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Behavioral and psychophysiological effects of the physical work environment

Research strategies and measurement methods

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GAMBERALE F, KJELLBERG A, ÅKERSTEDT T, JOHANSSON G. Behavioral and psychophysiological effects of the physical work environment: research strategies and measurement methods. *Scand J Work Environ Health* 1990;16(suppl 1):5-16. An international course on the behavioral and psychophysiological effects of the physical work environment was held in Stockholm, Sweden, in April 1988 by the Nordic Institute of Advanced Training in Occupational Health and the Swedish National Institute of Occupational Health. It dealt primarily with the behavioral and psychophysiological responses to aspects of the physical work environment and was devoted to neural and behavioral functions. The increasing interest in these functions is mainly motivated by the involvement of the central nervous system in the adverse effects induced by unfavorable environmental conditions of the workplace and by the need for more sensitive indicators than those based solely on recognized occupational disease and pathology. By describing the main aspects of the research strategies and the measurement methods used in this field of research, this paper provides a background for the assessment and evaluation of the early behavioral and psychophysiological indices of potential occupational hazards.

Key terms: behavior, psychophysiology.

The papers of this volume deal with the behavioral and psychophysiological effects of unfavorable environmental conditions in the workplace. The work environment stresses considered include neurotoxic substances, eg, industrial solvents, metals, pesticides (1); lighting (2); noise (3); vibration (4); heat and cold (5); electric and magnetic fields (6); physical work load (7, 8); workhours (9); and multiple stresses (10).

The purpose of the present paper is to provide an introduction to the other papers of this volume by focusing on the objectives of this field of occupational health research, on the research strategies used, and on the methods adopted to assess exposure-related behavioral and psychophysiological changes.

Generally, the term behavior is used to refer to three functional systems. One is related to the capacity of the nervous system to deal with information. Another is concerned with feelings, emotions, and motivation. The third is a control function which determines how behavior will be expressed. Psychophysiology refers to the discipline concerned with the study of the physiological correlates of behavior.

The terms behavioral and psychophysiological, as they are used in the present context, refer more to the type and level of measurement of effect variables than to theoretical considerations regarding the relation between subjective experience, behavior, and physiology. Thus behavioral effects refer to those functional changes in the central nervous system (CNS) which can be observed and assessed by the use of, eg, self-rating scales, psychophysical methods, and psychometric tests. Likewise, psychophysiological effects refer to effects indicated by certain electrophysiological and endocrinological changes which reflect underlying functional processes in the CNS, ie, processes on which behavior depends.

There is unequivocal evidence that relatively small changes from the optimum work environment can affect work efficiency and comfort. There is also evidence that adverse effects on the nervous system, such as reduced functional capacity, alteration in the psychophysiological state, or other behavioral changes, may be caused by exposure to different chemical or physical environmental factors at the worksite and by factors linked to the physical work load, the organization of work, and the production processes. Today these effects are recognized as warning signs of potentially serious health hazards in the work environment which can no longer be neglected. Adverse effects of this type may be present among the workers long before any clinical symptoms of occupational disease and pathology appear. Consequently, the early detection of these effects is becoming one of the most important tasks of modern occupational health practice.

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Research strategies

It may be of interest to consider the extent to which the assessment methods and strategies used in the study of the behavioral and psychophysiological effects of the physical work environment differ from those used in a neuropsychological or neurological examination of a patient suspected of brain disorder or behavioral disabilities. Although both disciplines are concerned with the examination of the nervous system by studying its behavioral products, clear differences emerge not only concerning the objectives of the investigations, but also with regard to the type of behavioral data collected and to the treatment of these data.

Neuropsychological or neurological studies are usually undertaken for diagnostic purposes. The issue may be, eg, to discriminate between psychiatric and neurological symptoms, to identify possible neurological disorders, to distinguish between different neurological conditions, or to provide behavioral data to localize the site of a brain lesion. The behavioral data collected during the examination are also used to evaluate the effects of the subsequent therapy or rehabilitation and to answer questions about the patient's capacity for self-care. In all these cases the focus of interest is the individual and his or her functional and emotional capacity.

In the study of the effects of the work environment, on the other hand, interest is focused primarily on the environmental conditions. The individual's behavioral data are of interest only to the extent that they reflect a statistical probability of having undergone changes related to the environmental conditions under study. In most cases there is no need, in this context, to provide individual diagnoses or a comprehensive description of the psychophysiological efficiency of the individuals examined. Thus in most cases the objectives of the investigation may be completely achieved if changes in certain sensitive parameters are shown to be related to certain environmental conditions. When this is the case, the examination has provided useful data with which to evaluate the work environment and which can indicate proper methods for improving the work conditions.

Other more fundamental differences between the neuropsychological and neurological examination of patients and the examination of workers performed with the aim of evaluating the work environment concern the kind of behavioral and psychophysiological parameters used, the use made of these data, and the need for experimental control. To give an example, the performance of a group of workers in a reaction-time task or the registration of the electrical activity of their brains (electroencephalography) or the firing pattern of some of their brain cells (evoked potential measurements) or the level of catecholamine excretion during a workday may say very little about the health condition of the individual workers. However, although they may completely lack clinical relevance, at the group

level the same data may deviate from what would be reasonable to expect under normal conditions. If the data collection is carried out with proper experimental control, the deviation observed may be interpreted as indicating an adverse action of the environment on the nervous system. It is clear that a research paradigm of this kind emphasizes the importance of identifying and evaluating effects which, although biologically relevant, need not necessarily be directly related to diseases and pathology.

The other papers in this volume give numerous examples of studies performed according to the described research paradigm. The use of effect variables of the behavioral and psychophysiological type does not impose any specific restriction with regard to the type of investigation which can be performed or with regard to the choice of the study design. [See also the paper by Iregren & Gamberale (1)]. As the other communications in this supplement demonstrate, these kinds of effect variables are used in highly controlled laboratory experiments on the effects of simulated loads of the work environment. The same variables are also used in quasi-experimental field studies performed at the worksite to assess acute, reversible effects of specific work conditions and in post factum epidemiologic investigations of suspected chronic manifestations of long-term exposure.

