International Society of Behavioral Medicine

The second congress of this society will take place in Hamburg, FRG on July 15–18 1992.

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Towards a Federation of European Psychophysiology Societies

For several years we discussed the possibility to bring the psychophysiological research of our different Societies together, in order to facilitate high quality meetings. In July 1989 we decided during the first European Congress of Psychology in Amsterdam to propose a first Federative Meeting of our Societies in June 1991. Although not all the administrative fuss and bother for the foundation of a Federation has disappeared at this moment, we think the time has come to act. Therefore we are happy to announce

The first meeting of the European Psychophysiology Societies

This meeting will be held in Tilburg, The Netherlands, 26–29 June 1991. Invited lectures, free paper sessions and poster sessions will be included in the program. The official language will be English.

The deadline for submission of abstracts is April 1, 1991. In a later mailing members of the societies will receive details regarding instructions for authors, abstract forms, preregistration forms from their Secretary. For additional information contact the Chairman of the Local Organizing Committee:

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A multiparameter study in non-invasive cardiovascular assessment

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Keywords: cardiovascular functions, non-invasive methods, electrocardiogram, impedance cardiogram, pulse wave velocity, respiratory sinus arrhythmia, systolic time intervals.

ABSTRACT The general intention of this study was empirically to evaluate the selection of cardiovascular parameters that are suited for the assessment of individual differences in haemodynamics and for multivariate pattern analysis of stimulus and individual specific responses. Multiple cardiovascular recordings in 42 male student subjects included measurements of electrocardiogram, impedance cardiogram, phonocardiogram, ear densitogram, carotid pulse curve, upper and lower arm rheograms, calibrated finger pulse, finger temperature, respiration, and intermittent automatic blood pressure. Experimental conditions were mental arithetic under distracting noise, maximal handgrip, and rest. Parametrization was performed on a beat-to-beat basis and resulted in about 200 measures for each cardiac cycle as well as a considerable number of indices. The selection of relevant parameters was performed according to a set of rational criteria. Findings are presented concerning the consistency of various measures, e.g. pulse-wave velocity, systolic time intervals, parameters from the electrocardiogram and impedance cardiogram. Aspects of within-subject and between-subjects correlation are discussed, as well as specific issues regarding standardization.

Introduction

Multiparameter studies in cardiovascular psychophysiology have been suggested by a number of investigators, since evidence continues to accumulate that research referring to haemodynamic pattern may be more productive than investigations of single measures. Such enhanced interest in multichannel recordings and functional analysis has become increasingly obvious in several research orientations, including the following:

(1) More precise haemodynamic analyses of task-induced cardiovascular changes (e.g. Obrist, 1981);
(2) Psychophysiological research that employs pharmacological agents to investigate the differentiation and interaction of alpha-adrenergic, beta-adrenergic, and cholinergic systems by simple or double blockades (e.g. Weiss, Del Bo, Reichek and Engelman, 1980; Stemmler 1990);
(3) Multivariate studies on covariance and consistency of activation parameters (e.g. Fahrenberg and Foerster, 1982);
(4) Differentiation of response specificities (e.g. Foerster, 1985);
(5) Psychophysiological research on cardiovascular disorders, especially hypertension (e.g. Fredrikson, 1986; Rüddel, Langewitz, Schächinger, Schmieder and Schulte, 1988);
(6) Longitudinal studies in which cardiovascular risk patients are assessed by standardized procedures (e.g. Steptoe, 1986).

A number of fortunate developments in physiological assessment would appear to facilitate such a multiparameter approach for psychophysiology. For example, various cardiovascular functions already can be registered in the psychophysiological laboratory by means of non-invasive methods, and there is a growing literature on such non-invasive measurement (for overviews, see Martin and Venables, 1980; Bernstein, 1985; Simon and Schoop, 1986; Schneiderman, Weiss and Kaufmann, 1989). Additionally more adequate parameters of haemodynamic functioning have relatively recently acquired accessibility for measurement, and multichannel assessments no longer appear to present serious problems for recording, data storage or parametrization. Another aspect is the increasing ease of beat-to-beat analysis, such data being necessary for more precise assessment of physiological functioning in the frequency and time domain, e.g. respiratory sinus arrhythmia, power spectra of pulse waves and other periodic signals, and quantification of transients.

Few multiparameter studies, however, actually exist, e.g. Allen, Obrist, Sherwood and Crowell (1987), Bunnell (1985), Newlin (1981). Furthermore, investigations of sufficient size with respect to number of subjects, variables and conditions to render generalizations possible are very rare, indeed, and there is also a scarcity of statistical data and of comprehensive between-subjects and within-subjects correlation designs. A multiparameter approach, however, could be accomplished by a rational and empirical evaluation of suitable sets of data, employing, for example, the partitioning of covariance as suggested in a previous study (Fahrenberg and Foerster, 1982; Stemmler and Fahrenberg, 1989).

Within an extended research programme in cardiovascular psychophysiology in our laboratory, a multiparameter study was recently conducted in order to develop the software system BIO, directed at beat-to-beat parametrization of multichannel recordings. The general intention of this study was empirically to evaluate selection of cardiovascular parameters that could best be used for a broad assessment of individual differences in haemodynamics and for multivariate pattern analysis of task and individual response specificities.

In our previous work (e.g. Fahrenberg and Foerster, 1982), a set of criteria was suggested that could serve, during a first stage, in the selection of appropriate parameters from a much larger pool of tentative ones derived from major physiological signals, such as the electrocardiogram, impedance cardiogram, and pulse wave recordings. There are several formal criteria and basic requirements that should be fulfilled to render a certain measure promising for research questions in differential psychophysiology. Essential aspects include the following:

(1) Evidence of effective discrimination between rest and task conditions and between subjects, as judged by appropriate statistical tests and conventional significance levels.
(2) Sufficient instrumental reliability of measurement as indicated by percentage of missing data (e.g. less than 30% in beat-to-beat analysis in the case of particularly difficult parameters), percentage of error variance in two-factorial (subjects × conditions) ANOVA (e.g. less than 50%) and split-half reliability (equal means and variances in two subsamples derived by odd-even method).
(3) Sufficient reproducibility of measurement as indicated by short-term stability coefficients (e.g. initial to final rest condition r_{tt} at least 0.70).
(4) Non-redundancy as compared to other measures from the same cardiovascular channel (e.g. systemic correlation based on the residual term from partitioning of covariance less than 0.80),
(5) No extreme anomalies of distribution.

