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COVARIATION AND CONSISTENCY OF ACTIVATION PARAMETERS

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Individual differences in activation processes, as well as the consistency and predictability of these differences, constitute a classical issue eliciting much theoretical discussion in this field and as such poses an essential question for any practical application of psychophysiological methods. A typical activation experiment assessing 125 male students on four self-report and 21 physiological measures under five conditions (rest, mental arithmetic, interview, anticipation and blood taking) was performed supplying an empirical basis for a multivariate analysis. A partition of covariance, factor analyses, item analyses and scale construction procedures as well as models engaging an increasing number of components were used to study the covariation and consistency of these activation parameters. Several biometric problems that are generally thought to complicate the evaluation of such data (i.e. non-linear relations, the problem of initial values, differing sensibility curves of physiological response systems, individual response specificities) are considered and tested empirically.

Findings suggest that the use of a single variable or a composite measure as an 'indicator' of individual differences in state or reaction aspects of activation is inadequate, due to empirical inconsistency and the lack of predictability between functional subsystems. A multicomponent model or a set of marker variables, having empirically derived discriminative efficiency as well as reliability estimates, seem to be preferable.

1. Introduction

The covariation of activation parameters is one of the classical issues in psychophysiology and as such has been the subject matter of several studies and critical reviews (Duffy, 1972; Wenger and Cullen, 1972; Lader, 1975; Haynes and Wilson, 1979; Myrtek, 1980; Fahrenberg, 1982). Although there is a broad agreement as to the generally low common variance in psychophysiological measures, the consequences regarding methodology and applied psychophysiology seem to be less clear. While there is little support for an unidimensional continuum of activation this theoretical construct continues to

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be viable and is widely used in present day psychophysiology. Many contributors refer explicitly, or at least implicitly, to such concepts like activation or arousal and many experimenters tend to suggest that, for instance, a single parameter of electrodermal activity or of heart rate change is not of interest *per se* but could be viewed as an indicator of such theoretical constructs. In univariate experimentation analysis of variance designs have been primarily applied focusing on main effects, thus avoiding the basic problem of covariation and consistency of activation parameters. Such problems are, however, unavoidable as soon as individual differences are correlated or predicted in practical application of psychophysiological methods, particularly when a multimodal assessment of complex treatment effects is undertaken.

Concerning the covariation problem, a large number of studies have been conducted, most of them, however, applying small-scale analyses with very limited samples of subjects and variables. Moreover in this field there has been a neglect in the use of those concepts and multivariate procedures that are familiar in differential psychology and that have proved useful in the construction of psychological tests (i.e. concepts of item analysis, internal consistency, partition of covariance in a four-modal data box – subjects, variables, conditions, replications of particular conditions – and factor analysis) to obtain communality estimates and dimensionality of complex data sets.

The present multivariate study is designed: (1) to provide a sufficient empirical basis as to the covariation and consistency of activation parameters; and (2) to assess the appropriateness of an unidimensional as compared to a multicomponent model of activation processes.

2. Methods

2.1. Procedure

The empirical data are taken from a typical activation experiment considering a broad spectrum of dependent variables under various stimulus conditions. The present experiment has been designed to determine whether individual differences in activation state and activation reaction can be reliably predicted from five dispositional variables. Since this investigation has been reported elsewhere (Fahrenberg, Walschburger, Foerster, Myrtek and Müller, 1979, 1982) an abbreviated summary of the procedures may suffice. Male student volunteer subjects ($N = 125$) took part in a study comprising: (1) personality assessment by paper and pencil tests; (2) cardiovascular assessment; and (3) a typical activation experiment, subjects being randomly assigned to two different instruction sets. Self-report data and physioligical recordings were obtained for each of the following conditions which were presented in identical order to obtain comparable results:

Rest phase 1 (recording 120 sec).
Mental arithmetic 1 (recording 120 sec).
Interview (four recordings of 30 sec each before subject spoke).
Mental arithmetic 2 (recording 120 sec, replication of the task using a parallel form).
Anticipation of blood sample taking (recording 60 sec).
Blood taking (recording 60 sec).
Rest phase 2 (recording 120 sec).

Self-ratings of the subject's state in Rest phase 1 were obtained at the end of that phase by six Likert-type scales: 'alert', 'tense', perceived 'heart rate', perceived 'muscular tension', 'irritated', subjective evaluation of the experiment itself as to whether it was 'meaningful' or not. After each preceding phase the subjects were asked to estimate their state change with Rest phase 1 as a reference point, using a 21 step verbally anchored graphic rating scale (0 = being unchanged, ±10 being the highest possible increase or decrease respectively).

Polygraph recordings were obtained in 10 channels: electrocardiogram ECG, finger plethysmogram, electrodermal activity EDA, pneumogram, electromyogram EMG (forehead and extensor digitorum), eye movement and blink activity, electroencephalogram EEG (0_2–P_4), finger temperature, and an intermittent noninvasive blood pressure recording. Detailed information about procedure, recording technique, automatic parameter abstraction by means of specially developed computer software, and scoring has been reported elsewhere (Fahrenberg et al. 1979, 1982).

