	81.7	16.1	86.5	16.3
Free speech	139.2	18.8	70.1	15.2	77.5	14.8
Cold Pressor Test 2	143.9	16.9	84.2	15.9	69.7	11.3
Concluding rest	129.9	14.4	68.1	11.5	63.3	10.2
Baseline laboratory 2	135.9	14.3	80.0	11.4	61.4	10.7
Upright tilt	131.3	13.1	94.8	9.9	84.4	13.6
Exercise 100 Watt	181.5	17.4	84.1	15.7	112.5	11.8
Climbing stairs	163.9	24.2	82.9	13.1	107.3	22.0
Daytime (mean)	136.7	12.6	83.6	9.4	84.8	10.6
Night (mean)	119.2	12.2	69.7	7.9	58.8	8.7
Night (minimum)	104.7	11.6	—	—	54.1	8.5

^aValid BP measurements for 85 subjects; heart rate not available. ^bValid BP measurements for 81 subjects

Table 2 Laboratory-field prediction of mean daytime blood pressure and heart rate according to three models of multiple regression: Beta-weights, R^2 and adjusted R^2 based on 98 subjects.

Task/ Situation	Systolic BP β	Diastolic BP β	Mean BP β	Heart Rate β
Model I: Five predictors from the Laboratory (fixed)				
Baseline lab. 1	.03	.21	.19	.35*
Mental arithmetic	.02	.01	.19	-.21
Concentration task	.43*	.22	.14	.42*
Free speech	-.41*	.01	-.15	.08
Upright tilt	.66**	.26*	.42**	.02
R^2 / R^2_{adj} ^a	.48/.45	.35/.32	.46/.43	.44/.41
Model II: Two predictors from Ambulatory Monitoring (fixed)				
Night mean	.32**	.41**	.39**	.29**
Climbing stairs	.47**	.59**	.53**	.63**
R^2 / R^2_{adj}	.46/.45	.70/.69	.62/.62	.59/.58
Model III: All seven predictors together in a stepwise solution				
Night mean	.24** (2) ^b	.37** (1)	.31** (1)	.19** (1)
Climbing stairs	.28** (3)	.57** (2)	.40** (2)	.52** (3)
Baseline lab. 1	-	-	-	-
Mental arithmetic	-	-	-	-
Concentration task	-	-	.18** (3)	.29** (2)
Free speech	-	.19** (3)	-	-
Upright tilt	.40** (1)	-	.16* (4)	-
R^2 / R^2_{adj}	.56/.53 ^c	.73/.71	.68/.66	.64/.61

Notes:

^aAll R^2 and R^2_{adj} values are highly significant ($P < .01$); for the β -weights: * $P < .05$, ** $P < .01$.

^bThe order in which a predictor was entered is given in parenthesis.

^cFor conservative testing of R^2 from Model III the number of seven predictors were included in adjusting R^2 throughout.

gression analyses were conducted with respect to daytime mean ambulatory measures as criterion variable. The rationale for the three regression models was to examine the utility of laboratory measures for the prediction of daytime means as compared to the night mean and stairs test as field-based predictors.

Model I is concerned with the predictive validity of five measures from the laboratory assessment, namely baseline Laboratory 1, mental arithmetic, concentration task, free speech, and upright tilt. Measures from the Cold Pressor Test and physical exercise were disregarded here because their predictive validity appeared to be in the same order of magnitude or even lower.

Findings from the multiple regression analysis with forced inclusion of the five predictor variables (fixed model) are depicted in Table 2. The R^2 values in the last row of that block display that the portion of the explained variance ranged from one third to almost one half.

Interestingly, measures from the upright tilt were here the most important predictors for the blood pressure variables SBP, DBP, and MBP. Likewise the measure from the concentration task and baseline Laboratory 1 are outstanding in prediction of mean daytime heart rate. Baseline (with the exception of heart rate) and measures from mental arithmetic appear to be redundant compared to other predictor variables of this regression model.

Laboratory measurements substantially predict average daytime levels of blood pressure and heart rate. Since a standard of comparison to evaluate the observed effect size is not available in the literature, a different approach is preferred in the present investigation. Individual differences in average daytime blood pressure presumably can be explained to a substantial amount of variance when a baseline measure (average blood pressure at night) and a response measure (e.g., climbing stairs) are employed. Of interest is whether laboratory

tasks that were specifically designed to assess cardiovascular responses can explain comparatively more variance or predict specific components of variance in blood pressure responsiveness that is manifest in an average daytime level.