The pool of available measures can be classified according to such criteria, and certain preferences for including or disregarding a particular measure can be made less arbitrary. Such criteria, of course, refer only to basic requirements, and the conclusions will, of course, also depend on reasoning derived from physiological knowledge and theory concerning the validity of a given parameter in depicting haemodynamic change, as well as the specific experimental hypothesis under study. The present multiparameter investigation was guided by such statistical and physiological considerations. It was specifically designed as a pilot study researching the psychophysiology of labile blood pressure regulation assessed both in the laboratory and by ambulatory monitoring (Heger, 1990). The basic aim of the study has been to define subgroups according to psychophysiological reactivity, haemodynamic and psychological pattern.

The original German report of the present investigation included an extensive review of the literature pertaining to issues in non-invasive cardiovascular measurement, a discussion on conventional definitions and further derivation of parameters with the intention of a rather exhaustive parametrization (Fahrenberg and Foerster, 1989). In this article, we provide a condensed account in order to make some of the more significant findings and conclusions available to the English-speaking audience. The presentation of results from this multiparameter study is restricted to those sections of the original report that refer to pulse wave velocity, systolic time intervals, selected parameters derived from the electrocardiogram and impedance cardiogram, and respiratory sinus arrhythmia. Furthermore, within-subject and between-subject correlations for a selection of relevant parameters are also presented and discussed.

Method

Subjects and design

Forty-two male students (none from psychology courses) were recruited by advertisement for the study. They ranged in age from 19 to 29 years, with a mean age of 24.6, and all reported being in good health. Subjects were paid for their participation.

A repeated measurement design was employed to assess baselines and task-induced changes in various cardiovascular functions. Partitioning of covariance between and within subjects contributed to empirical evaluation of cardiovascular measures and led to selection of certain parameters according to specified criteria.

Apparatus and procedures

The laboratory equipment used was a 16-channel polygraph (Hellige), an impedance cardiograph (Instrumentation for Medicine Inc. model 400), a rheograph (Siemens model 2226), an automatic blood pressure measurement device (Boucke Infraton Tensiomat FIB 4/6), and a Hewlett-Packard computer 1000/65.

The general procedure was similar to the course that was outlined in preceding publications (Fahrenberg, Foerster, Schneider, Müller and Myrtek, 1986; Fahrenberg, Schneider and Safian, 1987) so that a condensed account may suffice. Subjects were seated in a semi-reclining padded chair in a sound-dampened and air-conditioned room. After electrodes and transducers were positioned and checked, general instructions were given concerning the initial rest phase, and specific instructions were presented via tape recorder prior to each subsequent condition. The following conditions were employed: initial rest, mental arithmetic, breath-holding manoeuvre, preparing a free speech, Valsalva manoeuvre, handgrip exercise, cold pressor test, and final rest.

Initial and final rest, a mental task and a physical task were used to depict intra- and inter-individual variations. Both tasks are familiar to the cardiovascular laboratory:

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 dB (standard filter A) (duration, 330 sec).

Handgrip exercise. Subjects were asked to press a handgrip with their left hand exerting maximal pressure (duration, 120 sec).

Physiological recording

Multiple recordings of cardiovascular and respiratory functions were registered on 14 channels.

The electrocardiogram (ECG). This was recorded from standard lead II using Ag-AgCl electrodes (Hellige 217 110 02) and electrolyte (Hellige 217 083 01).

The impedance cardiogram (ICG). This was recorded with a conventional electrode arrangement by positioning Mylar band electrodes over the neck (first and second electrode at 3 cm distance) and thorax (third electrode over xiphoid process and fourth electrode 3 cm below). An alternating current of 100 KHz 4 mA was used.

The phonocardiogram (PCG). This was registered by a KHM electro-dynamic microphone (Diefenbach, Frankfurt) at the position of maximal magnitude of heart sounds determined for each individual by ausculation.

The ear densitogram. This was obtained by means of a Hewlett-Packard HP 780–16 transducer attached to the upper part of the right ear.

Carotid pulse. This was obtained by a Infraton transducer (Boucke, Tübingen) attached with a special bandage over the left carotis.

Upper and lower arm *Rheograms* (corresponding to brachialis and radialis pulse) were registered employing four Mylar band electrodes and electrolyte (Hellige 217 08301) analogously to the ICG, but using 30 KHz 1 mA alternating current to avoid interference. The first and second electrodes were attached at the proximal section of the right upper arm and the third and fourth electodes at the distal section of the lower arm nearest to the radialis pulse site, observing a minimal electrode distance of 3 cm.

The radialis pulse. This was obtained by means of an optoelectronic transducer (Klenk, München) of 16 mm diameter attached by adhesive collar over the right radialis artery.

The finger plethysmogram. This was obtained by employing a pneumatic system consisting of a plastic finger cylinder sealed by foam rubber material. A Boucke Infraton pressure transducer was used to convert air volume change to an electric signal. By injecting a 2 μl volume in this system and measuring the relevant volume of the finger tip, a semiquantitative calibration could be achieved.

Finger temperature. This was measured using a Platinum Pt 100 film thermoresistor (Hellige, Freiburg) attached at the third finger of the right hand.

Respiration. This was recorded using an air-bellows thorax belt, positioned a few cm below the fourth ICG electrode.

Blood pressure (SBP, DBPIV, DBPV). This was recorded intermittently by a non-invasive automatic procedure (Boucke Infraton Tensiomat) that provides Korotkov sounds on the first channel and cuff pressure signal on the second channel. Positioning of microphone and cuff were carefully checked, and calibration procedures were performed routinely using auscultatory measurements as criteria.

The extended, German language research report provides further specifications, for example, on preparation of the skin, characteristics of transducers and couplers, and filtering procedures (Fahrenberg and Foerster, 1989). Sampling rate was 4 ms, and after A/D conversion (12-bit precision), the data were stored on digital tape for off-line analysis.

