COMMISSION OF THE EUROPEAN COMMUNITIES

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EVALUATION OF WORK REQUIRING PHYSICAL EFFORT

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EUR 5221 e

Published by the Commission of the European Communities
Directorate-General Scientific and Technical Information
and Information Management
Luxembourg 1975

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Foreword

This review of the present state of ergonomic research to evaluate work requiring physical effort, was requested by the Commission of the European Communities (Directorate-General for Social Affairs). It is intended primarily for practical use in industry. It deals first with the methods available and discusses their applicability to future studies in coalmining and the iron and steel industry.

It also sets out to present, for practical application, the results of the research programme carried out with the support of the Commission, on the subject of "The metabolism of work and working posture". These, together with other published results provide a documentary record of the techniques now available for evaluating work requiring physical effort.

Darmstadt, 1973

1. Introduction

We have chosen for this review and discussion of research results the title "Evaluation of work requiring physical effort". This requires one or two definitions before we proceed. Let us start with the term "evaluation". By this we mean a scientific appraisal of phenomena described, recorded data or results derived from them.

This appraisal becomes an evaluation in that it has to be done at the levels listed below (ROHMERT, 1972) which relate to men at work; these set out to assess the industrial ergonomic and organizational conditions under which work

can be done
is tolerable
is acceptable
is satisfying

The first two levels (performable, tolerable) are scientific classifications, but social classifications are also necessary to measure acceptability. For instance, different group attitudes (employees and employers) or different conditions in the labour market (shortage of workers or unemployment) may alter the estimation of acceptability of a job. Job acceptability is always linked to the acceptance of the work and working conditions by the worker.

Job satisfaction is similarly difficult to assess. Although this is far more of an individual matter than acceptability, satisfaction at and with a job is again closely linked to prevailing social values.

It is obvious from what has been said above that, for evaluating work requiring physical effort the methods and criteria used for assessing whether work is performable and tolerable are essential and most important as a basis for agreeing on job acceptability.

Lastly, the qualifying phrase "work requiring physical effort" means that we shall be restricting ourselves solely to the assessment of "muscular work", and the supplementary effects of physical, environmental factors will not be considered separately. This qualification implies that we draw a sharp distinction between all types of work involving conversion and processing of information, and jobs involving muscular work.

2. Expanding the term "effort" by the term "stress"

Work requiring "effort" may be actively demanding or passively arduous. In both cases, effort can be regarded as the response to a demand which must be made of a person to complete a task. Particularly in its active sense, effort clearly depends on the worker's will. Therefore, for describing or measuring effort it is necessary to find suitable measurable variables for determining the worker's will. However, since ordinal differentiation (more or less, very arduous) in respect of passive "effort" represents a rudimentary system of evaluation, we may usefully use the term "stress" to describe this passive meaning.

If we look at the meaning of "stress" in the engineering sense, particularly in respect of materials and mechanical technology, rather than the general, everyday meaning, there is a clear distinction between "stress" and "strain" (work load) (cp. for example SCHARDT, 1968).

By applying the technical terminology to ergonomics, we obtain the following definitions (cp. ROHMERT et al., 1973).

Strain (work load) is the sum total of all the factors which affect a person, both via his receptor system (sense organs) and/or by making demands on his effector system (muscles), at work.

On the other hand, by stress we mean all the effects of strain on the person, resulting from his particular characteristics and capabilities. Thus, stress depends on strain (work load) and individual characteristics (e.g. physical capacity, training) (see also SCHMIDT [005])[x].

Comparing this definition of stress with the passive meaning of the term "effort" shows that any rating scale for effort would have to have a zero which depended on will and subjective feeling, since, from the point of view of motivation, some work may be regarded as "not requiring any effort" whereas stress, as defined above, would have to be greater than zero, even in these cases.

[x] [...] Reference to a report on research from the "Occupational physiology and psychology" programme sponsored by the Commission of the European Communities, Research No.: 6242-22-1 [...]

Thus, to summarize, effort can be described as the subjective perception of physiological stress produced by a measurable work load or strain. So it may be possible to quantify stress by measuring suitable physiological variables but, as with other "measures of feeling" in ergonomics (e.g. phon or effective temperature) to quantify effort we have to rely on a subjective rating scale based on comparisons.

Thus, we can use inquiry techniques familiar in psychology and sociology (e.g. questionnaires or interviews) to evaluate work at the level of acceptability and satisfaction, but these will be confined to assessing restricted groups of people (for instance, the group of railway postal service workers in Germany - ROHMERT, LAURIG and JENIK, 1973).

3. Theory of measuring stress

If, from the definitions above, strain or work load is regarded as the cause of stress, it follows from this cause-effect relationship that to measure stress we must first measure work load. SCHMIDT [005] has put this very simply by stating that stress is proportional to work load, with a proportionality constant which we can call an individual constant (see equation 1):

$$\text{work load} \cdot \text{individual constant} = \text{stress} \quad (1)$$

This statement also shows that we can measure stress by measuring work load, if we make suitable assumptions regarding the "individual constant".

If, from our definition, work load is regarded as a sum total of various demands, then separate components will have to be measured to obtain this sum. According to TORGERSON's definition (1958), "measurement" involves allocating numbers to represent the properties of objects. TORGERSON's concept requires, as a minimum, an ordinal rating scale with which to compare the properties to be "measured". However, since strain or work load may be produced by sociological or psychological factors which cannot be quantified by allocating them numbers in the scientific sense, these unquantifiable factors will be called "work load <u>factors</u>". On the other hand, all measurable factors (for instance, strength, time, methods, also temperature or acoustic pressure) will be called work load <u>parameters</u>. Thus, the following equation can be postulated for describing work load:

$$\text{work load} = f(\text{work load parameters, work load factors})^{x)} \qquad (2)$$

It then following for stress, that:

$$\text{stress} = g(\text{work load parameters, work load factors, individual characteristics and capabilities}) \qquad (3)$$

It follows from this that work load and stress cannot be measured directly, since there are concepts to which measurable properties can only be <u>ascribed</u> by the equations above.

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x) f(...), mathematical expression for: "function of", for postulating various general functions by selecting different small letters such as f, g, h.

Thus, from equation 3 we obtain the analytical, that is the deductive approach already alluded to, for measuring stress: Stress is determined as a dependent variable from a functional relationship between measured work load parameters and individual characteristics. However, for this analytical approach we need to know the corresponding functional relationship, and hitherto this is only known for a particular form of work requiring physical effort (static holding work: MONOD, 1956, ROHMERT, 1960, 1962) in a form which can be used for dealing with practical problems.

We therefore have to determine the lefthand side of equation 3 directly by measuring suitable physiological indicators of stress; this is an inductive approach to measuring stress. In practice, we regard the physiological variable "pulse rate" as having the property of varying with stress. Pulse rate would then be called a stress parameter, analogous to the concept of a work load parameter, since it is measurable in the sense defined above. It is again true that only the measurable part of stress is determined, and so the equation underlying the "measurement" is:

$$\text{stress} = h\ (\textstyle\sum \text{stress parameters})^{\text{x)}} \qquad (4)$$

which expresses the fact that measuring a stress parameter, e.g. pulse rate, only measures part of the stress.

However, unlike the deductive approach, use of physiological indicators of stress may, in certain circumstances, also include the effects of non-measurable work load factors. For instance, this is particularly true of pulse rate, which may be affected by mental factors, especially emotional factors, as well as the physical aspects of the work (RUTENFRANZ, ROHMERT and ISKANDER, 1971; ROHMERT et al., 1973).

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x) $\sum$ mathematical expression for "sum of"

This characteristic, which is the summation of a number of physiological parameters of stress, may be a source of error if equation 4 alone is used without regard to the work load. Therefore, as a rule we now base our approach on a combined formula for stress, developed from equation 3, in which both stress parameters and work load parameters are recorded and linked as follows by calculating regression and correlation:

$$\text{stress parameters} = g_1 \text{ (work load parameters, residual variance)} \quad (5)$$

The assumptions made for stress in equation 2 are used in this formula. The parameter of residual variance which remains can be regarded here as a measure of the precision of the measurable part of stress.

Linear multiple regression equations are generally used to describe the function g_1, but these only admit one dependent variable as a parameter of stress. Generalizations with several stress parameters as functions of several work load parameters can be achieved by extending the multiple correlation calculation, the "canonical correlation". However, this method has rarely been used in ergonomic studies to date (ROHMERT et al., 1973; LAURIG, in the press).