Altogether six psychological (self-report) variables of the activation process being considered here and 161 physiological parameters were obtained comprising the primary item pool. This large number of parameters has been derived because: (1) some parameters have been arithmetically derived from primary measurement, e.g. pulse wave velocity (*R*-wave of the ECG and finger pulse); (2) special parameters from EEG and EDA recordings have been included for exploratory purposes; and (3) several variability measures were used. The general intention aimed at providing a broad spectrum of parameters, though many of these may be rather unfamiliar to most researchers in this field, and subsequently applying a strict empirical selection procedure to this primary item pool, thus yielding a set of relevant variables.

2.2. Selection of activation parameters

An empirically based rational selection procedure was applied to reduce the primary item pool. In order to be defined as an *activation variable* a particular variable should meet the following criteria:

(1) Using a two-way ANOVA-design (subjects, conditions) both the subject and the condition effects should be significant at the $p \leq 0.05$ level for the given variable.

Table 1
Pool of four psychological and 21 physiological activation variables according to specified criteria: abbreviations, dimension and short-term stability coefficients ($N = 125$) [a]

		Dimension	r_{tt}
1 Alert	Self-rating	CS scale units	0.47
2 Tense	Self-rating	CS scale units	0.51
3 Irritated	Self-rating	CS scale units	0.49
4 Pulse	Self-rating of perceived heart rate	CS scale units	0.45
5 HR-M	Heart rate (ECG)	M bpm	0.94
6 PWV-M	Pule wave velocity (ECG-R/finger pulse)	M cm/sec	0.92
7 PVA-M	Pulse volume amplitude finger	M units	0.84
8 TF-M	Finger temperature minus room temperature	M 0.1°C	0.86
9 BPSYS	Systolic blood pressure	M mm Hg	0.88
10 BPDIA	Diastolic blood pressure	M mm Hg	0.72
11 EMGA-M	Electromyogram ext. dig.	M 0.01 μV×sec	0.45
12 EMGF-M	Electromyogram forehead	M 0.01 μV×sec	0.79
13 EMGF-S	Electromyogram forehead variability	SD 0.01 μV×sec	0.60
14 EBF-M	Eye blink frequency	M rate/min	0.87
15 EBTA-M	Eye blink total activity	M 0.01 μV×sec	0.90
16 RR-M	Pneumogram respiration rate	M rate/min	0.81
17 RA-S	Estimated respiratory activity variability	s.d. 0.01 l	0.43
18 RI	Respiratory irregularity (rel. power of residual spectrum)	M %	0.62
19 EDAC-S	Electrodermal activity SD of AC-signal	s.d. 0.01 μS	0.79
20 EDDC-M	Electrodermal activity M of DC-signal (SCL)	M 0.01 μS	0.96
21 SCRS-M	Electrodermal activity max. slope of an SCR	M 0.01 μS/sec	0.83
22 SCR-G	Electrodermal activity number of SCR ≥ 0.3 μmho	M rate/min	0.81
23 EE1-M	Electroencephalogram 1–6 Hz dominant frequency	M 0.1 Hz	0.77
24 EE2-S	Electroencephalogram 7–13 Hz s.d. of dominant frequency	s.d. 0.1 Hz	0.66
25 EE2P-M	Electroencephalogram 7–13 Hz relative power	M 0.1 %	0.92

[a] CS change score, M mean, s.d. standard deviation, r_{tt} short-term stability coefficient: Mental arithmetic 1/Mental arithmetic 2.

(2) At least two experimental conditions should be discriminated significantly from Rest phase 1 by that variable (Scheffé tests).

(3) The short-term stability coefficient, used as a reliability estimate by comparing Mental arithmetic 1 and Mental arithmetic 2 (about 20 min later) should be $r_{tt} \geqslant 0.60$.

(4) There should be no *extreme* anomalies in the distributions (i.e. skewness $\leqslant 3.0$ and kurtosis $\leqslant 10.0$ during Rest phase 1 and Mental Arithmetic 1); use of data transformations (e.g. McCall's transformation), basically would not solve such problems since the entire data set must be subjected to transformation, and still, extreme anomalies in distribution could occur for the one or the other experimental condition.

(5) There should be no substantial redundancy of this variable when compared to other parameters of the same recording channel or functional system respectively, i.e. the coefficient $r_{ws} < 0.70$ (see below for partition of covariance). This criterion is intended to provide not only a representative but simultaneously a parsimonious selection of variables. Whenever two or more variables from a functional system are highly related, the variable which meets criteria (1) to (4) best and which also is most familiar in the literature is chosen.

A complete documentation of statistical results for the six psychological and 161 physiological variables considered here has been reported by Fahrenberg et al. (1979).