A number of **anthropometric measures** were taken besides weight and height, e.g. distances from the jugulum to the position of pulse transducers, ICG electrode distances, and circumference and width of the thorax.

Parametrization

The last 90 sec segments (i.e. segments that exclude the initial heart rate acceleration effect) of each of the following four conditions were submitted to beat-to-beat analysis: Initial rest, mental arithmetic, handgrip exercise, and final rest. The last 100 sec segments were used for computing indices of respiratory sinus arrhythmia. Also included were blood pressure data (but not beat to beat).

The software systems BIO by Foerster and CARSPAN (van der Meulen and Mulder, 1987) were employed for parametrization of physiological recordings. BIO is an advanced system for interactive analysis of multiple recordings of cardiovascular and other biosignals in psychophysiological research. A full description is provided by Foerster in Fahrenberg and Foerster, (1989).

Subsequent data screening was performed by means of visual inspection and by employing software routines for outlier detection. This stage was important, since estimation of the percentage of missing data provided an essential criterion for the subsequent evaluation and selection of parameters.

In the course of beat-to-beat analysis for each cardiovascular measure, the corresponding phase of the respiratory cycle was recorded (i.e. inspiration, inspiratory pause, expiration, expiratory pause) so that a test of phasic respiratory effects upon other variables was made possible.

Parametrization resulted in a large number of primary measures and derived indices, since a rather exhaustive analysis was intended. Thus, for each cardiac cycle, about 200 parameters were obtained (e.g. 47 parameters from the ECG, 52 parameters from the ICG, and 30 measures from each pulse curve). Many of the derived measures (e.g. pulse-wave velocities, systolic time intervals, and indices of cardiac output) were computed employing two differ-

ent triggers (the Q- and the R-wave of the ECG or the zero-crossing point and the upstroke notch of the ICG dZ/dt signal as well).

The specific definitions and formulae cannot be given here, but such specifications are available together with the relevant statistical data in the extended report (Fahrenberg and Foerster, 1989).

Data analysis

In order to evaluate and select parameters, the aforementioned criteria were employed based on appropriate statistical analysis that included inspection of distributions, correlation coefficients, and two-factorial ANOVA (subjects $\times$ conditions). Furthermore partitioning of covariance was performed as previously described (see Fahrenberg and Foerster, 1982; Stemmler and Fahrenberg, 1989). Thus, between-subject correlation coefficients (pooled variances and covariances across conditions) and within-subject correlation coefficients (pooled across subjects) were obtained. The residual correlations are a mixture of subject $\times$ condition components as well as remaining systematic and unsystematic sources of covariance. If two variables are physiologically or physically closely related (nearly redundant), or technically or algebraically dependent, these correlations necessarily will be high (see above references for details). Thus, the residual source of covariation is employed as an index of *systemic* relationships between variables. Parameter studies seek to identify such redundant variables in order to find substitutes for those difficult to measure and in order to specify rather unique parameters.

The initial and final rest phases were employed to estimate coefficients of stability over a time interval of about 30 min.

Results

Pulse-wave velocity (PWV)

Various measures of PWV are depicted in Table 1. Obviously, as reflected by the generally modest correlation coefficients, one cannot speak of a single PWV measure, but a number of relevant and related measures. PWV (and pulse-transit time, PTT, likewise) greatly depends on the peripheral pulse that is employed and depends on the reference points used to define (1) the central trigger for the cardiac cycle, and (2) the arrival of the pulse wave at the periphery. Systematic comparisons of two trigger points (Q- and R-wave of the ECG) and various reference points (nadir, upstroke at 10%, 20% and 25% of amplitude, deflection point and peak of pulse curve) suggest that the ECG-R-wave and the 20% upstroke point are generally more reliable with respect to effective discrimination and stability coefficients than other points (at least using our parametrization procedures).

In the present investigation, PWV is computed for the distance between jugulum and pulse transducer. This bias should be acknowledged here regarding between-subjects comparison of average PWV for a proximal pulse (e.g. the carotid pulse (0.9 ms), and a distal pulse (e.g. the radialis pulse (3.4 ms)).

The systemic correlations is highest for both measures referring to radialis site (i.e. for radialis rheogram and conventional radialis pulse, and for carotid pulse and brachialis rheogram). PWV measures derived from the two rheograms, both referring to a rather homogeneous section of the arterial system, only moderately correlate with each other. This could be due to a possible lack of precision of measurement since the distance between the respective electrodes was so short. The PWV based on the ear densitogram and finger plethysmogram, although related between subjects, appear to be rather independent of other measures in systemic correlations. Since stability coefficients are comparatively low for both measures, they should be regarded tentatively. Relative ease of measurement and stability coefficients suggest that Radialis PWV may be preferable.

Pre-ejection Period (PEP)

Measures of pre-ejection period vary substantially according to reference points that are chosen. The mean PEP during rest is 54 ms for parameter R1, 68 ms for R2, 36 ms for R5, 72 ms for R6 and 25 ms for R7 (see Table 2 for definitions). Since the ECG-R wave is employed as trigger for all PEP-measures, an additional period of about 45 ms should be consisdered for duration of Q-R when comparing these PEP measures to those of other

Table 1 Measures of pulse-wave velocity (PWV) employing ECG R-wave trigger and 20% amplitude reference point. Coefficients of correlation between subjects above diagonal; systemic relationship below diagonal; and coefficients of stability on diagonal.

	1	2	3	4	5	6
(1) Carotid PWV	(0.90)	0.52	0.47	0.64	0.65	0.41
(2) Ear PWV	0.26	(0.54)	0.25	0.50	0.46	0.38
(3) Brachialis PWV (Rheogram)	0.72	0.19	(0.84)	0.72	0.59	0.58
(4) Radialis PWV (Rheogram)	0.47	0.16	0.48	(0.91)	0.86	0.60
(5) Radialis PWV	0.38	0.13	0.37	0.88	(0.86)	0.44
(6) Finger PWV	0.24	0.07	0.29	0.23	0.22	(0.68)

n between 38 and 42 due to missing data. Within subjects df $\geq$ 38.0, r $\geq$ 0.31, p $\leq$ 0.05; r $\geq$ 0.40, p $\geq$ 0.01; between subjects df $\geq$ 36.0

Table 2 Measures of pre-ejection period (PEP) employing ECG R-wave as well as Q-wave as trigger and various reference points. Correlation coefficients arranged in accordance with Table 1.