Model II was therefore designed to examine the amount of variance in average daytime blood pressure that can be explained by two readily available measures from ambulatory monitoring, i.e., average night value and the climbing stairs measure. Obviously, the two field-based measures substantially predict daytime blood pressure and heart rate. With respect to DBP, MBP, and HR the values of R^2 are noticeably higher as compared to Model I which employs the laboratory tasks.

Model III is concerned with a comparison between laboratory-based and field-based predictors by including both sets of variables in a multiple regression. Results from a stepwise regression and from a model with forced inclusion of all predictors are essentially in accordance, but only the stepwise model is presented here. The night mean and climbing stairs test appear to be substantial predictors with respect to blood pressure variables and heart rate. Measures from upright tilt are significant for SBP and MBP. However, the predictor variables that are derived from psychophysiological tasks in the laboratory are generally less important. Only the free speech task with respect to DBP and the concentration task with respect to heart rate and MBP seem to have an incremental validity.

When the R^2 values are compared across the three models, it appears, according to model III that a significant ($P < .05$) but relatively small increase in explained variance is achieved. The increase of 8% for SBP in Model III as compared to Model II is highly significant ($P < .01$). It should be taken into account that in Model II a relatively large R^2 was already apparent.

The regression analyses were conducted for the total sample. However, the relationships may not be the same among the different blood pressure groups. Nevertheless, the Box-Test for the set of eight variables (seven predictors and criterion) in each of the four physiological variables revealed that homogeneity of variance-covariance matrices can be assumed for the groups of 41 normotensive and 40 borderline hypertensive subjects ($P > .05$ for SBP and HR; $P = .04$ for DBP and MBP).

The question can be raised whether the laboratory-field prediction depends on the amount of physical activity during ambulatory monitoring. The segmentation that was obtained for daytime records of 46 subjects, i.e., from the second part of the present study, allowed for separation of blood pressure and heart rate measurements at high vs. low levels of activity. The pattern of significant beta weights appears to be very similar. The predictive validity of the climbing stairs measurements is slightly reduced for low activity BP measurements as compared to high activity BP measurements, but variables from psychological laboratory tasks have no specific advantage in prediction of low activity BP measurements. These findings are tentative and need further refinement and control (see K  ppler et al., 1993).

Coefficients of correlation between daytime mean systolic blood pressure and single tasks were upright tilt $r = .66$ ($df = 96$), pretest day rest .54, climbing stairs .53, baseline laboratory 1 .44, physical exercise .43, concentration task .40, Cold Pressor Test .37, free speech .35, and mental arithmetic .34. Similarly, the correlation coefficients concerning heart rate were baseline laboratory 1 .63, concentration task .63, Cold Pressor Test .55, upright tilt .53, free speech .52, mental arithmetic .48, climbing stairs .48, and physical exercise .42. Findings indicate higher correlation coefficients between daytime means and measures obtained during upright tilt and during climbing stairs than between daytime means and measures during physical exercise.

For comparison with the findings by Baumgart et al. (1990), correlation coefficients were computed between blood pressure measurements in the laboratory (after five minutes rest in reclining position, mean of two days) and ambulatory measures. The coefficients were for mean daytime values $r = .60$ ($df = 96$) for SBP, .57 for DBP, and .68 for MBP; for mean nighttime values .49 for SBP, .48 for DBP, and .60 for MBP.

Group differences

The ambulatory monitoring and the laboratory assessment were combined to evaluate group differences between subjects with borderline hypertensive, mildly elevated, and normotensive blood pressure. A multivariate analysis