The remaining four psychological and 21 physiological activation variables are presented in table 1. A few exceptions have been made from the criteria given above. The self-ratings are characterized by modest short-term stabilities and high r_{ws} coefficients but do provide sufficient discrimination between conditions. Typically the EMG parameter EMGA-M and EMGF-S as well as slope of SCR have displayed abnormal distributions. EMGA-M and RA-S have reliabilities below 0.60. Parameter EBTA-M correlates highly with EBF-M and EE2-S with EESP-M. Parameter RA-S lacked discriminative power regarding the experimental conditions, which is perhaps due to its rather low reliability. These parameters have, nevertheless, been included to form the secondary item pool. Their elimination already at *this* stage of the analysis would have left too few marker variables for certain functional systems thus prematurely preventing the formation of possible item clusters or scales.

For this secondary item pool the following statistical analyses, which are the primary subject of the present paper, were performed: partition of covariance, analysis of internal consistency, item analysis, as well as factor analysis on certain subsets of items and on the total item pool. As most of these statistical procedures are familiar in the literature it will suffice to comment on the partition of covariance, which, as of date, has not been applied to psychophysiological data except for the attempt made by Mathews and Lader (1971).

Table 2
Essential concepts and matrices in partition of covariances

	Cross-products		Norm	Correlation		Interpretation
	Matrix	Formula		Matrix	Technique	
Total	S_T	$\sum_i \sum_j (x_{ij} - x_{..})(y_{ij} - y_{..})$	diag (S_T)	R_T		Total matrix over all subjects and conditions
Condition j	S_{Cj}	$\sum_i (x_{ij} - x_{.j})(y_{ij} - y_{.j})$	diag (S_{Cj})	R_{Cj}	R	Interindividual covariation (conventional r), i.e. correspondence of relative position of subjects on different variables for condition j
Subject i	S_{Si}	$\sum_j (x_{ij} - x_{i.})(y_{ij} - y_{i.})$	diag (S_{Si})	R_{Si}	P	Intraindividual covariation, i.e. correspondence of relative degree on different variables over conditions for subject i
Between-conditions	S_{BC}	$\sum_j (x_{.j} - x_{..})(y_{.j} - y_{..})$	diag (S_{BC})	R_{BC}	P	Intraexperimental covariation, whereby individual differences, response specificities and interactions are largely partialled out by averaging over subjects
Between-subjects	S_{BS}	$\sum_i (x_{i.} - x_{..})(y_{i.} - y_{..})$	diag (S_{BS})	R_{BS}	R	Interindividual covariation between subjects, whereby differential effects of particular conditions and interactions are largely partialled out by averaging over conditions
Within-conditions	S_{WC}	$\sum_i \sum_j (x_{ij} - x_{.j})(y_{ij} - y_{.j})$	diag (S_{WC})	R_{WC}	R	Pooled covariation over all conditions, coefficient $r_{WC} = 1.0$ means that relative position of subjects in different variables within conditions do correspond, but between conditions may not necessarily correspond
Within-subjects	S_{WS}	$\sum_i \sum_j (x_{ij} - x_{i.})(y_{ij} - y_{i.})$	diag (S_{WS})	R_{WS}	P	Pooled covariation over all subjects, coefficient $r_{WS} = 1.0$ means that time series of measures in different variables within a subject do correspond, but between subjects may not necessarily correspond
Error	S_E	$\sum_i \sum_j (x_{ij} - x_{i.} - x_{.j} + x_{..})(y_{ij} - y_{i.} - y_{.j} - y_{..})$	diag (S_E)	R_E		Pooled error and subject×condition interaction
Averaged R				$\overline{R_c}$	R	Average interindividual correlation obtained across different conditions
Average P				$\overline{R_S}$	P	Average intraindividual correlation obtained across different subjects

2.3. Partition of covariance

The essential concepts and matrices used when partitioning covariances in a four-modal data box (subjects, variables, conditions, replications of particular conditions) are presented in table 2.

This statistical procedure is well suited in more closely examining different aspects of covariation of activation measures in a complex activation process. A further differentiation is possible by using state measures as well as state change (reaction) measures – arithmetic differences (DIF) or autonomic lability scores (ALS) according to Lacey or AHA-scores, a newly developed change score which separates the initial value effect from the $a(a-b)$ effect (Myrtek, Foerster and Wittmann, 1977). Coefficients r_{cj} can be computed for each of the experimental conditions while the other matrices are computed for the five experimental conditions Rest phase 1, Mental Arithmetic 1, Interview, Anticipation, Blood taking. Since the subjects had been assigned to two different instruction sets, the effects of this set, although proving to be negligible in the great majority of dependent variables (Fahrenberg et al., 1979), was partialled out statistically.

3. Results

3.1. Partition of covariance

For descriptive purposes and to enhance the possibility of comparison within the matrix, correlation coefficients have been used here in which covariances have been normalized by applying $R = \text{norm}^{-1/2} \cdot \text{S} \cdot \text{norm}^{-1/2}$ (cf. table 2). This concerns the diagonals of the particular matrices; the average R and P matrices exist already in normalized form.