	1	2	3	4	5	QR
(1) PEP R1	(0.57)	−0.01	0.59	0.53	0.48	0.91
(2) PEP R2	0.07	(0.85)	−0.06	0.16	0.51	0.93
(3) PEP R5	0.46	0.11	(0.75)	0.30	0.44	0.88
(4) PEP R6	0.22	0.28	0.38	(0.92)	0.48	0.97
(5) PEP R7	0.20	0.44	0.27	0.57	(0.81)	0.53
QR	0.91	0.95	0.80	0.97	0.74	

PEP R1 employs the duration R-wave to begin (33% of maximum amplitude) of heart sound S2 subtracting LVET (defined to be the duration nadir to incisure of carotid pulse curve); PEP R2 employs the midpoint of heart sound S2; PEP R5 employs the nadir of the ear densitogram subtracting the duration from S2 to the incisure of the ear densitogram; PEP R6 employs the zero-crossing; and PEP R7 the upstroke notch of the ICG E-wave.
The QR column and row refer to the correlation between measures that employ the ECG R- or Q-wave, respectively.

Table 3 Measures of left ventricular ejection time (LVET). Correlation coefficients arranged in accordance with Table 1.

	1	2	3	4	5
(1) LVET 1 ICG	(0.89)	0.62	0.57	0.64	0.46
(2) LVET 2 ICG	0.67	(0.93)	0.86	0.73	0.47
(3) LVET 3 PCG	0.49	0.79	(0.82)	0.67	0.59
(4) LVET 4 CAR	0.30	0.38	0.28	(0.84)	0.64
(5) LVET 5 EAR	0.47	0.36	0.27	0.17	(0.93)

LVET1 employs zero-crossing of the dZ/dt signal and the X-wave minimum of the ICG; LVET2 employs the upstroke notch instead of zero-crossing; LVET3 employs heart sounds S1 (upstroke 20% amplitude) and S2 (upstroke 20% amplitude) of the PCG; LVET4 employs nadir and incisure of the carotid pulse; and LVET5 employs nadir and dicrotic inflection of the ear densitogram, d/DENT.

investigations. Additionally, Table 2 indicates that the choice of trigger (Q vs. R) is less relevant for parameters R1, R2, and R6 than for other measures, e.g. the R7 measure where R7 (Q) and R7 (R) correlate only 0.53. ECG-R, of course, would be the more reliable trigger.

Our findings also suggest that systemic relationships and between-subjects correlation coefficients between the various PEP indices are rather low. Relative ease of measurement and stability coefficients suggest that PEP which is derived from the ICG may be preferable. Nevertheless, it should be noted that even the two ICG estimates were not highly correlated with each other systemically or between subjects.

Left-ventricular ejection time (LVET)

Again, our results in Table 3 show that there are several possible parameters of LVET, many that are only loosely related to each other. Mean LVET during rest, for example is 293 ms based on the carotid pulse curve and 348 ms based on the ICG (employing the upstroke notch). Interestingly the latter LVET duration corresponds well with LVET derived from the phonocardiogram if the heart sound S2 midpoint is taken (352 ms) instead of the 20% upstroke reference point (325 ms) originally employed. LVET's based on carotid and ear pulse curves are rather stable measures in our analyses. Systemic relationships, however, are highest for measures from ICG and PCG.

Electrocardiogram

Table 4 shows that high stability coefficients and mostly low systemic relationships were characteristic for a selection of ECG parameters. Nevertheless, two obvious exceptions are (1) the relationship between interbeat-interval (RR) and T-wave amplitude (TWA), and (2) the association between duration of the electrical systole of the ventricle (QT) and TWA. Such relationships between ECG parameters, especially among amplitudes and among duration measures, indicate possible confounding of measures that may be relevant for within- and between-subjects designs.

Impedance cardiogram

Table 5 presents parameters selected from a larger set of ICG parameters. The stability coefficients are high, although amplitude measures appear to be slightly better than duration measures, i.e. PEP, LVET and R-Z. Furthermore, relevant discrepancies exist among parameters presumed to measure the same phenomenon, dependent upon whether the zero crossing or the upstroke notch of the dZ/dt signal is employed. Relative precision of measurement suggested the use of the zero crossing as the reference point in the present study for several reasons (see Fahrenberg and Foerster, 1989). Nonetheless the upstroke notch was actually preferred in an subsequent investigation, after we refined measurement (allowing for occurrence of the notch in the advanced upstroke) and modified corresponding decision rules for the interactive phase in parametrization. Additionally, employment of the latter quantification is in accordance with recent ICG guidelines (Sherwood, Allen, Fahrenberg, Kelsey, Lovallo and van Doornen, 1990).

Both magnitudes of the Heather Index (putatively indicating left-heart contractility) and the stroke volume indices differ according to the reference points chosen in parametrization of the component measures.

Anthropometric correlations with these ICG measures additionally indicate that relationships between body weight, height, and thorax measures on the one hand and LVET or stroke volume index on the other, are negligible when the upstroke notch is employed as reference point. Nevertheless, frontal electrode distance correlates 0.40 with SV index (notch) and 0.36 with CO index (notch).

Respiratory sinus arrhythmia (RSA)

Table 6 shows that systemic relationships exist between the various measures of RSA. It should be noted when evaluating these coefficients, that parametrization is based on rather short 100-sec segments and has not been logarithmically transformed to improve distribution characteristics. It is also notworthy that each of the three RSA indices correlates significantly between subjects and systemically with the simple mean square of successive differences of inter-beat intervals. On the other hand, significant systemic relationships between RSA parameters and heart rate or respiratory measures do not exist, although such correlations are evident from the between-subjects perspective. The respiratory activity index, essentially a measure of respiratory amplitude, was obtained from the pneumogram and was not calibrated in order to estimate tidal volume.