One inherent feature of behavioral and psychophysiological variables is their great diversity. In the following discussion, the review of the behavioral and psychophysiological effect variables has been divided into three sections: (i) subjective reactions (ii) performance measurements, and (iii) psychophysiological responses.

Subjective reactions

Whatever the capacity in which one is dealing with problems of the work environment, subjective reports constitute a basic source of information. Thus, for example, decisions to conduct objective measurements of the status of the person or the environment are generally based upon such reports.

Why collect subjective data?

An evaluation of the work environment from the worker's own point of view is in itself of obvious interest in almost all types of work environment studies since the subjective well-being of the worker is a goal common for most activities related to the work environment. A more specific reason for using subjective data is that they may provide an overall assessment of the effects of the environment, whereas other assessment measures generally reflect more specific effects. Furthermore, subjective data often contribute to the interpretation of the performance and psychophysiological effects. Thus, even if subjective data are sometimes collected as a less expensive substitute for objective

measurements, this certainly is not the only reason for using them.

A traditional objection to subjective methods is their alleged lack of reliability. However, there is overwhelming evidence that it is possible to measure subjective responses with good reliability, although, admittedly, the most reliable methods are often difficult to use outside the laboratory. Thus the reliability of subjective reports is generally no worse than that of most biological measurements used in this context. An unreliable subjective measurement is more often the result of deficiencies in the investigator's competence than of an inherent quality of these measures. Furthermore, it should be kept in mind that the main purpose of collecting subjective data in the present context is to identify environments which constitute a health hazard or occupational groups which may risk their health. For this purpose it is sufficient to discriminate symptom frequency or mean intensity at different points of time or in different groups. This objective of course makes much smaller demands on the measurement precision than would be the case in the use of subjective reports as a basis for the screening or diagnosis of individuals.

Different types of self-report data

The following types of data may be of interest in the evaluation of the effects of the work environment:

1. Descriptions of the level, duration, or frequency of exposure to different loads in the work environment. Such descriptions may sometimes be the only available source of information, eg, when data on exposure history are needed.
2. Descriptions of the response to a certain environmental load. Such reports need not be restricted to responses which by definition are subjective (eg, noise annoyance), but may also concern physical symptoms linked to an environmental factor (eg, eye irritation from solvents, headache from noise).
3. Descriptions of the mental or physical state (mood, symptoms) without an interpretation of its cause. The causal inference is then made on the basis of analyses of dose-response relationships.
4. Assessments of one's own performance or of other aspects of one's behavior, eg, the use of protective equipment or adherence to safety regulations.
5. Descriptions of stable individual characteristics which might affect one's response to the work environment (personality characteristics, sensitivity to various agents, etc).

Methodological problems

Subjective data may be collected in more or less systematic ways, from informal interviews to very sophisticated psychophysical rating methods. [See the

articles by Borg (7) and Gamberale (8) in the present issue.] The latter generally presuppose that the different environmental conditions studied are presented close enough in time to make a direct comparison between them possible. This is one reason why they are used rather limitedly outside the laboratory, in spite of their good reliability. Another reason is that they only yield relative ratings, which generally are of limited interest in applied settings. One does, eg, not only want to know how much worse one condition is than another, but also how bad each condition in itself is experienced to be, ie, ratings on an absolute scale are also needed. The problem of absolute scaling is discussed at length in the article by Borg (7).

One common threat against the validity of ratings is that the rating tasks are made too difficult, eg, by making demands that are too heavy on the subjects' memory or discrimination capacity. In such cases the risk is great that the subjects will base their ratings on their knowledge and hypotheses, rather than on their spontaneous experience. Thus, when asked to estimate the intensity or frequency of a certain symptom, they might report what they consider is the probable response in the given situation rather than the actually experienced bodily sensations. For an example see the article by Gamberale (8) in the present issue.

Other problems often mentioned are those of response bias (the tendency to avoid extreme response alternatives or to agree with statements) and social desirability (the striving to give a positive impression). A problem related to the latter is that, in some cases, the subjects have reason to believe that their answers may have important consequences for themselves, eg, change of job, economic compensation, sick leave. This possibility could, obviously, influence their answers.

Some of these problems become less important in studies of subjective changes within a group; the bias often only adds a constant to the rating and leaves the changes unaffected. Others can only be avoided by carefully worded questions and instructions including information to the subjects about the purpose of the study and about how data will be treated.

Measurement of mood

A change in mood is one of the more salient effects of, eg, many neurotoxic substances. Therefore methods for a valid and reliable measurement of mood are important in many contexts. A central question in this connection has been the dimensionality of mood, ie, in how many and in what dimensions should mood be described? This question was treated by Wilhelm Wundt, but only with the advent of factor analysis and other multivariate methods did empirical studies of the structure of mood become possible. Most such studies have used adjective checklists consisting of a series of mood descriptive adjectives with a response scale coupled to each word. Early studies concluded that it

was necessary to use 12 or more dimensions for the description of mood. Furthermore, the dimensions were generally found to be uncorrelated and mostly unipolar. Therefore, eg, vigor and fatigue were postulated as two independent dimensions and thus implied that a person's degree of vigor said nothing about how tired the person felt (11). Not unexpectedly, this outcome has been found to be a methodological artifact, and later studies have concluded that there is a small number of bipolar factors (12—14). The adjective checklists based on these studies all have a rather similar structure, containing around six subscales.