4. Forms of work requiring physical effort

From what has been said in Chapter 2, "work which requires physical effort' is defined as work requiring application of force, which the person must produce by muscular innervation. However, this force produced by tensing the muscles is not transmitted directly to the work object, tool or a machine. The muscle force is transmitted via lever arms formed by the limbs. Generally speaking the lever arms move and so the point at which the force is transmitted is not fixed but travels a moving path characteristic of the task. Thus, human work can be defined in terms of physics (physical work = force . distance). On the other hand, some tasks only require transmission of muscular force, and movement is not possible or desirable. The point of transmission of the force therefore remains more or less stationary, and the work cannot be defined in physical terms. Thus, observation shows us that we can distinguish between

dynamic and static muscular work.

This distinction is drawn in Table 1, with further subdivisions for our purposes.

If, in addition to this phenomenological type of distinction, we also use the stress on a person or his organs as criteria of classification, we can make a further useful subdivision:

In "heavy" physical work, large muscle groups are dynamically active (for instance, loading the heaps underground); however, the operation of tools, for example, often only requires the dynamic use of small, isolated groups of muscles (e.g. using screwdrivers, pliers or cutters, and cyclic assembly work). There are definite differences in stress in that, in the first case, the circulatory and respiratory system is stressed as well as most of the skeletal muscles, whereas in the latter case only isolated muscles, for instance the arm or hands, are used. ROHMERT (1966) therefore recommended the term "heavy dynamic muscular work" for dynamic work involving large, that is heavy groups of muscles, and "unilateral dynamic muscular work" for dynamic work involving small muscle groups.

Form of muscular work	Called: "... work"	Characteristics	Examples	Stress characteristics
Static	Postural	No movement of limbs, no force on working part, tool or control	Holding the upper part of the body whilst standing bent over	The circulation is impeded by internal muscle pressure when muscles are exerting only 15% of their maximal force, and hence this greatly reduces maximum duration of work (to a few minutes)
	Holding	Limbs do not move; forces applied to working part, tool or control	Overhead welding or rigging, carrying	
	Contraction	Sequence of static contractions	Castings cleaning	Transitional form; stress comparable to static work where movement is infrequent
Dynamic	Unilateral (dynamic)	Small muscle groups, generally with fairly high rate of movement	Hand-lever press, using cutters	Maximum duration of work limited by working capacity of the muscle
	Heavy (dynamic)	Muscle groups > 1/7 of total mass of skeletal muscles	Shovelling	Limited by ability of circulation to supply oxygen

Table 1 Classification of muscular work corresponding to different levels of stress

Although the term "heavy dynamic muscular work" is comparable linguistically with "work requiring physical effort", the qualifying word "heavy" refers, by definition, to the size of the active muscle mass. Therefore, the borderline between this and unilateral dynamic muscular work is more or less pragmatic, since there has to be agreement on when a working muscle mass can be described as "heavy". However, if we tackle the question from the point of view of circulatory stress, the answer is not provided by the minimum size of the muscle mass (or muscle group). Here, cardiac performance is not the limiting factor for endurance. The limit is set by the work capacity of the muscles themselves; this is, roughly speaking when the vascular lumen in the muscles or the surface areas available for exchange within the muscle, have been regulated to their maximum limit (Müller, 1957). The "limiting mass" is about 1/7 of the total mass of skeletal muscle, according to the results of MÜLLER (1957, 1962) and HOLLMANN (1972). Thus, heavy dynamic muscular work is being done if a task demands the dynamic use of more than 1/7 of the mass of all the skeletal muscles.

In applying this numerical statement in practice, we can check the proportion of skeletal muscles in the extremities used as effectors. This shows that heavy dynamic muscular work is being done when the dynamic activity involves:

both legs or
both arms or
one arm and one leg

and the upper part of the body or back muscles to apply force to levers, cranks, tools or objects to be manipulated.

Unilateral dynamic muscular work is therefore being done when the dynamic activity involves:

one foot or
one arm, one hand or
the fingers of both hands

and the forearms.

However, this definition of unilateral dynamic muscular work only covers the physical components of an activity. If the activity requires a high degree of coordination of the sequence of movements, we term this "sensomotor activity", although hitherto this has not been satisfactorily distinguished from unilateral dynamic muscular work in the literature. Since we set out here to deal with the evaluation of work requiring physical effort, we need not discuss sensomotor activity any further. However, for the further discussion it might be useful to distinguish unilateral muscular work from sensomotor activity as far as possible since, formally unilateral dynamic muscular work must be regarded as work requiring physical effort. If we again look pragmatically at the practical forms, the typical features of unilateral dynamic muscular work are movements with the accent on force whereas, with sensomotor work, the predominant elements are skill (i.e. complex assembly problems, frequent preparation in terms of the systems of predetermined times). Finally, the type of movement can help us to draw the distinction in practice: if there is a ballistic (hammer) or controlled movement (crank, crowbar or lever), this can generally be assumed to be unilateral dynamic muscular work.

A further division of static muscular work is also useful so that we can define whether the static muscular work involves applying force to a work object or tool, or whether it is for stabilizing a body posture. Since practical examples of the first type of static muscular work generally involve <u>holding</u> parts, objects or tools, the term "static holding work" is reserved for these cases (ROHMERT, 1960, 1961). As yet there is no generally accepted term for the second type of static muscular work. A term such as "postural work" would suitably make a clear distinction.

Finally, another special case of a mixed form of muscular work must be mentioned. This is called "static contraction work" and applies where a sequence of separate static contractions are required in succession, producing the innervated type of dynamic muscular work, but the stress must be regarded as typical of static muscular work (e.g. castings cleaning, repetitive movement of levers or devices with a short travel (SCHLAICH and BREDEMEYER, 1966).

Generally speaking, the type of muscular contraction required for static muscular work is inappropriate to the functional capabilities of skeletal muscle, since even at low tensions compared with the maximal potential force, ($\sim$ 15% Fmax), the oxygen supply is blocked by pressure produced within the muscle and so maximum duration of work is reduced. This also applies to static contraction work, since the time between the single static contractions is too short to enable enough oxygen to reach the muscle via the circulation (ROHMERT, 1960 b). Thus there is not a distinct borderline between static and dynamic work as regards stress, since constricting the circulation and hence the oxygen supply may even reduce the maximum duration of dynamic muscular work where the frequency of movement is low, i.e. tends towards zero (although this also applies to situations in which the frequency of movement is fairly high).

5. Determining work load

5.1. General approach to analysing work load

In line with the discussion on measurability of work load and stress, work load will be analysed by measuring work load parameters and describing work load factors. For this description, qualitative documentation (for instance, using photography or simple description of work) must include a substantial amount of measurable working conditions. Therefore, based on theory, work load factors are given nominal categories. The measurable part of work load characterized by work load parameters can be illustrated by an equation (similar to those in Chapter 3). This is based on the assumption that work load has two main components, which we must be able to analyse, namely duration of work load and its level. Therefore:

$$\text{work load} = f_1\,(\text{duration of work load, level of work load, remainder}) \qquad (6)$$

where the remainder would allow for all the work load factors going to make up the work load. Therefore one way to analyse work load is to find suitable parameters for measuring the level of work load in conjunction with a continuous time measurement.

One possible way of finding a parameter for measuring level of work load for all forms of dynamic muscular work is to establish a measure of heaviness physically, similar to the physical definition of work. For static work, we can use a similar approach at least for static holding work, by substituting the physical definition of work by the operational definition

$$\text{work}_{\text{stat}} = \text{force} \,.\, \text{time}$$

(or more precisely: $\text{work} = \int_0^t \text{force} \,.\, dt$; from ROHMERT, 1959).

If a person's bodily posture at work is regarded as depending on the work or its design, then a bodily posture described (or photographed) can be regarded as a nominally defined work load factor. However to assess bodily posture quantitatively, we must measure every individual mass in the human body, its centre of gravity and changes of centre of gravity, in order to determine the level of work load by a mathematical description in accordance with physical laws. This sort of approach, called biomechanical analysis, also sets out to devise generalized, mathematical-mechanical systems for simulating human beings, for studying different combinations of levels of work load (BOUISSET, 1967, JENIK, 1973). However, for natural sequences of movement of separate limbs and movements of the whole body, the necessary combination of different equations gives rather complex systems of algorithms which can only be economically handled by electronic data processing (KROEMER, 1973), so we shall not go into these methods of work load analysis in any more detail.

5.2. Methods for studying work load

5.2.1. Determining the duration of work load

As we can see from the general work load equation derived in Section 5.1. (equation 6), recording the duration of work load is essential for work load analysis. Scrutiny of the methods used in research projects at workplaces in coalmining and the iron and steel industry,[x)] being carried out with the support of the Commission of the European Communities, shows that the methods commonly used for time and work study (see, for example, REFA, 1973) need to be modified or developed for work load analysis.