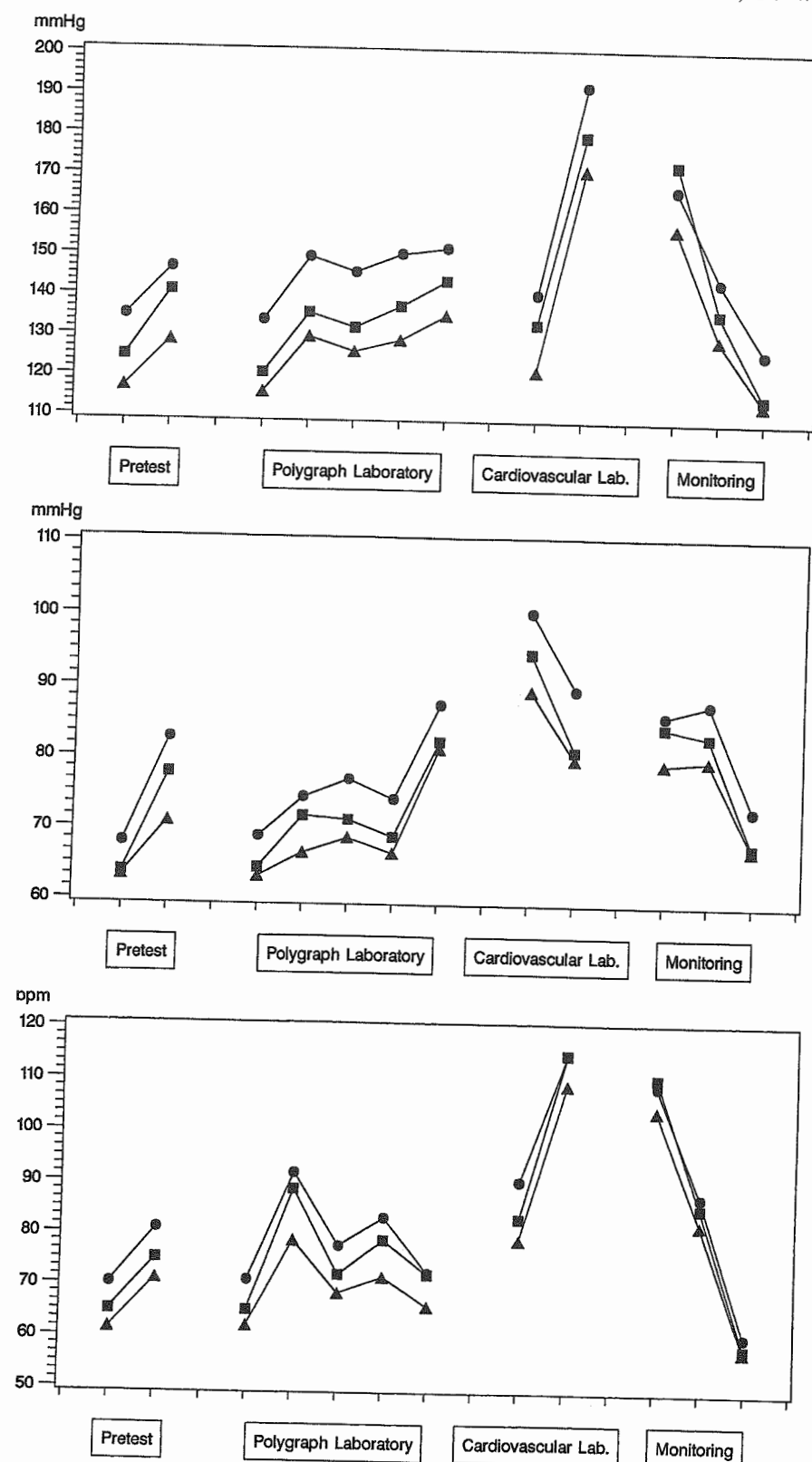


Figure 1 Mean responses for systolic (top) and diastolic (middle) blood pressure and heart rate (bottom) in subjects with borderline, mildly elevated, and normotensive blood pressure. ● = 40 borderline hypertensive subjects, ■ = 17 subjects with elevated blood pressure, ▲ = normotensive subjects.

was conducted for 12 conditions and 98 subjects. The three groups under study have, of course, different systolic blood pressure levels. This finding is highly significant in the MANOVA overall test (F -statistic for Pillai's Trace $F = 3.96$, $df = 24/122$, $P < .0001$) and in each separate MANOVA in all four subsets of conditions: Pretest day including rest and interview ($F = 9.61$, $P < .0001$), Laboratory 1 (Polygraph Laboratory) including baseline, mental arithmetic, concentration task, free speech, and Cold Pressor Test ($F = 4.73$, $P < .0001$), Laboratory 2 (Cardiovascular Laboratory) including upright tilt, exercise 100 Watt ($F = 14.85$, $P < .0001$), and ambulatory monitoring including climbing stairs, daytime mean and night mean ($F = 8.05$, $P < .0001$).

However, of interest is that the results for heart rate are inconsistent (see Figure 1). Borderline hypertensive subjects exhibit a higher heart rate on pretest day ($F = 3.31$, $df = 24/138$, $P < .01$), in Laboratory 1 ($F = 2.40$, $P < .01$) and in Laboratory 2 ($F = 4.33$, $P < .01$), but not during ambulatory monitoring ($F = 1.01$, $P > .05$). The overall test for group differences in heart rate, therefore did not attain significance ($F = 1.27$, $P > .05$). Whereas the ANOVA for single laboratory tasks all show significant F -values, the three F -values relating to heart rate levels during real life are insignificant ($P > .05$).