The possibility of a further reduction in the number of mood dimensions has been discussed by several authors (12, 14, 15), and it was confirmed by recent reanalyses of old data by Watson & Tellegen (16), who concluded that, basically, there are two dimensions of mood. Figure 1, based upon findings of Kjellberg & Iwanowski (17), shows that mood basically seems to vary in an evaluation and an activation dimension. However, since there are few nonevaluative activation adjectives, it is difficult to measure these two basic dimensions directly. Instead factor analyses usually

yield dimensions which form diagonals in this system, as shown by the figure. This two-dimensional structure has been validated in many languages and is now well established. The exact content of these dimensions possibly varies between contexts, but at least when mood is described in an occupational setting a stress (tense, nervous-relaxed, calm) and an arousal (energetic, lively-tired, sluggish) dimension seems to give a description of mood which is adequate for most purposes. Mood adjective checklists for the measurement of these two dimensions have been developed both in English (15) and in Swedish (17). In the Swedish version, which is included in the computerized test battery of the Swedish Performance Evaluation System (18), a further problem with the existing mood rating scales has been remedied. Since these instruments have generally been developed with the use of student populations, some of the words included are incomprehensible or appear unnatural as descriptors of mood in other groups. Such words have been excluded in the Swedish version. (See also reference 19.) A further advantage of a two-dimensional instrument is that it can be made very short. Thus, in the Swedish version, each dimension is measured by six adjectives (three for each pole) and only takes a couple of minutes to complete.

Figure 1. The two-dimensional structure of mood. (Neg = negative, Pos = positive)

Performance measurements

The effects of the work environment on performance have been studied for some time although not always with the objective of identifying environments hazardous to the workers (figure 2). Rather, practical industrial and military problems have provided the impetus for such studies, and their principal aim has been to improve productivity and the quality of job performance by providing a suitable physical work environment. However, performance measurement may also be used for predicting accident risks or as an indicator of the state of various CNS functions. In the latter case a performance decrement is viewed as a sign of impaired function which, given an appropriate study design, may be attributed to the work environment. As shown by figure 2, studies may also differ with respect to whether the individual or the environment is the focus of interest, ie, whether results are used as a basis for measures directed towards the individual or towards improving the environment.

The objective determines the type of task of interest. When safety risks are to be assessed, it is necessary to observe performance in the real work task or a simulation of that task. If, on the other hand, the aim is to assess mental or neurological functioning, the realism of the task is of little consequence. The important thing is to choose tests which tap the affected mental functions of interest.

In a clinical context one is generally interested in detecting gross deviations from normal functioning, and this differentiation is accomplished in a comparison

ASPECT OF MAIN INTEREST	OBJECT OF MAIN INTEREST	
	The individual	The environment
Productivity effects	Identification of sensitive individuals	Identification of environments which lower productivity
Safety risks	Identification of sensitive individuals	Identification of environments with high accident risks
Mental or neurological functioning	Identification of sensitive, diagnosis of injured individuals	Identification of environments hazardous to health and well being

Figure 2. Goals in studies of the effects of the work environment on performance.

of the person's performance with that of a norm group. Obviously, tests developed for such a purpose do not necessarily have the sensitivity required for detecting nonclinical effects.

Classification of performance tests

Performance tests have been developed and applied within many different fields of psychological research. This is one reason why there is no generally accepted taxonomy of performance tasks and thus no agreement among researchers concerning the identification, definition, and measurement of performance functions which might be relevant to the study of the effects of different environmental conditions.

In traditional test psychology the dominant systems for classifying performance have been based upon factor analysis, eg, Thurstone's primary abilities. In work environment research experimental psychology and, especially, information processing research have been more influential on both the classification and the choice of performance tests. There is by no means no generally accepted model of information processing within this research tradition. However, the general striving has been to identify the processing stages involved in the performance of a task. Generally the proposed models contain the following components: (i) sensory processes, (ii) perceptual and attentional processes, (iii) working memory, short-term memory, (iv) long-term memory, (v) central and specific processors, (vi) response (motor) processes. Thus the process starts with the infinite amount of information reaching the sense organs. Parts of this information are selected, organized, and identified by perceptual and attentional processes. Relevant parts of this extracted information are kept in a working memory where it is available for further processing that also requires that information be picked up from the long-term memory. On the basis of the result of this processing, a response is selected and executed. In all stages there are capacity limitations of one kind or another which may lead to a disturbance in the processing and to performance deterioration. In table 1 different types of processing failures are presented, together with tasks typically used to detect them. These models make apparent the difficulty of pinpointing the stage responsible for a certain performance decrement. If, eg, performance on a short-term memory task deteriorates during a certain exposure, it is impossible without appropriate controls to determine whether this phenomenon reflects an input or processing failure (misdirected attention or memory).

Choice of performance tests for assessing a certain environmental factor

On what grounds should one choose performance tests for a certain study, ie, which tests can be expected to be sensitive to a certain factor in the work environment? The easiest case is when one is interested in

specific, peripherally mediated capacity decrements, ie, when the environment directly interferes with the functioning of a sense organ or with motor functions. Examples of this situation are the masking effects of noise, the visual problems caused by poor lighting, lowered tactile sensitivity during cold exposure, and the problems of hand-arm control during exposure to whole-body vibration. Although the exact design of tasks measuring such effects may present difficult problems, it is generally fairly obvious which functions should be measured.

When functional changes mediated by the CNS are of primary interest, the choice of test is more complicated. From the information processing perspective it may be tempting to presume that a certain environmental agent exerts its effect by impairing a specific aspect of processing in a way parallel to the peripherally mediated performance decrements.

In fact there is little support for such a notion. The effects are seldom that well focused and most often seem to be the result of an effect on the general state of the individual rather than on a specific stage of the information processing. Therefore, by far the most common theoretical framework for interpreting the effects of the physical environment on performance studies has been arousal theory. This theory proposes that the state of the individual may be described as a position on a continuum varying from sleep and

Table 1. Deterioration of performance: examples of failures in different stages of information processing and of tasks indicating these failures.