The R_{WS} matrix of pooled covariation within subjects appears to be of particular interest here because it exhibits the degree of correspondence among the activation process parameters (i.e. intraindividual covariation), simultaneously allowing for different pattern of activation in different subjects. Substantial coefficients here would indicate that the selected activation variables demonstrate a consistent sequence under different stimulus conditions. The coefficient, r_{WS}, is an essential statistic for the description of systematic covariation or redundance in activation processes. In the present investigation, according to the recommendations set forth by Bartlett (1946), the estimated degrees of freedom ($df = (N_{Subj} \times N_{Cond}) - N_{Subj} = 125 \times 5 - 125 = 500$) should be reduced to $df = 125$ when testing for significance. Since the sampling distributions are not known, the coefficient, r_{WS}, and other statistics in this study, with the exception of the conventional r_{cj} coefficients, are not tested for significance. A mere comparison of the *relative* magnitude of these coefficients is preferred here for a more cautious interpretation.

The basic approach of this analysis of within-subject covariation resembles the scaling procedure suggested by Lykken (1975). Lykken's range correction method eliminates, however, individual differences in level and range. The coefficient R_{WS} on the contrary, maintains differences in range, thus providing a more adequate description of the within-subject covariation for the given subject sample. The results presented in table 3 indicate a relatively high degree of covariation in practically all of the psychological activation variables. As to physiological variables there is an evident covariation among parameters derived from the same channel or functional subsystem, i.e. EDA, cardiovascular system, EMG, EEG. With few exceptions covariation across systems is much smaller or even negligible. Psycho-physiological covariation with self-rating variables is highest with the cardiovascular parameters (heart rate, pulse wave velocity, pulse volume amplitude and blood pressure), electrodermal

Table 3
Pooled covariation within subjects (matrix R_{WS}) for activation variables (below diagonal) and coefficients of interindividual correlation (matrix R_{Cj}) during Rest phase 1 (above diagonal) [a]

		1	2	3	4	5	6	7	8	9	10	11
1	Alert	–	19	−01	13	22	28	14	08	26	21	19
2	Tense	80	–	34	45	33	13	14	08	07	27	09
3	Irritated	60	78	–	20	06	−05	−15	−16	−04	−03	−13
4	Pulse	73	84	80	–	41	12	02	−03	06	16	00
5	HR-M	57	64	49	64	–	34	22	22	25	36	10
6	PWV-M	67	68	58	68	76	–	09	17	67	21	16
7	PVA-M	60	55	48	52	40	60	–	72	22	33	10
8	TF-M	27	17	22	20	−02	32	45	–	25	24	02
9	BPSYS	59	60	46	59	73	77	53	22	–	35	19
10	BPDIA	49	48	40	47	51	58	46	18	67	–	11
11	EMGA-M	30	36	32	34	45	32	25	−03	29	24	–
12	EMGF-M	30	31	22	27	27	25	23	04	26	18	19
13	EMGF-S	24	26	22	22	14	21	21	17	17	07	14
14	EBF-M	46	45	37	43	48	50	45	12	50	41	24
15	EBTA-M	49	45	41	45	40	52	48	26	49	39	15
16	RR-M	42	46	34	38	51	38	32	−05	37	24	33
17	RA-S	11	13	14	10	15	14	12	12	10	07	10
18	RI	45	45	39	46	47	40	37	11	38	28	33
19	EDAC-S	32	29	35	30	07	25	40	25	11	08	11
20	EDDC-M	50	44	41	45	26	46	56	35	40	33	15
21	SCRS-M	16	17	17	16	02	12	21	07	02	02	08
22	SCR-G	53	58	47	55	60	55	57	00	48	39	40
23	EE1-M	43	41	33	39	40	40	41	09	37	33	24
24	EE2-S	34	37	27	34	36	36	28	06	28	24	18
25	EE2P-M	47	49	36	48	57	51	35	02	49	37	28

[a] Variables 7, 8, 23, 25 are reflected in sign thus representing homogeneous direction of activation (coefficients are given without decimal points).

activity (SCR and SCL) and less prominently for eye blink activity parameter, EEG-alpha and the index of respiratory irregularity.

The lowest covariation has been found for the parameters, standard deviation (s.d.) of EDA-AC signal, the slope of SCR, finger temperature, estimated respiratory activity, s.d. of forehead EMG, s.d. of dominant frequency in EEG alpha band. These parameters, therefore, are thought to be less suited for the description of activation processes, although their reliabilities and discriminative power are not bad for all cases.