Other cardiovascular parameters

The present parameter study started from a pool of parameters that was much larger than presented in this report. Especially the pulse waves and the impedance cardiogram yielded many measures of amplitudes and durations of signal components. Many of these parameters, however, did not meet the formal requirements as defined in the introduction. The high frequency of missing data, reduced coefficients

Table 4 Selected parameters from the ECG. Correlation coefficients arranged in accordance with Table 1.

	1	2	3	4	5	6	7
(1) Duration RR	(0.91)	0.33	0.70	0.10	−0.14	0.14	0.22
(2) Duration PQ	0.12	(0.93)	0.10	0.11	0.12	0.20	0.26
(3) Duration QT	0.13	0.09	(0.97)	0.15	−0.04	0.10	0.04
(4) Amplitude P	−0.33	0.03	0.08	(0.96)	0.14	0.71	0.14
(5) Amplitude R	0.27	−0.09	0.05	−0.08	(0.99)	0.20	0.28
(6) Amplitude ST	0.11	−0.05	0.17	−0.04	0.17	(0.95)	0.58
(7) Amplitude T	0.57	0.05	−0.51	−0.24	0.20	0.11	(0.94)

PQ is defined from beginning of P-wave to beginning Q-wave; QT is defined from start of Q-wave to end of T-wave; and ST-amplitude is measured at isoelectric J-Point + 80 ms.

Table 5 Selected parameters from the ICG. Correlation coefficients arranged in accordance with Table 1.

	1	2	3	4	5	6	7	8	9	10
(1) Amplitude E	(0.92)	−0.43	−0.29	−0.31	−0.02	−0.19	−0.35	0.86	0.26	0.33
(2) Amplitude X	−0.53	(0.96)	0.25	0.43	−0.19	0.28	0.29	−0.44	0.03	0.07
(3) LVET 1	0.04	0.22	(0.89)	0.62	0.51	−0.04	−0.05	−0.28	0.40	0.14
(4) LVET 2	−0.20	0.65	0.67	(0.93)	0.36	0.32	0.49	−0.42	0.19	0.22
(5) PEP 1	−0.32	0.61	−0.19	0.55	(0.92)	0.48	0.64	−0.18	−0.26	0.07
(6) PEP 2	−0.31	0.56	0.32	0.61	0.56	(0.81)	0.51	−0.32	0.11	0.26
(7) R-Z	−0.42	0.61	0.29	0.74	0.69	0.72	(0.83)	−0.69	−0.29	−0.22
(8) Heather index 2	0.79	−0.62	0.22	−0.53	−0.46	−0.48	−0.76	(0.82)	0.25	0.36
(9) Stroke volume index 1	0.76	−0.30	0.44	0.09	−0.36	−0.17	−0.23	0.47	(0.93)	0.90
(10) Stroke volume index 2	0.60	0.01	0.34	0.34	0.08	0.23	0.05	0.39	0.74	(0.93)

Left ventricular ejection time, LVET; and pre-ejection period, PEP. Stroke volume index (1) employs zero-crossing and (2) employs upstroke notch of the dZ/dt signal.

Table 6 Measures of respiratory sinus arrhythmia RSA. Correlation coefficients arranged in accordance with Table 1.

	1	2	3	4	5	6	7
(1) RSA MAMP	(0.83)	0.90	0.84	0.91	0.47	−0.17	0.19
(2) Absolute power, band 0.13–0.42 Hz	0.78	(0.89)	0.95	0.81	0.51	−0.20	0.24
(3) Absolute power, resp. freq. ± 0.02 Hz	0.62	0.82	(0.86)	0.77	0.43	−0.34	0.24
(4) Interbeat interval MQSD	0.73	0.58	0.37	(0.81)	0.23	−0.04	0.17
(5) Interbeat interval	0.07	0.10	0.10	−0.14	(0.91)	−0.06	0.10
(6) Respiratory frequency	−0.36	−0.15	−0.14	−0.19	−0.01	(0.75)	−0.26
(7) Respiratory activity index	0.02	0.06	0.01	0.16	−0.26	−0.37	(0.81)

RSA MAMP is measured by simple peak-valley method. Total power is derived from CARSPAN spectral analysis referring either to the 0.13–0.42 band suggested by Porges or based on peak respiratory frequencies of individual subjects ± 0.02 Hz. MQSD is the mean square of successive differences in inter-beat intervals.
A uncalibrated respiratory activity index equivalent to respiratory amplitude, is derived from the pneumogram.

of stability and low discriminatory efficiency with respect to subjects and conditions were the main reasons. Probably some of these parameters could be more reliably measured than in this study by developing more precise algorithms and by employing signal averaging techniques.

A number of parameters should be mentioned that are presently rather unfamiliar to psychophysiological investigators but nevertheless manifested sufficient reliability in our beat-to-beat analyses. Noteworthy among these are ICG parameters, such as duration of the A-wave, amplitude and peak-to-zero crossing time of the X-wave and ejection speed. Also rise time and peak amplitude in

peripheral ear and radialis pulses provided promising candidates.

Effect of respiratory phases

Given the controversy concerning whether only specific respiratory phases should be used when evaluating ICG measures (e.g. Doerr, Miles and Frey, 1981), a three-factorial ANOVA (subjects, conditions, and respiratory phases) generally revealed only small effects of respiratory phase and interaction of respiratory phase × subject on most cardiovascular parameters. In several instances it took the effects of the four conditions combined to reach a significance level $p \leq 0.05$. Noteworthy exceptions were E-wave amplitude and LVET (zero crossing) derived from the ICG, which exhibited, respectively, 34% and 9% of total variance due to respiratory phases compared to 4% in heart rate. However, the respiratory effect was in opposite direction for E-wave amplitude and LVET, thus probably compensating for each other so that stroke volume index and cardiac output were only slightly affected.

From these findings it seems appropriate to obtain such measures from continuous recordings instead of specific respiratory phases, e.g. expiratory pause. Furthermore, PEP and LVET are less affected by respiratory phase when employing the upstoke notch, rather than the zero crossing, as reference point.