Cause of failure	Task
<i>Missed relevant stimulation (or delayed response to the signal)</i>	
Lowered receptor sensitivity	Detection of near threshold stimuli
Misdirected attention	Vigilance tasks, divided attention tasks
Inadequate perceptual analysis	Search tasks (misses), vigilance tasks
<i>Intake of irrelevant stimulation</i>	
Distraction	Monitoring tasks with distractors
Inadequate perceptual analysis	Search tasks (false alarms)
<i>Processing deficits</i>	
Working memory deficits	Short-term memory tasks
Dysfunction of a specific or the central processor	Arithmetic, verbal, problem solving, etc
<i>Response selection and response failures</i>	
Incorrect selection of response	Choice reaction-time tasks with easily discriminated signal, but difficult signal-response relations (signal-response incompatibility); choice reaction-time tasks with few and easily discriminated signals and easy signal-response relations (inhibition failures)
Inability to perform the response	Manipulatory tasks, tapping

sleepiness at the low end to extreme excitation at the high end. Thus the effects of environmental factors like noise and vibration, as well as those of, eg, task characteristics and time of day, have been treated as being mediated by their effects on arousal level. Monotonous, low-level stimulation is generally presumed to lower the arousal level, whereas high-level, variable stimulation is regarded as arousing. Furthermore it is generally presumed that there is an optimum arousal level for every task and that this optimum is lower for more complex tasks (the inverted U function and Yerkes-Dodson's law).

Arousal theory assumes that the environment produces its effects by altering the general state of the person and says nothing of the specific processes involved. Thus, it gives rather imprecise predictions of how performance is likely to be affected. It is therefore often supplemented by Easterbrook's cue utilization hypothesis, which states that attention becomes increasingly selective when the arousal level is raised (20). This hypothesis would explain why the optimal arousal level is lower for more complex tasks than for easier tasks. Complex tasks typically require the utilization of more sources of information, whereas easier tasks generally permit very selective attention without performance being impaired. A corollary to this hypothesis is that, when arousal level is lowered below the optimum, the decrement is accompanied by a decreased ability to focus attention on the stimuli which are critical for the task at hand (20—23). Arousal theory is discussed further in Åkerstedt's (9), Enander & Hygge's (5), and Kjellberg's (3) articles on workhours, thermal stress, and noise, respectively.

Well-founded criticism has been directed towards this traditional unidimensional concept of arousal. (See, eg, references 23 and 24.) Alternative formulations have been suggested that imply that there are two types of arousal mechanisms (25) or several arousal states with different patterns of effects on performance (23). Another major target for criticism has been the mechanistic relation between arousal and performance proposed by the traditional formulations. The fact that the effects of various environmental loads seem to be sensitive to rather subtle changes in the task or the situation has cast doubts on such a notion. The introduction of the concept of effort has been one way of dealing with some of these results. (See the following discussion.) However, even though there undoubtedly are performance effects which cannot be predicted from arousal theory (eg, some effects of combined stressors), there is no rival theory of comparable explanatory power. Thus a rough grouping of environmental conditions into arousing and dearousing ones is fruitful when the choice of performance tests is considered. Factors such as monotonous tasks, sleep deprivation, exposure to solvents, prolonged exposure to low-level monotonous noise or vibration, and high room temperature normally lower the person's arousal level and may lead to an impaired ability to attend to

the critical stimuli. In performance this lower arousal level manifests itself as more missed stimuli and as slower responses. The tasks most sensitive to such dearousing factors are generally simple, monotonous tasks which make high demands on sustained attention and which give the subject poor feedback. Typical examples are prolonged simple vigilance and reaction-time tasks.

Other work loads, such as high work demands and intense and variable environmental stimulation, may lead to the opposite effect, ie, to arousal above the optimal level. The effects of such loads on performance are much less consistent than those of too low an arousal level. The most sensitive tasks usually seem to be those which make high demands on divided attention, information processing, and memory. Furthermore, the performance decrement is typically revealed as an increased error rate rather than as a reduced response speed. Many of the effects seem to be a consequence of overly selective attention, which is sometimes labeled "funnel vision." Other effects indicate a lowered ability to withhold highly prepared but erroneous responses.

Compensatory activities and the limitations of performance as an indicator of environmental load

The environmental effects on performance as a result of direct interference with peripheral motor or sensory functions are more or less unavoidable. Thus, eg, above a certain level noise inevitably deteriorates the reception of acoustic information.

In other cases compensatory activities from the individual may leave the performance level more or less unaffected. This compensation may sometimes be accomplished through new ways of performing the task, eg, through the more effective use of visual information than otherwise in a noisy situation. However, at least for a limited time, a person may be able to maintain the performance level merely through an increase in the level of effort. This increase is possible since the normal performance level generally lies below the person's maximum level of performance. Figure 3 illustrates how an environmental load may manifest itself in performance and effort given that the person chooses different ways of coping with the nonoptimal work conditions. A fourth possibility to take into consideration, which is not illustrated in the figure, is that the primary action of the environment is on the person's motivation. This action would manifest itself as a lowered level of both performance and effort. [For an elaboration of the relation between effort and arousal see the report by Sanders (24)].

Thus an unchanged performance level does not necessarily mean that the environment is without any effect; the performance may have been attained at a higher cost than otherwise would have been the case. Subjective ratings of effort and psychophysiological measurements may be used as indicators of effort and

may thus contribute to the interpretation of performance data.

Performance indicators

In traditional testing and in clinical neuropsychological studies, the frequency of correct responses (or errors) has usually been the main indicator of performance level. In experimental psychology, on the other hand, and in nonclinical studies of the work environment, response times have been performance measures of at least equal importance.