Inspection of the other matrices obtained by the partition of covariance method supports the interpretation of R_{WS} matrix. The R_{Cj} matrix of interindividual covariation, i.e. the conventional R-technique correlation coefficients, obtained during Rest phase 1 revealed, however, low consistency. From a total of 210 correlation coefficients, derived from the physiological variables, 35 coefficients were significant at $p = 0.01$ ($r \geq 0.23$ df = 123), merely 10 coeffi-

12	13	14	15	16	17	18	19	20	21	22	23	24	25
−07	−01	−09	−03	−11	00	−05	23	18	09	29	−03	24	19
05	06	16	10	−13	09	−04	00	04	−07	13	−08	00	−12
00	14	11	13	02	04	01	13	18	16	17	13	04	05
−01	00	01	−08	−30	10	−16	06	−03	05	04	03	−02	−04
04	−04	−05	−04	−21	12	−01	05	02	−03	25	00	−09	−03
11	12	03	02	00	03	−05	24	04	−08	32	02	08	06
−04	09	00	04	−15	17	01	09	−08	−04	12	−10	−07	−13
−01	11	07	06	−02	17	−03	−07	−17	−13	03	03	02	01
10	06	−02	−01	01	−08	00	27	05	−06	39	09	07	07
10	20	09	16	−17	16	−06	23	13	03	34	03	01	−04
−05	−08	11	01	14	01	21	17	01	−02	22	06	14	10
–	31	11	11	06	−02	07	−10	−07	−15	−10	02	07	−01
46	–	20	27	−11	42	11	05	10	04	11	23	04	12
22	16	–	84	06	12	14	−14	−11	−09	−07	27	01	09
23	25	80	–	06	17	18	−08	−02	02	−02	28	05	13
22	13	35	27	–	−44	12	−10	−02	−07	−17	16	15	23
03	22	18	17	−18	–	07	15	11	23	10	−06	−06	−10
17	16	35	32	42	19	–	−05	−04	−01	−05	17	16	15
10	23	18	30	28	14	22	–	54	75	68	−07	02	−03
18	21	31	42	20	14	27	56	–	53	55	04	14	12
12	18	08	17	20	13	12	66	40	–	32	−07	−05	−08
24	20	41	36	51	12	48	48	50	25	–	02	13	11
21	21	41	41	34	−03	30	22	23	15	42	–	41	73
19	17	30	30	28	11	32	26	22	17	37	55	–	76
27	16	43	39	42	08	41	21	22	10	49	65	75	–

cients being $\geqslant 0.50$. With a few exceptions, however, this correspondence is within a single functional system and not between systems.

As to psycho-physiological relationship the following was found: from 84 possible coefficients, five r_{Cj} were significant at $p = 0.05$ and nine at $p = 0.01$ levels, the highest being between perceived pulse and heart rate $r = 0.41$, tense and heart rate $r = 0.31$. When considering reaction scores derived from Rest phase 1 compared to Mental arithmetic 1, of the 210 coefficient in the physiological domain, 25 coefficients based on difference scores (compared to 23 ALS scores, 18 AHA scores) obtained significance at $p = 0.01$, six coefficients of these being $\geqslant 0.50$, but here again the correspondence is within and not between systems. The pattern of correlations is very similar, regardless whether state or reaction scores are used.

The highest coefficeints have been found in the R_{BC} matrix between conditions because individual response specificities and interaction variance have been eliminated by averaging over subjects in each condition and correlating this averaged time series over the five conditions. The coefficients r_{BC} reflect the *generalized* intraexperimental covariation due to synchronous variation acting in the same direction, i.e. the trivial fact that there is a mean reaction profile under the stimulating conditions of this experiment. As soon as a *differential* perspective is taken, however, no homogeneous process of proportional increments is evident in the parameters studied – as postulated by unidimensional activation theory.

3.2. Factor analyses

The 25 activation variables selected here were included in a factor analysis in a first step using: (1) state measures during Rest phase 1; and (2) change scores from Rest phase 1 to Mental arithmetic 1. The first principal component accounts for 14% (13% for change scores) of the total variance. Furthermore, the Scree test suggests a five-factor solution comprising 51% (41%) or an eight-factor solution 67% (61%) of the total variance. After Varimax rotation the eight-factor pattern resulting is clearly representative of the particular functional systems of activation process: self-ratings of activation, cardiovascular component (HR, PWV, blood pressure) peripheral vascular component (PVA, finger temperature), respiration, electrodermal activity EDA, muscular tension component (EMG), eye movement and blink activity, EEG-alpha component. In the five-factor solution the EDA and the EEG components remain independent while both cardiovascular components, and the EMG and EOG components merge. Self-rating variables concur with the cardiovascular pattern during condition of Rest phase 1 but appear more independent in the change scores from Rest phase 1 compared to Mental arithmetic 1.

Additional factor analyses including only the set of 21 *physiological* variables, using DIF as well as AHA and ALS change scores, single and combined

experimental conditions, as well as different techniques of factor analysis (e.g. image analysis, procrustes rotation), produced – relatively independant from the particular score or technique – further concurring evidence for a distinct solution of either seven or four physiological factor patterns with only a few inconsistencies during conditions of Anticipation and Blood taking (particularly with respiration parameters). More detailed information may be found in Fahrenberg et al. (1979). The results, obviously, lend little support to the concept of a major principal component that would account for a substantial proportion of variance but rather suggest the need for a multi-component model and, tentatively, the construction of more homogeneous 'sub-tests' derived from item analyses procedures.