Recovery function after sleep onset

The assumption was tested whether subjects with elevated and borderline hypertensive blood pressure would exhibit a different shape of the recovery function after sleep onset as compared to normotensive subjects, i.e., larger Alpha index. Actually, there is no significant difference between the three blood pressure groups for any of the three indices employed to assess individual differences in recovery, YD1, YD2, and α in SBP, DBP, and HR (the greatest F -value was found for HR, $F = 1.6$, $df = 2/89$, $P > .05$).

Discussion

The laboratory-field issue in blood pressure measurement closely corresponds to a basic issue in the theory of psychological tests: To what extent is a psychological test score that is derived from a restricted sample of behavior under highly standardized test conditions predictive for the individual's actual performance in relevant life situations? Pertaining to the methodology of psychological tests, a number of essential concepts and designs were developed and applied, especially in personality assessment and prediction. This methodology includes concepts of reproducibility (stability) with respect to single and aggregate measures, generalizability theory, prediction of individual differences by multiple regression equations, evaluation of internal validity, i.e., precision of measurement, and external validity, i.e., ecological relevance.

A laboratory-field comparison was designed to investigate the extent of cardiovascular responses elicited by a variety of mental and physical tasks in predicting daytime mean blood pressure and heart rate obtained by ambulatory monitoring. Here, response levels were preferred to change scores in a multiple regression design. It is noteworthy that initial-value dependencies were found for blood pressure responses in the present investigation (Fahrenberg et al., 1993). Compared to depicting a table of correlation coefficients, examining the amount of criterion variance that is explained by responsiveness to mental and physical tasks in the laboratory and evaluating the incremental validity of such tasks in prediction of blood pressure and heart rate in real life proved more valuable.

It may be concluded that several laboratory measurements substantially predict daytime blood pressure and heart rate. However, the incremental validity of psychological tasks is relatively small due to the overlap in explained variance. Only a few such predictors from the laboratory, such as concentration task with respect to heart rate, attained significance in the multiple regression when compared to predic-

tion by a baseline and the climbing stairs measure.

The systolic blood pressure level during upright tilt explained more criterion variance than other SBP measures. The regression analyses depict that this aspect of blood pressure responsiveness in the counterregulation of coping with orthostatic hypotension is not adequately assessed by the other laboratory tasks. It could equally mean that orthostatic regulatory processes due to change in posture essentially contribute to daytime mean systolic blood pressure. Cardiovascular response to upright tilt reflects habitual differences in baroreflex function. A more thorough approach, however, should account for different haemodynamic response patterns (e.g., Thulesius, 1976). In the present study upright tilt, nevertheless, provided a more substantial predictor than physical exercise which is apparently more often employed in diagnostic testing of borderline hypertensives (e.g., Franz, 1986).

Our investigation contributes to the evaluation of extensive and costly laboratory assessments such as ergometry or certain psychological tasks when assessing cardiovascular responsiveness as compared to ambulatory monitoring. The finding that psychological tasks had comparatively little incremental validity could also mean that cardiovascular responsiveness that is elicited by such tasks as mental arithmetic, concentration and tracking, or preparation of free speech contributed little criterion variance in daytime values. Or it could mean that such challenges were not present for subjects during ambulatory monitoring. The relevance of segmenting the ambulatory monitoring protocol according to behavioral aspects is evident here when the external validity of such laboratory tasks is examined.

The psychophysiological assessment revealed group differences in blood pressure and heart rate levels at rest and during behavioral challenge, i.e., mental and physical tasks, and also in recovery levels. Further evaluation using correlation and regression analyses showed that such group differences actually are attributable to baseline differences persisting throughout the assessment (see Fahrenberg et al., 1993). Findings indicate, however, that there is a noticeable difference between blood pressure and heart rate responsiveness. Whereas group differences in systolic blood

pressure persist across the extended assessment in the laboratory and the ambulatory monitoring, the corresponding group differences in heart rate only seem to develop in the laboratory under task conditions and rest conditions (which apparently are of a challenging nature). Such group differences in heart rate tend to disappear in daytime and night averages.

If this finding is confirmed, it may explain some of the inconsistencies in the literature concerning elevated heart rate in borderline hypertensive subjects (see, Fredrikson & Matthews, 1990; Pickering & Gerin, 1988). Whether these subjects exhibit an elevated heart rate (suggestive of an increased cardiac output) may depend on when heart rate baseline is sampled and the amount of time provided for rest and adaptation.