The technique of "Zeitaufnahme" (timing)[*xx] used in time and work study is intended primarily to document work cycles so that we can derive from them a methodical system of work and motion cycles. From this methodical system, the times for certain activities

x) In particular, reports by ROHMERT (007), TARRIERE (053) and FAURE (23/03)

xx)* Terminology taken from REFA's "Methodenlehre des Arbeitsstudiums", 1973. The symbol * will be used below to indicate terms taken from the "Methodenlehre".

determined by timing, can be used as a basis fr planning work cycles and pay. However, since this systematic fixing of the working method is regarded as absolutely essential for applying the times recorded as described, it is sufficient to take a sample time measurement from a selection of a series of repeated activity phases involved in the tasks. It is not usually considered necessary to study complete shifts, that is to say, study work cycles throughout the day.

However, we must assume that the reference period for ergonomic work load analysis is the whole shift even where activity stages are repeated several times within a shift, since stress depends not only on the total duration of each phase of the work load, but also on how quickly they follow one another (ROHMERT, 1965).

The number of shifts to be covered depends on the extent to which the shifts measured can be regarded as representative, in terms of the problem in hand. This question can usually be answered readily where the tasks involve activity stages repeated many times during the day (e.g. high-quantity industrial production). On the other hand, for work where the content is not repeated very often (e.g. in single-part production) it is difficult to draw hard and fast rules as to degree of representativeness and, in such cases, conclusions as to representativeness must be confined to the distribution of activity phases which can be obtained by sampling techniques over a series of shifts.

Thus, there are two possible ways to analyse work load:

a) continuous study of the work cycle*, by which the cycle in respect of time is studied in respect of the sequence and duration of each load phase during one shift;

b) discontinuous distribution study, by which the distribution in respect of time of each load phase is studied independently of its position in respect of time, within the shift.

For both methods, it is essential to define "load phases"; they are generally defined as definite periods in the shift (see Table 2) during which the worker does not experience any change

in the level of work load or heaviness of muscular work,
in the condition of his physical surroundings and
categories of known work load factors.

The criterion for classifying work load is therefore not the "cycle" as in time and work study, but the "load phase". Compared with work cycle studies, this can give a more powerful breakdown in respect of time, which depending on the problem in hand, can result in refinement of the analytical techniques typical of systems of predetermined times (e.g. MTM and WORK FACTOR) (see below).

Bearing in mind this difference in the requirement for the system used for classifying time, all the methods for measuring time familiar in time and work analysis, (summarized in Table 3 based on the above classification by the method of assessing the cycle in respect of time and distribution in respect of time), can be used for studying work load.

The other techniques listed for "analytical determination of time" using "systems of predetermined times"* (see, for example, SCHLAICH, 1967, or PORNSCHLEGEL, 1968) are of little value for assessing the duration of load phases during work requiring physical effort.

Load phases are	assessed by: description or measurement of	
characterized by:	qualitative work load factors	quantitative work load parameters
duration of work load	estimate (e.g. time budget study)	duration of a load phase
level of work load	work content and cycle form of muscular work bodily posture social and psychological conditions of surroundings	e.g. weights to be moved heaviness of muscular work somatogram, biomechanical analysis physical conditions of surroundings

Table 2 Ways of determining work load during work requiring physical effort

Table 3 Techniques for determining the work load parameter "duration of work" by studying work load

Work load studies

	Methods for determining duration of work	Surveys to be done at the workplace
Measurement of cycle in respect of time, for work load phases	Stop-watch timing with measurement of individual times* and/or cumulative time* Time unit: 1/100 minute	Observation of work cycles, timed according to work load phases and entered in time sheet according to previously defined work load phases
	Clocks with digital recording (e.g. timing computer, see REFA, 1973) Time unit: 1/100 minute	Allocating work load parameters to up to 10 time recording units by keying according to previously defined work load phases
	Magnetic tape storage Time unit < 1/100 minute	A multi channel tape recorder can be used in conjunction with a verbal description of the work cycle to define each work load phase by introducing time impulses by pressing a button (timing recorder: see REFA 1973)
	Magnetic tape recording with coding Time unit < 1/100 minute	As above, but up to four work load parameters can each be recorded with up to nine stages by push-button input. Also, synchronous recording of up to four stress parameters (see ROSENBROCK and ROHMERT, 1972)
	Film or video-tape recording Time unit for photography 1/1000 minute	Photography with defined film frequency or simultaneous pictures of clocks with digital or analog time indicators.
Determination of distribution in respect of time	Snap-reading method for measuring time (see HALLER-WEDEL, 1969) Time units: 1 minute	Discontinuous measurement of times according to a set, random time schedule. Previously defined load phases are entered in record forms.
	Snap-reading method for counting frequency (see HALLER-WEDEL, 1969) Time unit: proportions of observation time i.e. can be converted into minutes	Observation and recording of work load phases by counting according to a time schedule; the previously defined load phases are entered in record forms
	Analytical determination of time by using systems of predetermined times (WF, MTM, KSVZ) Time unit: fractions of seconds	Determination of the expected time required by set analytical techniques for individual system based on observed work cycles or film or video-tape recordings (see, for example, SCHLAICH, 1967, PORNSCHLEGEL, 1968)

Work load analysis

Analysis necessary	Value of the technique
Summarizing the separate times noted for the different work load parameters or type of work load into total times for different shift phases	Timing simplified by using multiple clock systems with combined release - where one clock is used, it is advisable to record cumulative time (in certain circumstances with a sweep)
Time sum per load phase is indicated during the study, as is the frequency of load phases recorded by each unit	The time sequence of individual times is lost, but it is possible to reconstruct from all units of the time recording a comprehensive analogous recording by a pen recorder.
On playback, the time impulses are fed to a clock showing time per load phase. The description of the cycle must be allocated accordingly.	Separate load phases can be defined when making the (synchronous) evaluation, but evaluation time = recording time. Cycle description must accord with the evidence on the magnetic tape at the evaluation. A stop watch is better for short phases and writing is not necessary during recording.
Fully automatic timing of load phases by electronic clocks - digital work load and stress parameters transferred to punched tape store or other data loggers	This system requires a great deal of equipment. Appropriate programme must be developed for evaluating the logged data. Only rational way to evaluate synchronously recorded work load and stress parameters for long-term studies, since hardly any manual analysis is necessary.
Counting of picture sequences necessary to determine the duration of load phases	Separate load phases can be defined at evaluation, restricted by problems of lighting and limited picture size.
Classifying and summating individual times for all load phases	Particularly suitable for assessing work which is not repeated regularly. Sequence of load phases can be estimated from record forms. Times are approximate values with specific scatters.
Summating recorded observations	As for snap-reading method of timing. Simultaneous observation of several workplaces possible. Observations can be timed when usin' a cycle-orientated form for recording the results. (see ROHMERT, LAURIG, JENIK, 1973)
Sequence of movements has to be analysed into its elements, coded according to instructions for analysis, and alloted times.	Laborious to analyse, only of limited application for body movements. Calculated times only comparable within each system.

The reason for this may be, firstly, the considerable amount of time needed for the analysis (it is estimated that it takes several hours' analysis to analyse one phase of the cycle lasting for one minute) and, secondly, the calculated times may be of only limited value for subsequent analysis of stress, since it is not really possible to estimate the scatter of the actual times to be expected for a load phase. According to SCHLAICH's results (1968), in cycles composed of several elementary movements there are liable to be inaccuracies of the order of ± 30 and 50% in the analysed times. This inaccuracy is said to be due to intra- and interindividual fluctuations in times for individual elementary movements, the variation of system error for each system of predetermined times and, finally, random scatter. SCHLAICH has calculated no more than ± 25% for intra- and interindividual scatter, and so the residual uncertainty must be regarded as ± 5 - 25%, although it may be higher if the particular system is more complex.

However, apart from these problems of timing, from the elementary movements defined in the individual systems (e.g. MTM: basic movements or WF: standard element movements) we can prepare a cycle-orientated description of individual load phases as a refined method of classification for work load studies.

5.2.2. Determining the level of work load

5.2.2.1. Operational description of the level of work load

In line with the attempt to describe load phases in 5.2.1. as a criterion of classification in work load studies, the first approach to classifying level of work load is to measure all the periods of inactivity, since in these load phases the work load level accounted for by the task = 0. However, in certain circumstances, other work load parameters due to the working environment must also be considered; these include a bodily posture which might be adhered to during a short break in the work. However, we shall not discuss the effect of these factors in this report, since we propose to report separately on thermal and acoustic environmental conditions. Thus, the first division of the load phases into

activity phase - inactivity phase

would seem to be applicable to most of the problems. The activity phases are generally further divided into cycles and the inactivity phases according to the cause of inactivity, similar to systems of classification used in work and time study.

Further analysis of inactivity phases is intended primarily to distinguish between breaks in work occurring regularly as part of the work cycle, which systematically reduce the work load but which have to be evaluated differently in stress analysis because they do not occur systematically.