Multi-parameter covariation

For the final correlational analyses, 16 cardiovascular parameters (see Table 7) were selected from the much larger pool according to previously specified criteria. However, a basic prerequisite of such investigations should be also examined, namely, that a sufficient amount of variance between conditions of the experiment is obtained.

Table 8 presents findings which indicate that mental arithmetic caused a moderate but consistent change in cardiovascular functions. The respective Scheffé-Tests are all significant $p \leq 0.05$, except for the stroke volume index. Although not presented in the table in order to save space, the handgrip task also led to obvious cardiovascular changes. Nevertheless, across conditions, the cardiovascular parameters differ in discriminatory power: according to percentage of variance that can be attributed to condition effect, heart rate ranks first, followed by PWV's, PEP, QT-time and RSA.

Correlation coefficients between and within subjects are presented in Table 9. However, only a few relationships (especially the obvious patterns of covariation within subjects) will be pointed out here.

Between-subjects correlations

Significant relationships ($p \leq 0.01$) exist between heart rate, QT time, LVET and PEP. Higher heart rate and shorter LVET are furthermore associated with smaller RSA. PEP and both measures of PWV are negatively correlated, whereas systolic blood pressure is positively correlated with PWV. On the other hand, higher diastolic blood pressure is related to smaller stroke volume index.

To point out how the relationship between different cardiovascular variables can be statistically dependent on variations in heart rate, we computed various partial correlations adjusting for heart rate (Fahrenberg and Foerster, 1989). Some of the formerly significant coefficients are now insignificant, e.g. QT and LVET, DBP and PWV radialis, and stroke volume index and RSA. However, other coefficients now reach the level of significance, e.g. QT and PWV radialis, PEP and stroke volume index, and PEP and RSA.

From inspection of between-subjects correlations, several aspects of components of beta-adrenergic (sympathetic) cardiovascular functioning are obvious but provide no evidence for a consistent inter-individual trait pattern comprising the essential indicants as has been formerly suggested in concepts like sympatheticotonia or general cardiovascular reactivity.

Within subjects correlations

Patterns of intraindividual change appear to be particularly relevant for haemodynamic approaches to cardiovascular psychophysiology. In this regard, the numerous highly significant relationships between heart rate and other cardiovascular parameters are particularly noteworthy within subjects (across four conditions and pooled within subjects). These are substantial correlations in most instances, not only regarding duration measures but also with respect to amplitude parameters from the ECG, PCG and ICG.

Among the systolic time intervals, PEP

Table 7 Selected cardiovascular parameters, abbreviations, units of measurement, and number of subjects with valid data.

Parameter	No. of Variable in Table	Abbreviation	Dimension	n
(1) Heart rate	—	HR	bpm	42
(2) ECG QT time	3/4	ECG QT	ms	41
(3) Pre-ejection period	4/2	PEP	ms	39
(4) Left ventricular ejection time	1/3	LVET	ms	40
(5) ECG P-wave amplitude	4/4	ECG P	per cent	41
(6) ECG T-wave amplitude	7/4	ECG T	per cent	41
(7) PCG heart sound S1 amplitude	—	PCG S1	units	41
(8) ICG X-wave amplitude	2/5	ICG X	0.1 Ω/s	40
(9) Stroke volume index	9/5	SV index	units(ml)	39
(10) Cardiac output index	—	CO index	units (1/min/m²)	39
(11) Systolic blood pressure	—	SBP	mmHg	38
(12) Diastolic blood pressure	—	DBP	mmHg	38
(13) Total peripheral resistance index	—	TPR index	units (mm Hg/1×min)	37
(14) Pulse-wave velocity carotid pulse	1/1	PWV CAR	m/s	41
(15) Pulse-wave velocity radialis pulse	5/1	PWV RAD	m/s	40
(16) Respiratory sinus arrhythmia	3/6	RSA	1/1000 ms²	42

PEP, LVET, SV and CO are based on zero-crossing reference point of the ICG. P-wave and T-wave amplitude are standardized on R-wave amplitude of the ECG.

Table 8 Selected cardiovascular parameters: basic statistics from two experimental conditions (rest and mental arithmetic), coefficients of stability (initial to final rest) and percentages of total ANOVA variance (four conditions).

	Mean		SD		Stability	Percentages of Total Variance		
Parameter	Rest	Mental arith.	Rest	Mental arith.		Subjects	Conditions	Residiuum/ Error
(1) HR	63.9	74.4	8.0	10.3	0.92	42	36	22
(2) ECG QT	381.9	363.2	22.6	51.2	0.97	25	12	63
(3) PEP	72.6	59.6	16.0	15.2	0.92	66	14	20
(4) LVET	301.2	296.6	20.9	19.8	0.89	74	5	21
(5) ECG P	10.0	12.3	5.9	6.7	0.96	82	8	10
(6) ECG T	37.8	36.2	12.8	17.1	0.95	70	7	23
(7) PCG S1	19.9	26.8	10.9	16.9	0.80	70	8	22
(8) ICG X	−755.1	−857.3	188.3	231.0	0.96	80	8	12
(9) SV index	114.8	115.5	24.2	25.1	0.93	87	0	13
(10) CO index	7.2	8.5	1.4	2.1	0.86	67	15	18
(11) SBP	115.8	128.2	10.7	14.6	0.65	49	18	33
(12) DBP	66.9	72.5	14.2	11.9	0.73	66	3	31
(13) TPR index	939.6	882.2	260.9	205.1	0.78	79	6	15
(14) PWV CAR	0.9	1.0	0.1	0.2	0.90	52	21	27
(15) PWV RAD	3.4	3.8	0.4	0.5	0.86	48	15	37
(16) RSA	1046.3	332.8	1245.3	371.0	0.86	59	12	29

Scheffé-Tests indicate that with the exception of SV index, all differences from rest to mental arithmetic are significant, $p \leq 0.05$.

exhibits more common variance with heart rate and other cardiovascular parameters than does LVET. For example, PEP decreases with increases in cardiac output index, P-wave amplitude and heart sound amplitude. PEP is also inversely related to pulse wave velocity; however, this effect, can, to a large extent, be traced to common variance with heart rate (for matrices with heart rate partialled out statistically, see Fahrenberg and Foerster, 1989). Additionally, PEP and T-wave amplitude from the ECG are positively correlated.