Error rates may be important for several reasons. As has already been mentioned, some environmental factors affect error rates rather than response times. Furthermore, if safety risks are assessed, a high error rate is generally more relevant than a slowing of the responses. The main disadvantage of error measures is that the task must be made difficult enough to provoke some errors even among the best performers. If not, the error measure becomes too unreliable and insensitive. Then the task becomes very frustrating for less able persons and may have undesired effects on their performance.

When response times are measured, all responses are used for assessing the effects, not just the items which yielded incorrect responses. Therefore a more reliable measure is obtained. The fact that response times give a graded measure of the response to each item also means that it is possible to detect effects that are not great enough to lead to an error, but merely to a delayed response. This possibility, in turn, means that one can use tasks which are rather easy and nonfrustrating without too much sensitivity being lost.

The possibilities of precise measurements of response times have been greatly enhanced by the recent and rapid development of computerized testing. This and other aspects of computerized testing are discussed in the article by Iregren & Gamberale (1).

General demands on a performance test used for the evaluation of environmental effects

There are considerable differences between tests regarding the extent to which they satisfy general psychometric requirements such as reliability, sensitivity, specificity, theoretical interpretability, face validity, appropriate difficulty level, acceptable duration, and repeatability. The relative importance of these requirements also varies considerably as a consequence of the aim and design of the study. Repeatability is, eg, of crucial importance in studies involving repeated measurements, which is often true of experimental laboratory investigations. In field studies it is almost always necessary to use tests of short duration in order to minimize the interference with the work process. Face validity is a further important aspect in such studies since it must appear reasonable for the person to perform the test.

Figure 3. Three ways of coping with nonoptimal work conditions reflected in different relative changes of performance and effort.

Psychophysiology

Subjective ratings and performance may not always be sufficient to obtain information on the behavioral effects of the work environment. Sometimes physiology is brought in as a complement, the result being "psychophysiology of the work environment."

Rationale

One main reason for employing psychophysiology in research on the effects of the work environment is to infer psychological changes when direct psychological measurement is either difficult, impossible, or inappropriate. Such may be the case when, eg, fluctuations in psychological load are monitored via heart rate measurement because the investigator needs continuous information which the individual cannot provide subjectively at a rate of one estimate per second. In addition, the fluctuations in load and the individual's response may not be conscious phenomena and thus not available for report to the investigator. An extreme but common example of the latter may be measurement of recovery processes during sleep.

Another major application of psychophysiology in the work environment is in the identification of psychosomatic risk situations or risk groups. This use of psychophysiology is based on the notion that psychological (or psychosocial) stimuli may cause physiological changes which, if sufficiently pronounced and sufficiently often repeated, may lead to disease (26, 27). This type of research may involve, eg, blood pressure or hormonal responses to particular work situations.

A third and very common reason for using psychophysiology is simply to support psychological data. For example, symptoms of "neck tension" at a computer terminal may be taken more seriously if accompanied by a physiological verification of muscle tension.

Arousal and physiology

The most central concept in psychophysiological research on the work environment has been "arousal." (See the discussion in the Performance Measurements

section.) The concept of "stress" is closely related but involves a concerted physiological mobilization to cope with increased psychosocial demands (26, 27). Both concepts have been the focus of much work environment research.

From the point of view of arousal the key structures in the CNS are the reticular activating system, which regulates the arousal level of the brain; the hypothalamus, which regulates visceral and somatic functions (body temperature, metabolism, endocrine balance); and the pituitary, which mediates much of the regulatory information from the hypothalamus to the endocrine system.

The sympathetic nervous system mediates signals from the brain to target organs in order to mobilize the body to meet demands for increased performance, eg, in an emergency situation. Among other things, increased sympathetic activity increases heart rate and heart contractility, constricts smooth muscles in, eg, the blood vessels, dilates the bronchi, inhibits gastrointestinal peristalsis, inhibits bladder contractions, stimulates the conversion of glycogen to bile, inhibits salivation, dilates the pupil, stimulates the sweat glands, and stimulates the adrenal medulla to secrete noradrenaline and adrenaline. The last-mentioned actually reinforces many of the prior effects by preserving or increasing the effects of the original signal of activation. The parasympathetic nervous system has a similar mediating role but in many instances partly counteracts the effects of the sympathetic nervous system.

Measurement methods

The changes in arousal/activation that have been described may be studied as changes in the electrical properties of the skin, picked up via skin electrodes, amplified, and transcribed on paper (or stored on magnetic tape) with the help of a polygraph — the traditional instrument in psychophysiology. If supplied with transducers converting movement, pressure, temperature, etc, to electric signals, the polygraph may be used to record respiration, blood pressure, skin temperature, etc (28, 29).

It should be emphasized that most physiological recordings are carried out in the laboratory. However, with the advent of techniques of telemetry and small individually worn tape recorders and polygraphs, it has become possible to conduct psychophysiological measurements in the normal life situation of the individual. This development is, of course, of the utmost importance for psychophysiological studies of the effects of the work environment.

Body fluids (urine, saliva, blood) are used to obtain information, particularly on hormonal responses to environmental demands. Among the target variables are adrenaline, noradrenaline, and corticosteroids. The procedure of collection and analysis varies greatly depending on the substance.

Physiological response systems

For a detailed overview of the response systems, see the article by Coles et al (28) or the one by Hassett (29).

Cardiovascular measures. Cardiovascular measures are by far the most frequently used in occupational psychophysiology. The reason is, of course, their sensitivity to mental and physical events, their outstanding clinical relevance, and their simplicity of measurement. The electrical changes of the cardiac cycle may be used simply as an aid in the counting of heart beats or, when described in detail (the electrocardiogram), to provide measures of various phases of the heart cycle. Heart rate has been the dominating output and has been related to almost every conceivable work environment variable. It may be used to obtain an impression of physical work load or mental work load or aversive reactions to work environment factors such as noise, vibration, danger, fumes, etc.