The summary in Table 4 shows that different systems of classification have been used to assess inactivity phases in different studies sponsored by the Commission of the European Communities. The "travel phases" which only occur with underground work for travelling to and fro between the surface and the workplace, may contain load phases which are relevant in terms of stress, since they take up an appreciable part of the shift time. Therefore, further differentiation of these times is important for work load analysis (see also ROHMERT [007]).

Activity phases are generally further subdivided into the observed cycles, where it is attempted to divide the task of individual workers into cycles relating to work load. This gives a sequence

Due to work cycle Due to interruption Self-selected Eating For examination Travelling (distinction between walking on foot, cable railway and train)	Interruption or stops with no further details as to cause Eating Time taking pulse Travelling (distinction between walking on foot, train)	Interruption, stop or waiting with no further details as to cause (a few references to machine times) "rest" (no further details) Eating
ROHMERT [007] Underground work	FAURE [03] Underground work	TARRIERE [053] Iron and steel production and processing

Table 4 Summary of the terms used in different reports to classify the reasons for inactivity phases

of only nominally different work load phases, for instance:

"loading by hand (shovel and pick)" FAURE /03/
or "unloading a roadway haulage unit" ROHMERT /007/

with, as yet, no ordinal distinction as regards level of work load. Generally speaking, with this sort of summary work load study we can make a further, formal classification of the activity phases into activities which directly promote the work in terms of the task, and activities which only serve indirectly to advance the work. ROHMERT /007/ calls these "main activity" and "subsidiary activity". Here, the term subsidiary activity certainly does not signify an avoidable activity phase; this is clear from the examples:

"Official talk with superiors"
or "Assisting at adjacent workplace"

As with the division into activity and inactivity phases, this classification into main and subsidiary activity is important for stress analysis, since subsidiary activities, although they are often irregular, may produce additional stress which would not have been planned for in the task.

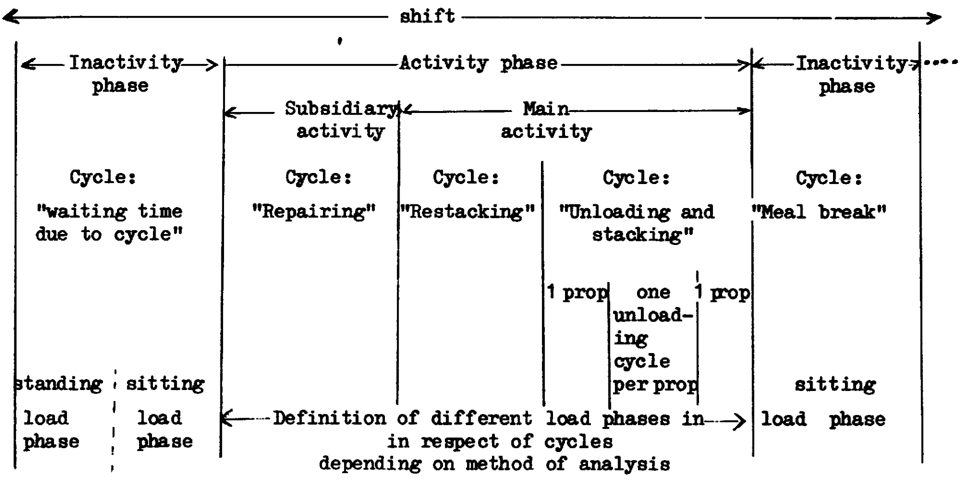


Fig. 1: Cycle-related diagram of the terms used in work load studies (Based on an example of unloading a roadway haulage unit described in ROHMERT /007/)

Figure 1 is a cycle-related diagram of the terms introduced so far, taking coalmining as an example. The figure shows that, strictly speaking, the term "cycle" can only be equated with "load phase" for inactivity phases, providing that the physical environmental conditions remain constant. Assuming that during the phase "waiting time due to the cycle" the worker
sits down, this would give two load phases, although here the bodily position is determined more by the worker than by the work. However, basically, the bodily posture determined by the work cycle must be regarded as a nominally defined work load factor (see 5.1.2.), and any timeable change (that is to say, changing to another category of bodily posture) represents a change of work load. It should be possible further to subdivide the subsequent activity phase (see Fig. 1) into load phases along the lines of the definition of load phases attempted in 5.2.1., by measuring work load level or heaviness of muscular work.

More detailed analysis of the cycle "unloading and stacking" (based on terminology of the systems of predetermined times) shows (see Fig. 2) that this is broken down into a series of repeated "unloading cycles" gone through for each prop to be unloaded. There are two other phases within an unloading cycle; a load is moved in the 1st phase and the worker moves without a load in the 2nd phase. The cycle starts again as he takes a fresh load. Since the level of work load in these two parts of the cycle is obviously different, these parts of the cycle can be called load phases. Fig. 2 shows that these load phases can in fact be further subdivided on the basis of the change in the type of muscular work of individual muscle groups. However, these components of a load phase are not completely independent of one another (putting down a prop necessarily means that it must already have been picked up) so that these components do not generally represent further load phases.

Cycle	Unloading cycle	Load phase and its component parts	Further subdivision of the cycle: "unloading and stacking"	Supplementary data: work load parameters and work load factors	Level of work load determined by	Predominant type of muscular work: Arms	Back	Legs
Cycle	Unloading cycle	Load phase and its component parts	Grasping and lifting a prop	Weight of prop Height lifted	Apart from accelerating and slowing phase, fairly constant, i.e. determined by the proportion of the prop weight supported by the worker + effect of the physical environment	dyn.	dyn.	stat.
			Holding and carrying to storing place (walking)	Distance to storing place		stat.	stat.	dyn.
			Bending and putting down prop	Position of prop		dyn.	dyn. stat.	stat.
		Load phase and its component parts	Straightening up	Stretched upright position possible?	Work only requires body movement, i.e. level of load determined by external load = 0, by bodily position and movement ≠ 0	no load	dyn.	stat.
			"Moving without load" from storing place to roadway haulage unit	Distance to roadway haulage unit		no load	stat.	dyn.
			Bending and reaching for prop in the haulage unit	Position of prop in the haulage unit		dyn.	dyn. stat.	stat.
			Grasping and lifting a prop					

Fig. 2: Load phases and their component parts, obtained by analysing the cycles according to changes in the type of muscular work, its heaviness and level of work load (Based on an example of two workers unloading a roadway haulage unit, described in ROHMERT [007]).

By examining this example, we find that it is better to delineate each load phase by a level of work load defined by a load or, in general terms, by the strength required of the worker, than by "heaviness of muscular work", for which there is no standard definition.

Thus, supplementing the definition in 5.1.2., a load phase can be defined from a level of work load demanded by the weight of the load to be handled (strictly speaking, this also applies to moving or stabilizing the body mass of the worker) or from the strength required of the worker. Generally speaking, we ignore any accelerations or slowing requiring additional strength.

Furthermore, more detailed analysis of the component parts of the load phases is required for subsequent analysis of stress and the methods used for this. For instance, if the stress on a worker is to be determined by measuring the stress parameter pulse rate, then we must measure other, supplementary work load parameters (such as conveying distances and height of stack) for each component of a load phase. On the other hand, if we are interested in the stress, for instance on the back muscles in relation to change in bodily posture determined by the work cycle, then laborious biomechanical analytical techniques may have to be employed if we wish to discuss the response of the stress parameter electrical muscular activity, as a function of time.

5.2.2.2. Energy consumption as a measure of level of work load

Apart from the operational description dealt with in 5.2.2.1. and the laborious analytical method for determining level of work load using biomechanical techniques, there is another possible approach, since measuring energy consumed during work provides us with a measure of level of work load on the same scale as biomechanical analysis (the proportionality scale), but by a much simpler technique.

On the other hand, results based on a proportionality scale are always preferable to nominal or ordinal results, although whether or not the greater expenditure and effort is justified must be decided in each case.

Another point in favour of measuring energy consumed at work to measure the level of work load is the large number of results already available from experimental work in the laboratory and from field studies in various areas (for instance, see DURNIN and PASSMORE, 1967, KATSUKI, 1960, SPITZER and HETTINGER, 1969), since this facilitates comparative assessment of the results.

We can postulate energy consumption as a parameter of work load (important for standardizing terminology) by drawing an analogy with the mechanical concept of work load. Let us visualize a person carrying out work requiring physical effort as a power engine in the physical sense. It is generally true to say that the mechanical work done by an engine is equivalent to the energy consumed, taking account of the efficiency. If we apply this principle to the working man, then the amount of energy consumed per unit time will increase in proportion to the man's output, i.e. the physical work load. The variation in the work load parameter "energy consumption" is therefore a measure, based on physical laws, of the level of the work load, the physical dimension being the thermal unit "calorie" (generally stated in kilo-calories (kcal)).