3.3. Item analyses

Item analyses were performed for the 25 activation variables with the intention of comparing models differing in the number of hypothesized components: (1) a single-component model with psychological and physiological variables combined; (2) a two-component model with psychological and physiological variables separated; and (3) a five-component model with one psychological and four physiological components as suggested by factor analysis. In the present study there were not enough variables to serve as parallel items, e.g. multiple EMG- and EEG-recordings or even more cardiovascular measures, so that testing of a eight-component model was not possible.

Internal consistency of the derived scales is conceived as one important criterion if these unidimensional and multiple component models are compared as to their measurement properties, reliability, and descriptive use in activation research.

The item analyses were developed in several steps starting from the particular item pools suggested by factor analysis by eliminating items of low item–total score correlation in order to achieve a maximal internal consistency and a close correspondence across data sets from Rest phase 1 as well as change scores for the other four experimental conditions. In table 4 the number of items is given, as well as Cronbach's alpha as an estimate of internal consistency, and correlation coefficients between item and the part–whole corrected total score, i.e. the average of standard T scores of the other items in this scale. It should be noted that the scales differ in the number of items. As a comparative reference, an estimated alpha according to Cronbach based uniformly on five items has been computed for each scale, using the Spearman–Brown formula and assuming equal variances and equal intercorrelations of items.

The five-component model has proven most appropriate with respect to internal consistency; the coefficients range between 0.53 and 0.82 or between 0.54 and 0.88 when based on five items. When compared to these five

Table 4
Results of stepwise item analysis ($N = 125$). Item–total correlation coefficients and internal consistency (Cronbach's alpha) are presented for state scores from Rest phase 1 and for AHA change scores from Rest phase 1 to Mental arithmetic 1 with respect to scales derived in models of 5, 2 and 1 components. Additionally the item–total correlation coefficients based on the pooled covariation within subjects (R_{WS}- matrix) of activation variables are given [a]

	5 components		2 components		1 component		
	State scores	Change scores	State sores	Change scores	State scores	Change scores	Matrix R_{WS}
1 Alert	14	52	14	52	36	36	75
2 Tense	51	67	51	67	28	47	80
3 Irritated	25	51	25	51	21	27	72
4 Pulse	39	54	39	54	18	42	77
α	53	76	53	76			
α (5 items)	58	80	58	80			
5 HR-M	38	35					71
6 PWV-M	39	52	33	31	35	33	77
7 PVA-M	30	19					49
8 TF-M	53	30					26
9 BPSYS	49	46	37	28	36	29	69
10 BPDIA	43	16	30	26	35	24	54
α	68	59					
α (5 items)	64	54					
11 EMGA-M							39
12 EMGF-M	22	21					48
13 EMGF-S	34	15					30
14 EBF-M	55	45	12	26	14	24	64
15 EBTA-M	59	51	22	30	19	28	62
16 RR-M							54
17 RA-S							16
18 RI							59
α	63	53					
α (5 items)	68	58					
19 EDAC-S	79	72	48	35	46	35	54
20 EDDC-M	62	63	37	47	37	34	59
21 SCRS-M	66	59	28	34	25	31	35
22 SCR-G	63	43	57	28	58	22	73
α	82	78					
α (5 items)	85	82					
23 EE1-M	58	19					65
24 EE2-S	65	49	23	16	24	18	64
25 EE2P-M	83	50	22	21	21	27	72
α	82	56	66	63	69	70	93
α (5 items)	88	68	45	42	48	49	73

[a] $r_{it} \geq 0.18$; $p < 0.05$. By stepwise analysis those items have been eliminated (–) that failed to reach an appropriate level of significance ($p < 0.05$) in at least one of the two scales (i.e. scales developed for state or change scores). As a comparative reference, an estimated alpha uniformly based on five items has been computed for each scale, using the Spearman–Brown formula.

components, the physiological component of the two-component model as well as the generalizing single-component model obviously are less consistent. In order to obtain but a modest degree of internal consistency for the single- and two-component models such essential activation variables as heart rate, peripheral pulse volume amplitude, respiration parameters as well as all of the EMG-parameters had to be omitted. Thus the resulting unidimensional physiological scale is but a mere fragment of the original parameter set. Consequently the notion of a generalized activation pattern seems to be inappropriate here.

An additional item analysis based on the covariation of 21 physiological activation variables pooled within subjects, r_{WS}, indicates which parameter under this perspective could be taken as a leading parameter (marker variable) for each physiological system. Thus the rank order and not the numerical size of item-total score coefficients based on r_{WS} in table 4 is interpreted. The findings suggest that the parameters PWV-M, HR-M and BPSYS are outstanding for cardiovascular system (PVA-M for peripheral vascular conditions also doing well), EE 2P-M for EEG, SCR-G for EDA, EBF-M (or EBTA-M) and EMGF-M for muscular activity, RI and RR-M for respiration. This evaluation, of course, is not based on hypothetical assumptions as to underlying physiological mechanisms but rather is derived by means of statistical analysis of empirically observed covariation.