Blood pressure represents the arterial pressure at the peak of cardiac contraction (systolic) or at the phase of the trough/relaxation (diastolic). It has mainly been used in clinical studies of work environment effects. Recently, however, self-measurement techniques have been used successfully. They have yielded important information about the covariation between blood pressure and work load.

Electromyography. Electromyography describes the electrical changes recorded for the motor units of a muscle through electrodes on the skin (or needle electrodes inserted in the muscle). Much of the psychophysiological research on conditioning, biofeedback, etc, would be difficult without electromyography. Stress, tension, and effort are often reflected in increased muscle tone. In the work environment electromyography has frequently been used to reveal poor work positions and behavior leading to incapacitating pain conditions.

Electroencephalography. The main source of information on brain activity is electroencephalography, which describes the electrical changes of the brain via electrodes pasted to the scalp. The spontaneous activity is analyzed visually or through computer analysis. It is the most appropriate for use at the low end of the arousal continuum, as a measure of sleepiness or sleep. It has been used to study the effects of, eg, night work, monotony, or toxic substances. The effects usually take the form of a lowering of frequency in the waking electroencephalogram. It may be of great importance in accident research, particularly in occupations that require the operation of vehicles or moving machinery. Although clinical electroencephalographic equipment is normally very cumbersome, recent developments of portable recorders have made field studies of ambula-

tory subjects feasible also in work situations. [See the article by Åkerstedt (9)].

A special application of electroencephalography is the evoked potential, ie, the effect of a peripheral stimulus studied at an electroencephalographic electrode site. The resulting pattern is related to attention, problem solving, fatigue, etc. The applications in, eg, toxicology seem very promising. The measurement technique requires stationarity and laboratory conditions.

Eye responses. Psychophysiological research on the eyes has focused on pupil size, eyelid movements, or eye movements. Recently some rather provocative research has related pupil dilation to task difficulty, attitudes, like/dislike, sleepiness, etc. The technique does, however, require stationary and cumbersome equipment (like video cameras) to obtain continuous recording of the pupil. Eyelid and eye movements are easier to measure through, eg, electrodes applied horizontally and vertically across the eye — electro-oculography. Apparently, blink frequency may be very high or very low during exposure to stress or boredom. Eye movements — their speed, smoothness, and precision — are related to psychological states and have been subjected to much research in relation to the ergonomics of work stations and similar areas. Both blink rate and eye movements are important variables in measurements of wakefulness and sleep. [See the article by Åkerstedt in this supplement (9)].

Electrodermal activity. Probably the most traditional psychophysiological variable is electrodermal activity. It is based on the observation that events in the brain (including emotional events) will, via the sympathetic nervous system, increase the activity in the sweat glands on the palms of the hands and on the soles of the feet. It is, however, very sensitive to movement disturbances and can hardly be used outside the laboratory.

Psychoneuroendocrine activity. Psychoneuroendocrine activity, in particular the secretion of adrenal hormones, serves as a useful indicator of stressful person-environment interactions (30).

These hormones are released from the cortex and the medulla of the adrenal glands. Recent neuroendocrinological research has revealed the pathways and neuroendocrine mechanisms involved in brain control of the endocrine system. Environmental demands are evaluated through cognitive processes. When demands are perceived as exceeding the individual's coping or carrying capacity (31), a chain of events is triggered. Through the sympathetic nervous system, signals are sent to the adrenal medulla, which secretes adrenaline and noradrenaline. Signals from the brain also pass via the hypothalamus and the pituitary to the adrenal cortex, which secretes corticosteroids, eg, cortisol.

Adrenal hormones can be measured in blood or in urine. Repeated blood samples reflect moment to moment variation in the amount of circulating hormone, whereas urinary measures give integrated estimates covering the period between two voidings. Thus, the choice between blood and urinary measures is partly a matter of the purpose of the study. Another important difference is that urine samples may be obtained with minimal interference in a person's daily life, whereas the sampling of blood cannot.

Although only a small fraction of catecholamines is secreted into the blood stream, this fraction tends to be fairly constant. Blood and urine measures reflect environmental impacts in a similar way (32). For cortisol, the correlation between measures obtained in blood and in urine is also fairly high (33).

The secretion of adrenal hormones is sensitive to several external factors which must be kept under control or carefully monitored. Smoking and the intake of caffeine and alcohol will increase the excretion of catecholamines, and various kinds of medication may also affect adrenal hormone production. The circadian rhythm of the hormones is pronounced (see the following discussion), and the time of day must, therefore, be controlled for in the design of a study involving hormone measures.

Interindividual differences are considerable when compared with intraindividual variations over time. Thus individuals tend to maintain a characteristic baseline level of excretion (34). Therefore, most investigations including these measures require that some form of resting or base-line measures be obtained. Only in study samples of considerable size can random selection be assumed to eliminate between-group differences in habitual levels of excretion.

Early studies of catecholamine response to mental effort demonstrated a tendency for men to react with a more pronounced response than women (34). Later, more systematic investigations have revealed that the size and direction of such a sex difference is dependent on sex roles and the type of challenge presented in each situation. (For a review, see reference 35.) Thus situations which challenge "female competence," eg, when the parent role is emphasized, have been shown to trigger a slightly stronger reaction in women than in men (36).

Numerous studies indicate that adrenaline excretion tends to be associated with emotional arousal, whereas noradrenaline, which is involved in blood pressure homeostasis, is more readily released in response to physical exertion. Cortisol, like adrenaline, affects various bodily organs but differs from adrenaline in its closer involvement in the immune system. Several models for assigning differential functions to the different adrenal hormones have been put forth. (See, eg, reference 37.) Frankenhaeuser & Lundberg (38) have emphasized personal control as a key factor in the regulation of catecholamine-cortisol balance. They suggested that effort with distress is associated with

an increase in catecholamines and cortisol, whereas effort without distress tends to increase catecholamine levels but maintain or even suppress the secretion of cortisol. Finally, distress without effort — usually low-control situations — tends to be associated with an increase in cortisol output.