Formally, therefore, level of work load must be equal to energy consumption times efficiency. However, efficiency calculated according to physical principles can vary from 0% (since no work is produced in the physical sense) to just under 30% in the most favourable cases during heavy dynamic muscular work. For the majority of occupations, the average efficiency is reported as 5% or less (LEHMANN, 1961). However, it must be remembered that these figures are based on the conventional mechanical definition of efficiency which itself is based on the actual external physical work done, that is the "effective output". If we include the energy required to move the body mass of the working man in "effective output", then the efficiency figure is higher (see JENIK, 1973).

The effect of the concurrent movements of the body mass on energy consumption also explains certain problems encountered when using energy consumed during work as a measure of the level of work load. According to the definition given in the introduction (see Section 3), strictly speaking the variation should depend solely on the work and not the worker. In practice, in certain circumstances, measurements of energy consumed during work show marked interindividual variations of up to 20%. If we reduce these variations by eliminating differences in working method, presumably the residual interindividual variations can be explained almost entirely by differences in body type. (The effect of body type on the level of energy consumption is discussed in SCHOTT's results, 1972).

On the other hand, there are no results to suggest that there may be a connection between energy consumption and physical performance, so that energy consumed during work can certainly not be regarded as a stress parameter.

Therefore, for practical purposes, energy consumed at work should be regarded as

<u>a physiological parameter of work load which is proportional to the level of the work load</u>

and which takes account of the concurrent movement of the worker's body mass due to the work cycle. So, here both concurrent movement of the body mass and maintaining an upright posture are regarded as work load factors which are included in the integral parameter energy consumed at work.

Thus, when using level of work load based on measurement of energy consumption, the formula for calculating function f_1 in equation 6 in Section 5.1. is the algebraic sum of all the energy consumed in the component parts of a work load phase, with the dimension: kcal/min x min.

Practically the only method now used to determine energy consumed at workplaces where work requiring physical effort is done employs the MÜLLER and FRANZ respiration meter (1952), which measures the volume of air expired during the activity. Chemical analysis of the expired air gives the proportions of oxygen and carbon dioxide which can be used to calculate energy consumption by means of standardized calculations or available programmes for EDP (ROHMERT [007], TEMMING & ROHMERT, 1972).+) Because of the technical improvements brought about by the introduction of the respiration meter over the DOUGLAS bags (see ASTRAND & RODAHL, 1970) routine examinations can now be done even under extreme working conditions, such as underground (see ROHMERT [007], TEMMING & ROHMERT, 1972). However, each measurement period has to be restricted to about 20 minutes because of the discomfort to the worker caused by the gas metering system, especially by the mouthpiece and nose clamp.

+) See Appendix 1: FORTRAN IV programme for calculating energy consumed during work.

As part of ROHMERT's research project /007/, supported by the Commission of the European Communities, two technical improvements in the methods for measuring energy consumption were devised. These were tested and used during studies on work requiring physical effort by miners.

Since any additional work load imposed on the workers by the measuring equipment must be kept to a minimum, especially for measuring energy consumption underground, TEMMING & HAAS (1969) have developed a low resistance breathing valve for use with the respiration meter (cp. Fig. 3). Comparative measurements showed that the new valve (weighing about 40 g, dead space approx. 35 cm^3) had a resistance of 2.5 mm H_2O at a mean ventilation rate of about 20 l/min, whereas valves used hitherto had a resistance of $\approx$ 10 mm H_2O. Even at fairly high mean ventilation rates of 60 1/min, the resistance remained below 10 mm H_2O with the new valve, whereas readings reached 50 mm H_2O with the old valves.

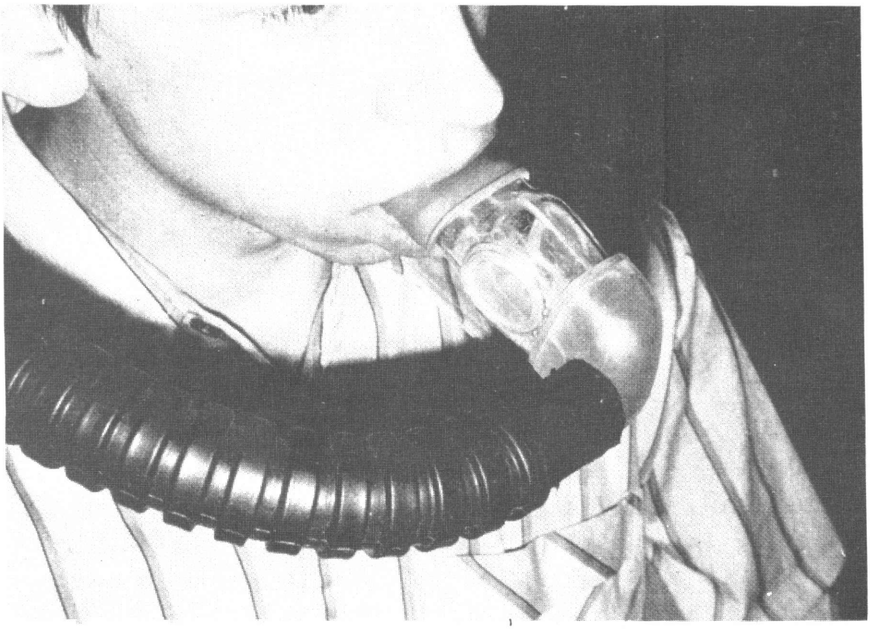


Fig. 3: The new valve in use

The second improvement was in storing and transporting the samples of respired air, which cannot usually be analysed immediately after measurement. Since the method proposed by MÜLLER and FRANZ (1952) for storing samples in glass containers cannot be used for studies underground for various reasons (e.g. sealing with a naked flame, fragility of glass containers), TEMMING and ROHMERT (1972) used brass cylinders to hold the samples for their studies. With a volume of 50 cm^3, these can be filled with an "analysis pump" up to about 20 atmos. press. This provides enough gas even for electrophysical analysis, and it can be stored for some time without loss due to diffusion.

However, measuring energy consumption (with a respiration meter) to determine the level of work load has some intrinsic limitations:

1. As already mentioned, most analytical techniques are electrophysical in concept and require about 500 cm^3 of gas for determining oxygen or carbon dioxide content. Since, with the MÜLLER and FRANZ respiration gas meter only, at most, 6 parts per thousand of the expired air is available as a sample, a very large volume of expired air is required. If respiratory minute volume is low, the test periods are fairly long and they may not be tolerated by the workers.

2. Test periods which, for the above reasons, are 10 - 20 min therefore give a figure for mean energy consumption at work for the test period and, in some cases, this may consist of several phases of the cycle, and possibly of several activity phases. The mean level of work load equivalent to the measured level of energy consumption, is therefore equivalent to the work load determined operationally by a work load study, as described by Section 5.2.2.1. To determine the level of work load for specific activities from the energy

consumed, the phase of the cycle must be sufficiently long to measure the energy consumption. If the phase of the cycle contains single, repeated cycles (see Figs. 1 and 2) then, from the work load study, different work load phases can be allocated to the mean level of work load measured. The level of work load found can be extrapolated to many similar work load phases, but interpolation to single work load phases or to their component parts is not recommended since the energy consumption measured for a particular phase of the cycle represents the sequence of single work load phases documented for this phase in the work load study. We can only interpolate if all the individual work load phases are definitely of comparable duration. The same applies to interpolation to one cycle, which again we cannot do unless all the cycles are of comparable duration (this means, for example, that the energy consumption for one cycle is only formally equal to 1/10 of the energy consumption measured for a phase of 10 cycles).

3. In practice, we cannot predict whether oxygen consumption is constant during measurement so that there is a steady state and "fractional" measurement is justifiable (see, for example, LEHMANN 1961 on this subject). This is particularly relevant to activities like the example described in Fig. 2, where work load phases of different work load levels are performed in cycles. In this case, the measurements must cover many cycles; if the measurement starts with cycle i and is to include n cycles, it must be stopped at the beginning of cycle i + n. If the "fractional" method is being used where the integral method should be used because there is a monotonic increase of oxygen intake, the actual energy consumed during work will be underestimated. According to HETTINGER (1970), integral measurement is also

recommended where the condition stated under 1 for a phase long enough for the measurement cannot in fact be guaranteed by the actual phase of the cycle worked, and this phase of the cycle, which is too short (i.e., generally less than 10 minutes), is followed by a break.

Since, as shown above, the energy consumed at work as a measure of level of the work load should, by definition, only be determined from the demands of the work, it must be possible to calculate energy consumed from the physical work corresponding to a specific work cycle. Up to now, this sort of analytical approach using biomechanical techniques has only been done for a few special cases of arm movements (JENIK, 1973) and there was a satisfactory correlation between calculated and measured energy consumption at work.