4. Discussion

Based on the criterion of internal consistency, a five-component model seems to be much more appropriate than a single- or two-component model for the present set of 25 activation variables. An alternative, of course, would be to use certain activation variables selected from each functional system according to their discriminative efficiency as specified above. These *marker variables*, i.e. a single variable that epitomizes a certain subsystem of activation, are empirically supported by analysis of variance, partition of covariances and estimates of reliability such as short-term stability. Marker variables of this kind should be interpreted as single dependent variables. The notion, however, should be discarded that such variables are indicators of an unitary dimension of psychophysiological activation. An individual's score on a specific activation variable may characterize the functioning of the particular response system but there is no sufficient empirical support to reliably assume a corresponding proportional score of state or of state change in another autonomic–somatic system of that individual. It has proven to be impossible to predict an individual's state or reaction score on one activation variable to a significant and substantial extent based on the score from another variable; this result not only holds for the often reported low or even insignificant correlation between subjective and physiological activation variables but also *within* the important

marker variables for different autonomic-somatic response systems.

As to the generalizability of the present results, appropriate reservations certainly should be made. This investigation did, however, take special precautions as to the subject sample size, which is considerably larger than usual, broad sampling and empirical preselection of dependent varibales, variety and intensity of stimulus conditions, different scoring methods for measuring change and handling of initial value problems, and a combination of psychometric procedures using the most important data sets and matrices assessed in this investigation.

A possible criticism may be raised that such a multivariate investigation cannot lead to reliable statements, since it utilizes a large number of variables, a stepwise selection process favouring capitalization on chance, and gives a partition of covariance without knowledge of the sampling distribution. There are, of course, different opinions as to which research strategies and methods of data analysis are best suited for differential psychophysiology. Nevertheless, it may be concluded that the partitioning of covariance is a useful method in presenting more precisely the various aspects of the covariation problem in activation theory than has been possible so far. Since the sampling distributions are not known, the coefficients reported here have only been compared and interpreted by considering their relative magnitude. The factor analyses have also been applied in an explorative manner in order to promote the preselection of activation variables for the construction of tentative scales. It should be noted, however, that the selection procedures and the stepwise item analyses used here should enhance the consistency within the data set due to the capitalization on chance that may occur. Despite this possible bias a considerable inconsistency and thus heterogeneity is evident among the activation variables.

A replication of the present study is desirable, since the findings of the statistical analysis, to be precise, only apply to the present subject sample, although the unusually large sample size ($N = 125$) does offer some assurance. In a subsequent study the analysis of a reduced set of activation variables now is being repeated in this laboratory.

Some further problems should be mentioned that complicate the evaluation of covariation and consistency of activation parameters. The item pool of the present investigation, although presenting an unusually broad spectrum of variables, is strongly biased due to available recording techniques. Many subsystems of the ANS are not at all or not adequately represented and, from a physiological point of view, in many instances parameters other than those included here would be more desirable. But such additional variables would probably further increase the observed inconsistency.

Two further biometric problems, although well known in other fields, but hardly ever investigated in psychophysiology have been studied in the present data. Different response systems seem to have characteristic sensibility curves

as is familiar with floor and ceiling effects in test scores. One system may even fail to respond at levels of stimulus intensity to which other systems exhibit a substantial response. Hypothetical sensibility curves for a few activation parameters have been discussed by Lader (1975) and Walschburger (1976). This approach has been followed up here by plotting measures in one activation variable against the sum of standard T scores of the other marker variables of activation (for more details see Fahrenberg et al., 1979). The resulting diagrams present evidence of: (1) non-linear sensibility curves for EMGF-M and PVA-M; and (2) empirical evidence that EDA-parameter, PVA-M and EE2P-M are most sensitive with relatively low stimulus intensities while heart rate seems to have discriminative power as well at relatively high stimulus levels applied in the present experiment.

Another aspect of non-linearity was investigated by polynomial regression analysis (Kerlinger and Pedhazur, 1973; Fahrenberg et al., 1979) and by visual inspection of scattergrams. In the 25 activation variables studied for Rest phase 1 and as well for difference scores from Rest phase 1 compared to Mental arithmetic, less than 10% of the polynomial regression coefficients indicated a significant non-linear relationship between two variables at the $p < 0.01$ level. Inspection of scattergrams revealed, however, that about half of these coefficients are probably caused by outliers; very few of these coefficients represent an increase in common variance greater than 10%. Generally speaking, it may be concluded that linear correlation methods are sufficient in their task of describing data relations in this study.

The problem of initial values also has been studied in these data but appears to be of negligible importance in physiological data. The possible initial-value effect in psychological data cannot be analyzed in this study because self-reported change scores had been obtained. As soon as the so-called $a(a-b)$ effect is partialled out the negative correlation of change scores to initial values becomes insignificant or, often, even a positive relation – higher change scores with higher initial values have been found (see Myrtek, Foerster and Wittmann, 1977; Fahrenberg et al. 1979). Thus none of the biometric problems, neither the problem of initial values nor a non-linearity of covariation, can be considered as offering an appropriate explanation for these inconsistencies exhibited in the present study.