As has already been indicated, the adrenal hormones have usually been used as indicators of emotional arousal and mental strain. Physical aspects of the environment have not tended to arouse a similar response from the adrenal glands. One exception is exposure to overstimulation and understimulation. (For a review, see reference 39.) These concepts have been used to describe extremely intense and/or varied environmental stimulation versus extremely weak and/or monotonous stimulation. Although, at a cortical level, overstimulation is associated with high arousal and understimulation with low arousal, both conditions usually elicit an increase in adrenaline excretion and negative emotional reactions.

More recently attention has been drawn to the combined impacts of physical and psychosocial factors in the environment. Although systematic studies of such combined effects are scarce, available data indicate that the physical environment may have its major impact on the excretion of adrenal hormones through the mediating or moderating effects of psychosocial factors (40).

For more-detailed information on the biochemistry of catecholamines, the reader is referred to the book by Lake & Ziegler (41). A comprehensive review of the psychobiological research on adrenal hormones has been presented by Lundberg (37).

Selection of measures

The type of variable used in a study would depend on the particular research question and whether the study is carried out in the laboratory or in the field and on whether the measurements need to be continuous or not. Quite clearly the laboratory offers the largest selection of variables. In any case, much of the decision will be based on which part of the arousal continuum is of interest.

As an example we may conceive of the investigator who is interested in mental or physical work load or the indirect effects of noise. He or she would need variables sensitive to high arousal levels and probably decide to use a portable recorder to obtain a continuous measure of heart rate as the central parameter. This person might also add automatic or self-measured blood pressure since these parameters also may have a high clinical relevance. These measures should be combined with frequent use of rating scales or diaries to describe the situation in which physiological changes occur. The investigator might also try to obtain urine samples for analyses of stress hormones.

Another investigator may be interested in the effects of monotony, infrasound, heat, neurotoxic substances,

or night work on sleepiness (and perhaps accident risk). He or she would be looking for indices of low arousal and probably use a portable recorder to obtain continuous measurement with electroencephalography and electrooculography during work, also together with ratings of sleepiness. This person might also introduce a more controlled situation by putting the subject in a dark room and measuring the time it takes before sleep patterns appear in the electroencephalogram/electrooculogram (a so-called sleep latency test). The neurotoxicologist would probably, in addition, want to study the effects of, eg, solvents in the laboratory under controlled conditions with known doses.

Circadian regulation

Finally, it should be emphasized that the behavioral and psychophysiological effects discussed in this publication all occur against a background level that oscillates on a 24-h basis, thus the term "circadian" — from *circa dies* about one "day" (42). The pattern is usually sinusoid, with a peak value sometime during waking and a trough during sleep. It is important to note that this pattern persists even when all possible external time signals ("Zeitgebers" or "synchronizers") are removed. The regulatory brain structure for the circadian rhythm is thought to be the suprachiasmatic nuclei in the hypothalamus.

Although the entire causal chain is unclear, the effects of circadian regulation are often striking. The variation in performance, eg, may exceed the effects of interindividual differences or fatigue several times. The circadian pattern is one of low levels in the early morning and high levels in the early evening, with some differences between different psychological functions.

With regard to physiology the day begins with a morning peak for cortisol (with a very high amplitude), potassium, and diuresis. Adrenaline peaks during the middle of the day, body temperature in the afternoon/evening, and the pineal hormone melatonin late at night. In all cases the circadian amplitude is at least as large as any effect of normally occurring environmental influences. Sleep propensity closely follows a circadian pattern with a maximum at the circadian trough of body temperature (or around the peak of melatonin secretion).

One important consequence of circadian regulation is that the position of workhours in the day-night cycle will have major effects on behavior and physiology. In addition, any psychological or physiological data that are not controlled for circadian phase will suffer from large unwanted biases.

Concluding remarks

One of the most important contemporary problems, an answer to which has a significant bearing from the preventive medical and social point of view, is the pro-

tection of workers and the improvement of the work environment in the interest of present and future generations.

The influences of the chemical, physical, biological, and psychosocial factors in the work environment are, as yet, not fully understood, and there is a need for the use of sensitive research methods. In addition these influences are interrelated and require the effort of various disciplines, among others physiology and psychology.

Over the last 15—20 years, both behavioral and psychophysiological methods have been increasingly applied in research concerning the adverse effects of unfavorable physical conditions in the work environment. This development has to be seen as a natural result of the fact that early manifestations of an adverse work environment almost always include behavioral and psychophysiological changes. The application of behavioral and psychophysiological methods has made an important contribution to occupational hygiene and has created a new perspective within this discipline.