However, there are a series of empirically-derived mathematical formulae for estimating level of work load for practical activities (mainly for transport workers) (LEHMANN & STIER, 1961, SPITZER & HETTINGER, 1969). However, these and similar handy formulae derived from energy consumptions during work must, from what has been said above, be based on the assumption that the worker has an average physique in terms of distribution of body mass, so that interindividual variation factors can be ignored. The same limitation applies to the tables given by LEHMANN (1961) for estimating the energy consumption in relation to bodily postures, body movements and nominal classifications of heaviness of work, and to the estimates obtained by comparison with groups of examples. (LEHMANN, MÜLLER & SPITZER, 1950, SPITZER & HETTINGER, 1969). As long as this limitation is borne in mind, the technique described can be successfully used for ordinal comparison of work requiring different amounts of physical effort, or different working situations, as long as there is a sufficiently detailed study of the cycle. This avoids the laborious and expensive approach of direct measurement of energy consumption.

5.2.3. Determining the work load from bodily posture

Although the terms "bodily position" and "bodily posture" are used interchangeably in the literature, it is a good idea to use the term bodily position to describe the basic positions such as standing, sitting and lying, which can be regarded as the end points of movements and which can be adopted as resting positions. Potential movements and positions of individual limbs or parts of the body can be regarded as variations of bodily positions, and termed bodily postures (ROHMERT, SCHOTT, TEMMING and FRIES, 1970, SCHOTT, 1972).

As already mentioned under 5.1., bodily posture during work is regarded as a work load factor which depends on the work and the working methods, since generally speaking, bodily postures can only be described qualitatively. Possible ways of analysing these quantitatively to determine the level of work load include summarizing the energy required by measuring the energy consumption for specific bodily postures and, secondly, biomechanical analysis by calculating the moments of the masses of each limb of the body. Using the summary approach based on difference in energy consumption compared with the "lying" position, SCHMIDT [005] gives the following list, in increasing level of work load, for each, qualitative bodily position or posture :

lying
sitting
standing
sitting, bent forward
squatting
kneeling
standing, bending
standing, very bent

Here, energy consumption increases from < 0.1 kcal/min for sitting to ≈ 0.6 kcal/min for the standing very bent position. This enables us to evaluate bodily postures according to the level of work load ascribed to them in terms of energy consumption, but this is made more difficult because we only have a nominal description of bodily posture. Therefore, ROHMERT et al. (1970) proposed a system for classifying bodily positions and postures and for assessing them quantitatively, and this was used to assess bodily positions of people photographed doing work underground.

Based on the bodily positions standing/sitting/lying, and the supplementary "special positions" squatting and kneeling, shown in Tables 5a and 5b, the nominal categories for each position are supplemented by postures of each part of the body, the possible variations of these and an ordinal description of the variation. Any supporting of bodily postures is also described systematically, and supplemented by a description of potential sitting positions. Although this classification is based solely on qualitative description, the subdivisions and ordinal description of possible variations greatly extend the simple summary description of bodily positions or postures described above and may provide a basis for analysing bodily postures in terms of work load.

However, the practical advantage of this system becomes particularly apparent when it comes to systematic classification of bodily postures adopted at workplaces, either from direct observation or by evaluation of filmed or televised recordings or photographs.

The classification described by ROHMERT et al. (1970) is supplemented by a numerical coding system which is stored on punched cards and provides for frequency analysis of each bodily posture using an EDP programme+).

+) See Appendix 2: Evaluation of bodily postures with a computer program in FORTRAN IV for EDP.

Bodily position and special position	Posture of	Nominal category of postural variation	Description of variation
Standing Sitting	Head Trunk	Flexion and extension in sagittal plane, lateral bending in frontal plane, rotation in horizontal plane	marked, medium, slight, no flexion/bending/rotation forwards/backwards-to right/ to left
Lying Squatting Kneeling	Arm (right/left) Hand (right/left)	Reach of arm in % of maximum, height relative to shoulder-joint, lateral position of hand relative to shoulder-joint	50% / 75% / 100% very far above, far ...., very far beneath very far outwards, far ...., very far inwards
	Leg (right/left)	Description of leg posture	very, fairly, slightly bent
	Foot (right/left)	Distance as % of maximum, height relative to hip-joint	25% / 50% / 75% / 100% above, slightly below ...., very far below

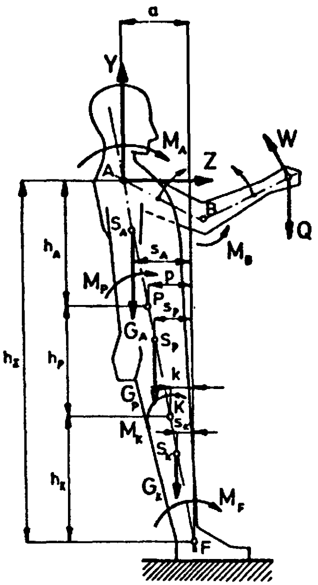
Table 5a: Classification of bodily positions and postures and their ordinal description

Support	Nominal category	Ordinal description
Feet on floor	Basic position Out-of-line position Combined Other leg posture	narrow - wide slightly - markedly
Additional supports by closing or supporting the upper extremity	Arms crossed on back, arms crossed on chest, arm (right/left/both) leaning or supported	not applicable
Additional support by leaning	right/left/both hands back/buttocks	
Description of seating	Stool or chair, on equipment or material, on floor	

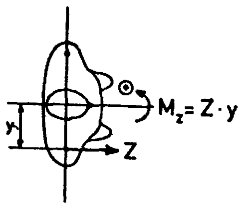
Table 5b: Supplement to the classification of bodily positions and postures, taking into account supports

Although this only provides an ordinal scale for assessing bodily posture, it is very unlikely that we shall be able to develop a more accurate technique to determine work load parameters applicable to bodily posture, for use at practical workplaces for work load analysis. ROHMERT et al. (1970) have shown that the system developed also enables us to use quantitative data (in addition to percentage data for reach of arm; for example, angles of rotation and position angle of limbs in space). However, to obtain such accurate data at the workplace involves very complicated measurements which can generally only be done under laboratory conditions.

All other attempts at a biomechanical approach have also been unsuccessful, partly because of their basic assumptions (for instance, as regards mass distribution and positions of centres of gravity), but also because of the considerable algorithmic complexity, and so they have been confined to the analytical treatment of selected special cases (see JENIK, 1973). Results obtained so far in these special cases do, however, clearly show the importance of the (mechanical) moments which give rise to bodily posture (see Figure 4). The moment equations clearly show that each change in bodily posture changes the lever arms of the weight components. However, since the weights remain constant, changes of moment are only produced by changes in the position of the body or the limbs. Thus, for a defined bodily posture there is, formally, a minimum level of work load level if the individual moments M_i are kept to a minimum.



A,P,K,F	- Mid-points of the joints
S_A, S_P, S_K	- Centres of gravity
Y,Z	- Reaction components
M_A	- Holding moment in shoulder-joint as an effect of the arm
G_A, G_P, G_K	- Intrinsic weights of each limb
M_P, M_S, M_F	- Holding moments in each joint
Q	- Weight being handled
W	- Resistance



Holding moment in hip joint P:

$$M_P = M_A + Z\cdot h_A + Y\cdot(a-p) - G_A\cdot(s_A-p)$$

Holding moment in knee joint K:

$$M_K = M_P + Z\cdot h_P + Y\cdot(p-k) - G_P\cdot(s_P-k)$$
$$= M_A + Z\cdot(h_A+h_P) + Y\cdot(a-k) - G_A\cdot(s_A-p) - G_P\cdot(s_P-k)$$

Holding moment in foot joint F:

$$M_F = M_K + Z\cdot h_K + Y\cdot k - G_K\cdot s_K$$
$$= M_A + Z\cdot h_\Sigma + Y\cdot a - G_A\cdot(s_A-p) - G_P\cdot(s_P-k) - G_K\cdot s_K$$

Sum of the holding moments

$$M_\Sigma = M_A + M_B + M_P + M_K$$
$$= 4M_A + M_B + Z\cdot(3h_A+2h_P+h_K) + Y\cdot(3a-p-k) - 3G_A\cdot(s_A-p) - 2G_P\cdot(s_P-k) - G_K\cdot s_K$$

Total load

$$L_\Sigma \approx \int^T M_\Sigma \, dt$$
$$\approx \int^T (M_A+M_B+M_P+M_K)\, dt$$

T = part of a work load segment

M_i = work load level

Fig. 4: Biomechanical work load analysis of the bodily posture "standing in working posture" (from JENIK, 1973)

These formal mechanical approaches suggest that in future it may be possible to analyse different types of bodily posture by computer simulation. Then it may be possible to produce ranked progressions similar to those obtained by considering work load in terms of energy consumption, by examining the change of (mechanical) work load. However, as yet there is no evidence of any correlation between analytical results of this type, and measurements of energy consumption for bodily postures.