Heart rate reactivity corresponds to blood pressure reactivity phenomena (office hypertension, white-coat hypertension) that apparently are introduced by social interaction, awareness of high blood pressure, and response to specific settings in the laboratory, office, or clinic (e.g., Pickering, Devereux, Gerin, James, Pieper, Schluskel, & Schnall, 1990; Rostrup, Mundal, Westheim, & Eide, 1991). It is noteworthy that this prolonged elevation of heart rate appeared in spite of the attempts to control apprehensive anticipation and test anxiety by providing for comparatively long time intervals between sessions (screening, first day and second day in the laboratory) and by including a pre-test interview together with specific attempts at familiarization of subjects and a training experience at the tasks. This finding underlines the importance of ambulatory monitoring because a thorough laboratory assessment that extended over two days and included many tasks did not reveal this differential heart rate activation-recovery profile.

Currently, daytime mean levels are selected as a criterion measure for laboratory-field prediction because measures of BP variability, at least in a student population, would include even more unsystematic variance due to differences in daily activities. Obviously, such findings concerning laboratory-field prediction need confirmatory evidence from assessments that allow for more controls and from subject samples which are more homogeneous in their pattern of daily activities. Such an in-

vestigation is presently conducted with hypertensives participating in a stationary rehabilitation program.

Reproducibility of measures, of course, is an essential prerequisite for generalizability and laboratory-field prediction, and the predictive validity has to be considered within the restrictions imposed by imperfect stability. The long-term stability of cardiovascular measures that were obtained by ambulatory monitoring was examined recently by Käppler et al. (1993). A follow-up study was conducted with 24 of the 98 subjects from the present study after 18 months. The coefficients of stability were .77 for daytime mean SBP, .69 for night mean SBP, .70 for daytime heart rate, and .72 for night mean heart rate ($df = 22$, $P < .001$). The rank order of subjects appears to remain rather stable and the change in mean blood pressure was not significant (first examination daytime mean 98.7 mmHg, s.d. 6.8; second examination 96.5 mmHg, s.d. 5.2, $df = 23$, $P = .10$). It may be concluded that ambulatory monitoring is appropriate for assessing rather stable traits of the individual. The increase in coefficients of stability as compared to previous studies (Fahrenberg et al., 1986; Myrtek, 1985) may be due to the fact that aggregate measures, i.e., average daytime values, were employed here rather than single measurements.

The evaluation of our findings concerning the laboratory-field predictability of blood pressure will also depend on empirical measures or estimates of utility, especially the practical relevance of such assessment to guide decision-making in hypertension management. Such issues are beyond the scope of the present investigation. From a psychophysiological perspective it may be concluded that further differentiation of 24-hour ambulatory monitoring is desirable. Concurrent registration of behavior settings, activities, and mood would allow for adequate segmentation of records (see Fahrenberg et al., 1991) and would facilitate symptom-context analyses of sudden blood pressure peaks. Such segmentation should account for posture and physical activity and should thereby attempt at reliable demarcation of sleep onset and of awakening so that the recovery function at night and the rise function in the early morning can be adequately discerned.

The recovery function of blood pressure also appears to be a relevant aspect of blood pres-

sure regulation as individual differences in the recovery curve would reflect the restitution (dampening) of elevated arterial pressure caused by demands of daily behavioral activities. The recovery index defined in the present study is a preliminary attempt to attain an operational definition for this plausible concept. The blood pressure groups, however, did not differ with respect to this index. It may, nevertheless, still be a valid measure of recovery provided that there are sufficiently reliable time series of cardiovascular measurements. A measurement interval of 15 or 20 minutes would be preferable. This index should be again employed among groups of subjects who are more homogeneous concerning daily activities and sleep onset time.

In conclusion, findings from the present investigation are suggestive with regard to the external validity of laboratory tasks that elicit blood pressure and heart rate responses. However, physical challenges such as upright tilt and the climbing stairs test apparently provide better estimates of individual differences in daytime mean blood pressure and heart rate than psychological tests. The incremental validity of such tests is less than expected. Findings underline the relevance of 24-hour ambulatory monitoring for the practical assessment of habitual differences in blood pressure level. It is evident that changes in physical activity and changes in posture should be recorded and accounted for when the evaluation of more specific psychophysiological aspects in borderline hypertension is intended (e.g., symptom-context analyses of sudden blood pressure rises).

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