References

- Iregren A, Gamberale F. Human behavioral toxicology: central nervous effects of low-dose exposure to neurotoxic substances in the work environment. *Scand J Work Environ Health* 1990;16(suppl 1):17—25.
- Wetterberg L. Lighting: nonvisual effects. *Scand J Work Environ Health* 1990;16(suppl 1):26—8.
- Kjellberg A. Subjective, behavioral and psychophysiological effects of noise. *Scand J Work Environ Health* 1990;16(suppl 1):29—38.
- Kjellberg A. Psychological aspects of occupational vibration. *Scand J Work Environ Health* 1990;16(suppl 1):39—43.
- Enander A, Hygge S. Thermal stress and human performance. *Scand J Work Environ Health* 1990;16(suppl 1):44—50.
- Gamberale F. Physiological and psychological effects of exposure to extremely low-frequency electric and magnetic fields on humans. *Scand J Work Environ Health* 1990;16(suppl 1):51—4.
- Borg G. Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health* 1990;16(suppl 1):55—58.
- Gamberale F. Perception of effort in manual materials handling. *Scand J Work Environ Health* 1990;16 (suppl 1):59—66.
- Åkerstedt T. Psychological and psychophysiological effects of shift work. *Scand J Work Environ Health* 1990;16(suppl 1):67—73.
- Theorell T. Family history of hypertension — an individual trait interacting with spontaneously occurring job stressors. *Scand J Work Environ Health* 1990;16 (suppl 1):74—9.
- Nowlis V. Research with the mood adjective check list. In: Tomkins SS, Izard CE, ed. *Affect, cognition and personality*. New York, NY: Springer, 1965:352—89.
- Kjellberg A, Bohlin G. Self-reported arousal: further development of a multi-factorial inventory. *Scand J Psychol* 1974;15:285—92.
- McNair DM, Lorr M, Droppleman LF. *Profile of mood states*. San Diego, CA: Educational and Industrial Testing Service, 1971.
- Sjöberg L, Svensson E, Persson LO. The measurement of mood. *Scand J Psychol* 1979;20:1—18.
- Mackay CJ, Cox T, Burrows G, Lazzerini AJ. An inventory for the measurement of self-reported stress and arousal. *Br J Soc Clin Psychol* 1978;17:283—4.
- Watson D, Tellegen A. Toward a consensual structure of mood. *Psychol Bull* 1985;98:219—35.
- Kjellberg A, Iwanowski S. Stress/Energi-formuläret: utveckling av en metod för skattning av sinnesmåning i arbetet [The Stress/Energy questionnaire: development of a scale for rating mood at work]. Solna (Sweden): National Institute of Occupational Health, 1989. (Undersökningsrapport 1989:26.)
- Gamberale F, Iregren A, Kjellberg A. SPES: the computerized Swedish Performance Evaluation System: background, critical issues, empirical data, and a users' manual. Solna (Sweden): National Institute of Occupational Health, 1989. (Arbete och hälsa 1989:6.)
- Cruickshank PJ. A stress and arousal mood scale for low vocabulary subjects: a reworking of Mackay et al (1978). *Br J Psychol* 1984;75:89—94.
- Easterbrook JA. The effect of emotion on cue utilization and the organization of behavior. *Psychol Rev* 1959;66:183—201.
- Hockey GRJ. Effect of loud noise on attentional selectivity. *Q J Exp Psychol* 1970;22:28—36.
- Hockey GRJ. Changes in attention allocation in a multi-component task under loss of sleep. *Br J Psychol* 1970; 61:473—80.
- Hockey GRJ. Changes in operator efficiency as a function of environmental stress, fatigue, and circadian rhythms. In: Boff KR, Kaufman L, Thomas JP, ed. *Handbook of perception and performance; vol 2 (cognitive process and performance)*. New York, NY: John Wiley & Sons, 1986;44:1—44:49.
- Sanders AF. Towards a model of stress and human performance. *Acta Psychol* 1983;53:61—97.
- Broadbent DE. *Decision and stress*. London: Academic Press, 1971.
- Cox T. *Stress*. London: The Macmillan Press Ltd, 1978.
- Weiner H, Florin I, Murison R, Hellhammer D, ed. *Frontiers of stress research*. Toronto: Hans Huber Publishers, 1989.
- Coles MGH, Donchin E, Porges SW. *Psychophysiology*. New York, NY: The Guilford Press, 1986.
- Hassett J. *A primer of psychophysiology*. New York, NY: WH Freeman and Company, 1978.
- Frankenhaeuser M. A psychobiological framework for research on human stress and coping. In: Appley MH, Trumbull R, ed. *Dynamics of stress: physiological, psychological, and social perspectives*. New York, NY: Plenum, 1986:101—16.
- Appley MH, Trumbull R, ed. *Dynamics of stress: physiological, psychological, and social perspectives*. New York, NY: Plenum, 1986.
- Åkerstedt T, Gillberg M, Hjemdahl P, et al. Comparison of urinary and plasma catecholamine responses to mental stress. *Acta Physiol Scand* 1983;117:19—26.
- Lundberg U, Hanson U, Andersson K, Eneroth P, Frankenhaeuser M, Hagenfeldt K. Hirsute women with elevated androgen levels: psychological characteristics, steroid hormones and catecholamines. *J Psychosom Obstet Gynaecol* 1983;2:86—93.
- Johansson G, Post B. Catecholamine output of males and females over a one-year period. *Acta Physiol Scand* 1974;92:557—65.
- Frankenhaeuser M. The sympathetic-adrenal and pituitary-adrenal response to challenge: comparison between the sexes. In: Dembroski TM, Schmidt TH, Blümchen G, ed. *Biobehavioral bases of coronary heart disease*. Basel: Karger, 1983:91—105.
- Lundberg U, de Chateau P, Winberg J, Frankenhaeuser M. Catecholamine and cortisol excretion patterns in three year old children and their parents. *J Hum Stress* 1981;7:3—11.
- Lundberg U. Human psychobiology in Scandinavia: II.

- psychoneuroendocrinology — human stress and coping processes. *Scand J Psychol* 1984;25:214—26.
38. Frankenhaeuser M, Lundberg U. Psychoneuroendocrine aspects of effort and distress as modified by personal control. In: Bachmann W, Udris I, ed. *Mental load and stress in activity: European approaches*. Amsterdam: North-Holland, 1982:97—103.
 39. Frankenhaeuser M, Johansson G. On the consequences of understimulation and overstimulation. In: Levi L, ed. *Society, stress, and disease; vol 4 (working life)*. London: Oxford University Press, 1981:82—9.
 40. Evans GW, Johansson G. A multivariate perspective of environmental stress. *Arch Complex Environ Stud* (in press).
 41. Lake CR, Ziegler MG, ed. *The catecholamines in psychiatric and neurologic disorders*. Boston, MA: Butterworth, 1985.
 42. Moore-Ede MC, Sulzman FM, Fuller CA. *The clocks that time us*. Cambridge, MA: Harvard University Press, 1982.