6. Determining stress

6.1. Usefulness of parameters of stress now available

The theoretical discussions in Section 3 show that, generally speaking, we must adopt the inductive approach for measuring stress.

As a general rule, a physiological variable can be regarded as a parameter of stress (equation 4 and 5 in Section 3) if it alters as the level of work load and duration of work load alter, and shows interindividual (and possibly intra-individual) variations depending on physical capabilities.

However, for a physiological variable to be regarded as a suitable parameter of stress, it must be possible to record it whilst the person is working. This reduces the value of a number of biochemical variables as stress parameters (for instance, the chemical composition of the blood or urine), and other characteristics which can only be determined during prolonged interruptions of work or before the beginning and at the end of shifts. These variables are less suitable as stress parameters since they cannot be used to establish any correlations as a function of time, as in equation 5 (Section 3).

Table 6 is a summary of the most familiar stress parameters for evaluating work requiring physical effort which comply with these requirements. We can distinguish here between directly recorded parameters of stress and stress parameters obtained by calculation.

However, there are further restrictions on the type of study which can actually be performed at workplaces, and so only some of the stress parameters in Tab. 6 can be used for research in the field. For instance, any technique which involves inserting sensors into the skin (e.g. needle electrodes) must not be used for field studies because conditions of hygiene and sterility cannot be guaranteed at workplaces. The use of implanted sensors may not be confined to the laboratory, but it cannot really be regarded as a routine method for ergonomic studies on a large number of test subjects, even if we disregard the risk to the test subject, which certainly should not be underestimated.

Therefore, techniques for measuring stress parameters in ergonomics must also comply with the following requirements (see also LAURIG, 1969):

there should be no risk to the worker,
there should be minimum interruption of the work cycle,
it should not impair social contact within a working group,
it should be possible to use it over any period of the shift.

The recording method must also be acceptable to the workers even under extreme conditions of workplace or environment (e.g. underground).

Method	Stress parameter measured	Stress parameter deduced
Physiological	Pulse rate	Instantaneous pulse rate Smoothed instantaneous pulse rate Mean pulse rate Variability of pulse rate Increase of pulse rate Summed recovery pulse
	Pneumotachygram	Recuperation pulses Respiratory rate Respiratory amplitudes (insp.-exp.) Mean respiratory volume
	Blood pressure	Diastolic, systolic pressure Blood pressure amplitude
	Sweating rate Interior body temperatures	
Electro-physiological	Electrocardiogram (ECG)	Shape and amplitude of individual wave periods of each segment
	Electromyogram (EMG)	Electrical activity (EA) and relative readings derived from it
Biochemical	O_2, CO_2 content of expired air	Respiratory quotient

Table 6: Some stress parameters which can be recorded as a function of cumulative time (stress parameters underlined can be monitored by telemetry in ergonomic field research)

(However, we should also mention that the method for measuring energy consumption at work described in the context of work load studies only complies with some of these requirements.)

A general view, ignoring for a moment the individual parameters, shows that techniques for measuring stress parameters can basically be regarded as a sequence of steps involving

a sensor to convert the physiological signal into a physical measurement;

transmission of the data,

data storage

data processing and analysis.

It is also clear that the requirements stipulated cover each stage up to and including data storage, since, for example, there is no way of avoiding impairing the work cycle or social contact because a member of the research team must always be present to read the recording equipment or record measurements.

TARRIERE's experiments [053] (see also ROHMERT, LAURIG, JENIK, 1973) show, however, that all the requirements can be complied with, if it is possible to use telemetry (i.e. wireless). As a result of considerable advances in the development of efficient miniaturized transmitters, these units are now available commercially. This means that telemetric transmission of stress parameters is now possible if suitable sensors to convert the stress parameters into electrical impulses can be developed, as long as they can be attached to the worker so that they definitely do not impede the work cycle. Recent publications (DEMLING & BACHMANN, 1970, KIMMICH & VOSS, 1972) show that the technical problems of developing sensors for all the directly measured stress parameters listed in Table 6, have largely been solved. However, up to now the requirement that attaching the sensors does not impede work for prolonged periods during the shift only appears to have been complied with in respect of pulse rate and electromyography. Transmission of the other stress parameters in Tab. 6 which can be measured directly has been reported in the medical field (that is, in occupational, sports and military medicine), but there are no examples of this in ergonomic field research, apart from one or two casuistic studies. Since analysis of electrocardiograms recorded during occupational work has so far been limited mainly to preventive medicine (see WOITOWITZ et al., 1970), discussion on the method will be confined to the stress parameters "pulse rate" and "electromyogram", which can both be transmitted by telemetry.

Although these can be used to assess stress parameters which are important in work requiring physical effort, and they comply with all the requirements listed, telemetry techniques have not yet been used in underground research (FAURE [003], ROHMERT [007]) sponsored by the Commission of the European Communities. This is because, at the time, (1966 - 1969), the transmitters and receivers were not fully developed. For instance, they were not fully transistorized and this meant that they were not sufficiently proof against fire damp. However, the mining authorities approved simpler recording techniques (see ROHMERT [007]).

6.2. Methods of determining suitable parameters of stress

6.2.1. Recording the stress parameter "pulse rate"

6.2.1.1. Pulse rate during each cycle

Pressure variations in an artery (pulse wave), pulse-induced changes of blood flow in skin folds or changes of electrophysiological potential (ECG) due to cardiac contraction, are suitable indicators of pulse rate. The last two have been mainly used hitherto for recording pulse rate.

Fig. 5: The firedamp-proof, battery operated pulse counter designed by E. A. MÜLLER, in use.

Initially, MÜLLER and HIMMELMANN (1957) utilized the light transmittance of the ear lobe, which fluctuates with the pulse wave, by attaching an electric bulb to the front of the ear lobe and a photoelectric cell at the back. The voltage fluctuations of the photoelectric cell as the blood flow varies in the ear lobe are amplified several times and used to drive a mechanical counter. The electrical power supply, amplifier and counter are placed in a closed box and worn by the worker on his back, causing minimum hindrance (see Fig. 5). However, the work cycle may be impeded to read the counter for individual work load phases or cycles, since the work cycle has to be interrupted briefly, to do this.

If the ECG signal is used to measure pulse rate, the precordial lead must be used, not a limb lead as is often used clinically. Generally this requires two (or three) electrodes with special adhesive foils fixed on the chest (about over the sternum - right clavicle and below the left nipple at about the level of the fifth costal arch).

They can be attached more firmly with adhesive plaster strips to ensure that they remain in position for fairly long periods of the shift (see Fig. 6). The changes of potential recorded by the electrodes are usually fed into small, light, portable telemetry transmitters (see Fig. 6, TARRIERE /053/).

Portable tape-recorders with a long recording time can also be used for stress studies in which it is only intended to record pulse rate as a function of time or document any ECG changes (long period ECG) where it is not desired or necessary to correlate work load and stress. For further details, see the report by WOITOWITZ et al. 1970 (they also give further details about conventional precordial leads).

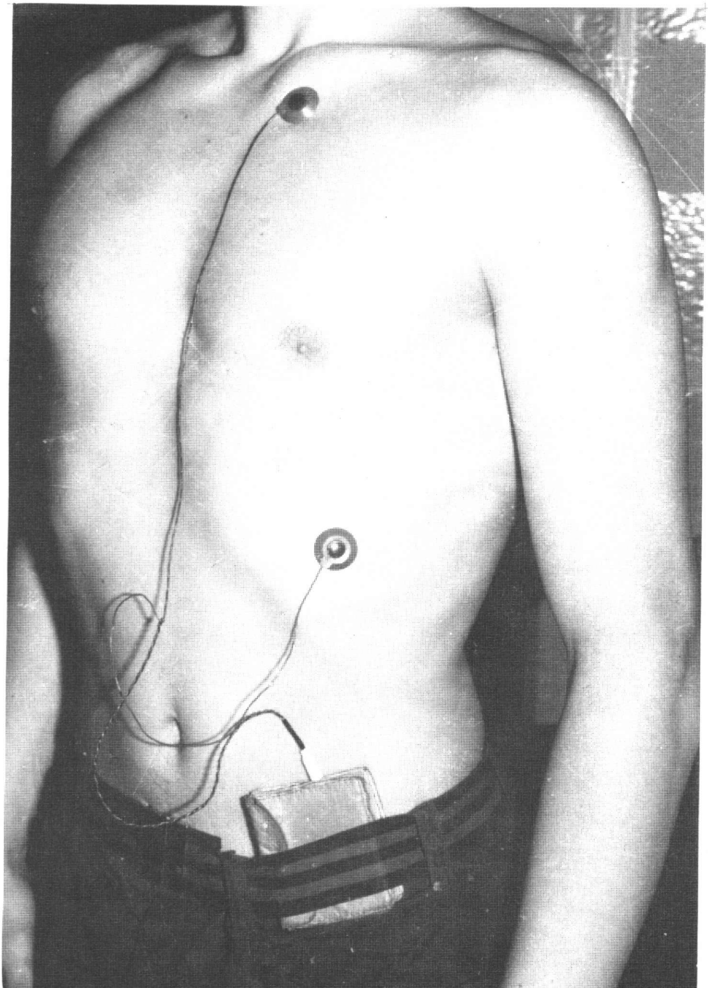


Fig. 6: Attachment of precordial electrodes for electrocardiogram telemetry for recording pulse rate.