Table 9 Correlation coefficients between subjects (above diagonal) and within subjects (below diagonal).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(1) HR	—	−68	−32	−43	00	−21	30	−56	−28	22	20	19	06	21	36	−41
(2) ECG QT	−37	—	10	40	01	−02	−01	35	23	−07	02	01	−01	00	−04	25
(3) PEP	−73	33	—	−51	−02	15	−26	19	−26	−33	−20	05	34	−41	−36	−21
(4) LVET	−58	19	11	—	−05	01	−01	25	40	09	−17	−29	−40	00	−23	43
(5) ECG P	62	−23	−51	−38	—	31	08	32	18	16	28	−12	−15	18	08	−13
(6) ECG T	−47	−46	39	26	−24	—	−04	01	17	12	−12	−17	−15	−16	−31	23
(7) PCG S1	64	−24	−56	−36	46	−30	—	−12	15	39	24	19	−13	60	40	−03
(8) ICG X	−79	32	74	43	−45	37	−62	—	03	−32	−04	−09	07	−02	−26	20
(9) SV index	−11	03	−24	36	−13	09	07	−22	—	81	03	−40	−74	21	08	35
(10) CO index	77	−32	−81	−37	48	−34	58	−84	44	—	11	−25	−68	33	31	06
(11) SBP	40	09	−39	−11	35	−45	27	−30	00	33	—	45	26	38	40	−03
(12) DBP	16	−18	−24	02	12	−03	12	−09	04	20	20	—	74	26	31	−09
(13) TPR index	−34	20	40	20	−23	10	−27	44	−41	−52	−02	29	—	−10	05	−23
(14) PWV CAR	79	−29	−72	−34	54	−41	65	−66	08	72	43	21	−30	—	65	−03
(15) PWV RAD	62	−24	−56	−25	43	−37	55	−49	−02	52	36	17	−17	61	—	−34
(16) RSA	−43	27	33	20	−29	08	−26	23	04	−32	−23	−21	09	−38	−35	—

For df = 38, $r \geq 0.31$, $p \leq 0.05$; $r \geq 0.40$, $p \leq 0.01$.

Turning to other relations, P-wave amplitude is positively associated with heart sound amplitude, cardiac output index and pulse-wave velocity, and negatively with PEP, LVET and ICG-X wave. T-wave amplitude is inversely related to duration of QT, systolic blood pressure, pulse-wave velocity and CO index, and positively related to PEP and ICG-X wave amplitude. Changes in stroke volume correlate significantly with LVET, CO and TPR. Although blood pressure measures displayed only weak associations generally, systolic blood pressure was positively associated with pulse-wave velocity. Several other significant coefficients are also evident in Table 9 but are not discussed here.

It should be mentioned that the majority of intraindividual relationships were still apparent after partialling out heart rate (exceptions being correlations with PWV measures). Statistically adjusting for heart rate serves to increase within-subject correlation coefficients in certain instances, especially the relationship between PEP and LVET, from 0.11 to −0.57 (although between subjects the coefficient decreases from −0.51 to −0.75) and between PEP and stroke volume, from −0.24 to −0.47.

A few noteworthy findings should be described that could not be included in the tables. First, certain ECG parameters like PQ duration and amplitude at J-point +80 ms (an estimate of the amplitude of the ST segment) manifested a relative independence from other cardiovascular measures. Secondly, a few significant within-subject correlations were obtained for amplitude of the finger pulse, it being positively associated with finger temperature 0.38, and negatively related to diastolic blood pressure −0.32.

Discussion

Our findings indicate that parameter selection in multiple cardiovascular assessments must be carefully evaluated. A rational-empirical approach seems to be more appropriate than following either certain laboratory traditions, ad hoc decisions or rules of thumb in selecting or disregarding available parameters. Our own choice of strategies and criteria of evaluation in this study certainly may be questioned by others. Nevertheless, such attempts at clarification and standardization of methodology appear to be important and should inevitably contribute to progress in the area.

The present multiparameter study surpasses recent investigations with respect to the broad spectrum of parameters used but still is rather limited concerning task conditions and length of segments that could be submitted to such time-consuming parametrization. However, such limitations do not basically prevent specific conclusions from being made. Basic cardiovascular parameters like pulse-wave velocity, systolic time intervals PEP and LVET, indices for stroke volume and cardiac output derived from the impedance cardiogram, can be defined in several ways concerning the choice of the reference signal and the reference points. Such parametrizations will differ in absolute value and in reliability, and the common variance of these measures generally is not sufficient to allow their being interchanged. Cross-laboratory comparison and replication of certain findings obviously could be adversely affected by such discrepancies in parametrization.

Results from the present study illustrate just to what extent different parametrizations may be at variance (see Tables 1–5). For example, PWV, PEP and LVET are each not single specific measures, but rather families of measures: interpretation of such parameters may be misleading when relevant isues regarding definition are not adequately taken into account. Hopefully such findings as ours will lead to more concern about standardization, as suggested by recent guidelines (e.g. Sherwood *et al.*, 1989; Fridlund and Cacioppo, 1986).

Findings from the present study also contribute to other issues with respect to standardization of measurement. Respiratory phases significantly affect LVET, amplitude measures as well as cardiac output indices derived from the ICG. However, LVET and E-amplitude are inversely affected so that the over-all changes are rather small. Continuous recording and measurement, therefore, appear justifiable, at least with levels of activation that are common within the psychophysiological laboratory. Electrode distances in ICG recordings, however, should be noted and controlled if a between-subject comparison of stroke volume index (ICG) and cardiac output index (ICG) (currently still with dubious validity) is intended.

Another potentially important issue here is how to deal with the general dominance of heart rate in influencing intra- and inter-individual patterns of covariation between other cardiovascular parameters. Statistical compensation by partialling out heart rate cannot resolve this problem, and may in fact introduce distortions and sources of bias: partialling out such relationships would be a statistical approach to a basically physiological issue because heart rate and other cardiac measures (e.g., specific left ventricular function parameters) are inherently related by principles of cardiodynamics. Instead of employing indices 'corrected for heart rate', it may be preferable to make a thorough analysis of whether a particular parameter will add incremental predictive validity. This could be achieved by a multiple regression approach referring to relevant criteria. Of course, a subsequent state would be to determine what such incremental prediction may mean physiologically.