The observed inconsistencies may be partially accounted for by response specificities, since there is accumulating evidence from recent studies that about one third of all subjects in psychophysiological experiments exhibit a significant and, in some individuals, a rather stable individual response specificity that constitutes a substantial percentage of the total variance (see Foerster and Walschburger, 1980, 1982; Foerster and Schneider, 1982).

Reviewing recent contributions to psychophysiological assessment Haynes and Wilson (1979, p. 343) use the term *response fractionation* as a general concept for 'lack of significant covariation, nonsignificant common variance,

or dyssynchrony among overt behavioral, cognitive, subjective, and physiological measures'. Some aspects of this fractionation phenomenon have been articulated in the work of Lacey (1967) on directional fractionation and, particularly, on individual response stereotypy. It may be noted, however, that this concept has many essential historical antecedents, much older than Lacey's concept – for example the classical etiological theory of *locus minoris resistentiae* and the constitutional research about physiological, biochemical and adaptive individuality (see Fahrenberg, 1977, 1979; Myrtek 1980). Starting from biofeedback research Schwartz (1977) put forward the concept of patterning, and discussed differential response topography and sequences of patterns in general terms referring to some preliminary work. Thus, response fractionation has been accounted for by various explanations and interpretations that assume a genetic and embryological basis or a gradual development of response characteristics due to differential learning or due to cognitive coping processes. Compared with these conjectures the essential *physiological* arguments much more seem to be within the field of actual observation and experimentation.

On physiological grounds much could be said as to systemic and individual conditions that might determine various degrees of coupling between different functional systems of the organism. Therefore, an even stronger orientation towards physiology, and a better understanding of the underlying mechanisms and synergistic patterning, seems imperative in future psychophysiological research.

What are the practical implications of the observed inconsistencies? The assumption that a single measure, e.g. one-channel recordings of EDA, EEG or heart rate, reliably indicates or predicts individual differences in general activation seem to be obsolete. Composite scores or an index in analogy to psychometric test batteries have been used by a few researchers, for example Wenger and Cullen (1972), Thayer (1970) and Walschburger (1976), but this concept seems not to be very promising in psychophysiology. The correlation matrices (with the exception of R_{WS}) as well as a factor and item analyses revealed inconsistencies that discourage such composite scores.

These empirically derived statements are in agreement with the critical review on psychophysiological assessment, given by Haynes and Wilson (1979). These authors also have suggested that multiple measures should be taken when feasible instead of a single measure and also have disapproved of the use of an index of generalized physiological functioning. Haynes and Wilson ask for careful selection of these psychophysiological measures considering expected effects of the experimental or therapeutic design, as well as consideration of underlying physiological mechanisms and differential sensitivity of response systems. General strategies, particular recommendations or statistical data, however, are not given by these authors, although procedural guidelines appear to be essential for psychophysiological assessment in research and in the

applied fields, e.g. studies concerning anxiety, stress–strain, outcome of psychotherapy and biofeedback.

The present study, how incomplete it may appear, has intended to provide a broad empirical basis and some rational criteria for analyzing covariation and consistency and for selecting appropriate marker variables when a multivariate assessment of individual differences in activation processes is undertaken. This empirical–statistical qualification of activation parameters based on discriminative efficiency, as well as specificity and reliability, of course, is only one relevant aspect along with the given author's particular theoretical concepts that guide the selection and operational definition of dependent variables in a specific study.

The concept of a unitary dimension of activation is not supported by the present multivariate study and, consequently, in the assessment theory of activation processes different aspects and strategies have to be distinguished, employing specific procedures for specific aims: for the investigation of: (a) group differences; (b) individual differences; and (c) intraindividual processes. The general activation state and activation reaction in different groups of subjects probably can be compared by testing sample means for a selected physiological parameter, e.g. heart rate, or a few other activation variables. On the contrary, individual differences in activation state or reaction are hardly to be diagnosed reliably, based on one or a few activation variables, because of their inconsistency (with respect to interindividual comparison). Intraindividually, however, the R_{WS} coefficients indicate, within the limits imposed by that statistical technique, that substantial covariation can be said to occur. For a given subject the various measures tend to agree as to which conditions are more activating than others. An unidimensional model eventually could be appropriate in describing intraindividual activation processes but suitable parameters and possible individual response specifities have to be investigated in each case.

The assessment of activation processes either should restrict itself to the *general psychophysiology* of average reaction profiles or should develop more precise strategies for *differential psychophysiology*. This study on the partitioning of covariance as well as our studies on the substantial amount and stability of individual response specificities in many subjects suggest – at least in some instances – an individualizing approach to psychophysiological assessment although the methodological problems of such single subject designs are obvious in this field too.

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