Evaluation within our study of the large pool of parameters according to a specified set of formal requirements led to selection of a number of basic parameters. The covariation of the resulting parameters that depict cardiovascular change under stimulation by typical laboratory tasks may also be of particular interest for understanding autonomic mechanisms.

Parameters of left ventricular function, i.e. PEP, LVET, stroke volume index and PWV's covary modestly to moderately, the magnitude of the within-subject correlations depending more or less on mutual covariation with heart rate. Interestingly, PEP and cardiac output index are significantly related within subjects to ECG P-wave and T-wave amplitudes and ICG X-wave amplitude, as well as to heart sound amplitude. Thus a rather broad pattern, although of moderate consistency, emerges that may be attributed to beta-adrenergic influences on the heart, and especially on the left ventricle.

T-wave amplitude TWA, a presumed index of myocardial activity, intraindividually covaries moderately with duration of the electrical systole of the ventricle (QT time), systolic blood pressure and PWV's. These findings contribute data to the discussion of PEP and TWA as valid non-invasive measures of left ventricular performance.

A clear alpha-adrenergic pattern did not emerge here. Such a pattern was supposed, but was not apparent, for parameters of peripheral circulation, i.e. finger plethysmogram, finger temperature, diastolic blood pressure, and total peripheral resistance index. Nevertheless, it should be noted that the selection of tasks in terms of the range of variation of these measures here did not facilitate the observation of such pattern. The RSA changed significantly in response to mental arithmetic;

however, a broader vagal pattern could not be discerned. The reason that a definite pattern of vagal influences on the heart did not appear in the present study can be sought, too, in the selection of tasks and in the lack of further indicants of vagal activity besides RSA.

A parameter study of this kind obviously may also serve heuristic purposes, since measures previously rather unfamiliar to most investigators may have a chance to emerge as comparatively reliable and valid parameters of cardiovascular change. In this regard, the present study directs attention especially to X-wave amplitude derived from the ICG, amplitude of the first heart sound, P-wave amplitude derived from the ECG and other parameters not explicitly referred to in this article, e.g. rise time of ear pulse and ejection speed derived from the ICG (see Fahrenberg and Foerster, 1989).

Our study initially was designed to comprise a broader range of tasks than thus far analysed. The general intention was, besides evaluating a broad spectrum of cardiovascular measures, to conduct a multitrait-multimethod study with respect to alpha-adrenergic, beta-adrenergic and cholinergic (vagal) components of activation. It would be interesting in the future to investigate convergent and discriminant validities of the selected parameters that are supposed to represent such systemic influences rather purely. Highly specific marker variables, of course, cannot be expected in such assessment because of the basic synergisms in cardiodynamics and haemodynamics which must be acknowledged. Nevertheless, we have recently conducted another experiment (Fahrenberg, Foerster and Ewert, 1990), based on the results presented here, and containing additional tasks and other physiological functions, (e.g. electrodermal activity, and electromyogram recordings) that could be used in the context of such general research questions employing a multitrait-multimethod rationale.

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A test of preparedness theory in anxiety-disordered patients using an avoidance paradigm

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ABSTRACT In a test of the preparedness theory of phobias, we exposed obsessive-compulsives, agoraphobics, simple phobics, and normal controls to fear-relevant (e.g. pictorial snake) and fear-irrelevant (e.g. pictorial flower) slides that were sometimes followed by shock. If subjects pressed a button, however, the slide was removed and shock was prevented. Subjects were encouraged to delay avoidance responding as long as possible. Consistent with preparedness theory, fear-relevant slides prompted faster avoidance responses than fear-irrelevant slides during the acquisition phase when shocks could occur. Moreover, fear-relevant slides evoked larger SCRs than fear-irrelevant slides during extinction when shocks no longer occurred. Diagnostic status, however, did not influence either avoidance responding or electrodermal responding to fear-relevant or fear-irrelevant slides.

The preparedness theory of phobias holds that people are biologically prepared to acquire persistent fears of stimuli that have threatened the human species throughout its evolutionary history (Seligman, 1971). Most tests of this theory have involved comparisons between skin conductance responses (SCRs) conditioned to slides of fear-relevant (e.g. pictorial snakes) and fear-irrelevant (e.g. pictorial flowers) stimuli within a Pavlovian aversive conditioning paradigm (for a review, see McNally, 1987). Although the theory implies that fear-relevant stimuli should also be potent cues for instrumental avoidance behavior, no published study has addressed this issue. In the present experiment, we examined whether fear-relevant stimuli prompt more avoidance than do fear-irrelevant stimuli.

Anxiety-disordered patients characterized by chronic arousal and pervasive avoidance might be especially susceptible to developing persistent avoidance responses and persistent SCRs to fear-relevant stimuli. Indeed, Pitman and Orr (1986) reported that anxious patients exhibited greater electrodermal resistance to extinction to fear-relevant stimuli than did normals. In the present study, we compared electrodermal and shock-avoidance responding to fear-relevant and fear-irrelevant stimuli in obsessive-compulsives, agoraphobics, simple phobics, and normal controls.

We hypothesized that fear-relevant stimuli would be associated with larger SCRs and more robust avoidance than would fear-irrelevant stimuli. Because chronic arousal characterizes agoraphobics (e.g. Ehlers, Margraf and Roth, 1988) and obsessive-compulsives (e.g. Kelly, 1980), as does pervasive avoidance, we further hypothesized that these patients would exhibit larger SCRs and more avoidance to fear-relevant stimuli than would simple phobics and normal controls.

Finally, we investigated the effects of threat imminence by presenting slides for either 5 or 10 secs. Thus threat (i.e. shock onset) was more imminent in one condition (i.e. 5 sec) than in the other (i.e. 10 sec). Also, by varying slide duration we tried to prevent subjects from responding merely on the basis of duration *per se*, as in Sidman (1953) avoidance. Thus, for example, if duration were not varied, subjects might simply count to four (for a 5 sec slide) before responding, irrespective of stimulus content.