Irrespective of the way in which the phenomenon characteristic of each beat is detected and transmitted, the first two methods above give a series of electrical signals corresponding to the sequence of electrical beats. With the E.A. MÜLLER type pulse counter described above, these signals are counted mechanically. This can also be done with the signals from the ECG (number of R-R periods or R waves). Pulse rate is then calculated by counting the signals recorded during a specific counting period (= reference time base). By definition, pulse rate is taken as the number of beats per minute, and so the reference time base is one minute. Thus, with these pulse counters, pulse rate is obtained by reading off the total pulse count after each minute and calculating the differences.

However, for a stress study at the workplace, there is the problem that the cycles, cyclic phases or load phases vary considerably in duration and that, in practice, this period is never a multiple of whole minutes. Therefore, ROHMERT [007] selected cycles as the reference time base, so that the pulse counter is read at the beginning of each new cycle and recorded in a special record form, together with the cumulative time. By dividing the number of beats in each cycle by the duration of the cycle, we obtain mean pulse rate, with the dimension [pulse/per minute of the particular cycle]. The limitation of this method is that the intervals between reading the pulse counter are short where the cycle (or cyclic phases or load phases) are short. ROHMERT [007] states that the shortest phase period which can be assessed by this method is about 0.5 minutes. If we assume a reading error of ± 1 beat per 0.5 minutes, then there is a methodical error of at least 4 beats, when converting these short phases to pulses/minute).

However, assuming that the cycle generally consists of discrete cyclic phases and load phases, it is clear that, when calculating mean pulse rate, the marked changes of mean pulse rate occurring at peak stress during individual load phases will hardly be noticeable, since they may well be balanced by stress minima in other load phases.

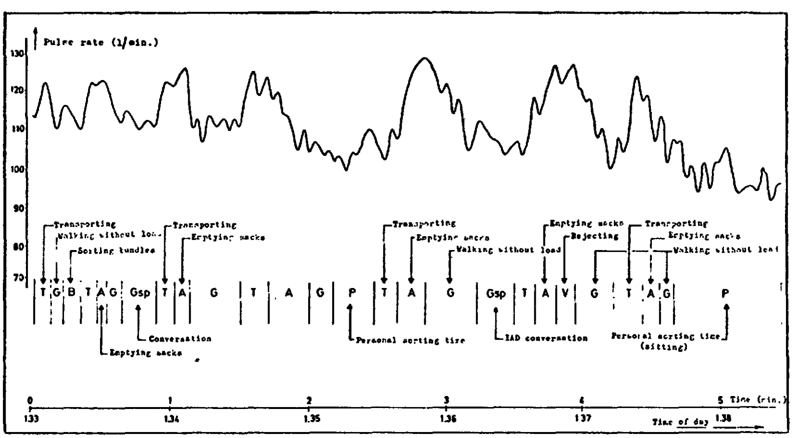
This shows that calculating mean pulse rate smooths out the actual fluctuations due to stress; hence, the reference time base for stress studies should be each load phase where possible. This also shows, as a general rule, that data for stress parameters as a function of time can only be used for stress analysis if a recording of work load parameters as a function of time is also available and can be used to explain the changes in stress.

Irrespective of the risk of underestimating the actual stress, the requirement that load phases are used as a reference time base for stress studies restricts the use of pulse rate determination by counting beats to activity phases with long cycles without marked fluctuations in the level of work load which would produce several load phases within the cycle. Therefore, TARRIERE [053] and ROHMERT, LAURIG, JENIK (1973) used the technique of determining the smoothed instantaneous pulse rate. Instantaneous pulse rate is taken as the "instantaneous pulse rate" which can be calculated from the time between two beats (e.g. from the R-R period in the ECG) by the equation (see also LAURIG, 1969)

$$\text{pulse rate (1/min)} = \frac{1}{\text{time between 2 beats (minutes)}}$$

As a rule, this conversion is not done digitally, but by an analog computer with appropriate condenser circuits so, again, it is not as accurate as was originally hoped; this is expressed by the term smoothed instantaneous pulse rate. If the actual instantaneous pulse rate is calculated digitally, a natural irregularity in the pulse rate makes it difficult to draw more precise conclusions from the results, but recent studies indicate that this variation in pulse rate itself is a derived stress parameter (ROHMERT et al, 1973).

If the smoothed instantaneous pulse rate computed is fed as an analog potential into a recorder with a constant paper feed rate, the resulting curve shows the pulse rate in relation to cumulative time. The example of pulse rate in a railway postal worker in Fig. 7 (from ROHMERT, LAURIG, JENIK, 1973) shows that pulse rate definitely follows the different levels of work load in the load phases described. The figure also shows the coding of each load phase by letters. Since the analog data for pulse rate can also be expressed digitally, work load and stress parameters



Instantaneous pulse rate Vp Pol. (through service D 364/20.2.69)

Fig. 7: Smoothed instantaneous pulse rate in a railway postal worker (ROHMERT, LAURIG, JENIK, 1973)

can be analysed and allocated automatically if pulse rate and coded load phases are recorded synchronously on tape (see ROHMERT et al. 1973). This recording in the form of machine-readable data is also essential if electronic data processing is to be used subsequently.

6.2.1.2. Determining the increase of pulse rate

The general response of the pulse rate in Fig. 8 shows that pulse rate generally rises at the start of work requiring physical effort, so that in fact it is not the overall pulse rate measured during the work which is characteristic of stress, but the change in pulse rate compared with an initial or reference rate, that is to say, therefore, the increase of pulse rate due to the work calculated from the difference between pulse rates at work and at rest (see KARRASCH & MÜLLER, 1951) or the reference pulse rate.

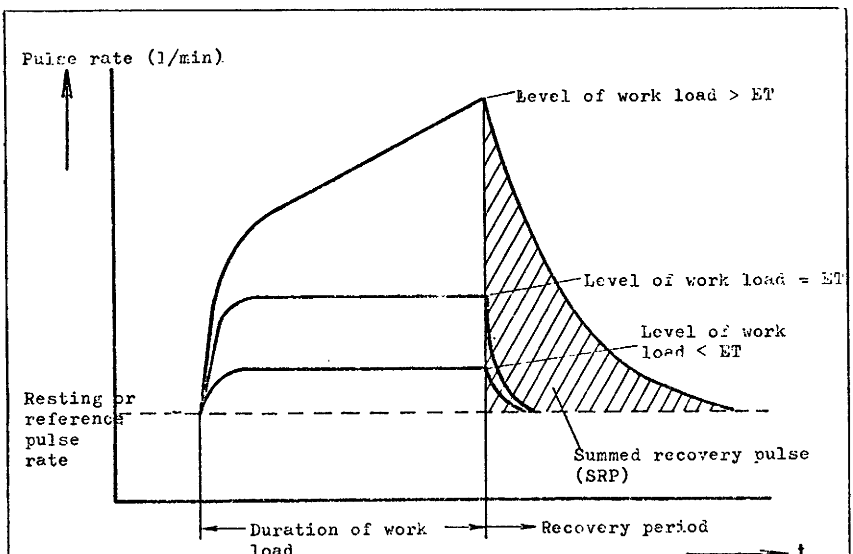


Fig. 8: Diagram showing response of the stress parameter pulse rate, as a function of time

The magnitude of this difference is therefore a measure of stress, although the absolute value of this depends very much on the choice of reference rate, since the initial pulse rate at the workplace is generally higher than a resting pulse rate measured under fundamental conditions.

However, this also shows that, when assessing interindividual stress, comparison of interindividual pulse rates during work tells us less if we do not have any figures for individual reference pulse rate to enable us to calculate the increase in pulse rate.

Finally, Fig. 8 shows a typical property of stress parameters which is particularly marked with pulse rate and can be largely explained physiologically (see, for instance, MÜLLER, 1961). It is well known that increase of pulse rate and level of work load only show a close correlation up to an specific intra-individual level of work load, which varies from person to person. Once this specific level of work load level (which has been called the "endurance threshold" (ET) by KARRASCH & MÜLLER, 1951) has been passed, we see the "rise in pulse rate due to fatigue" described by CHRISTENSEN (1931); the gradient of this rise depends on the level of work load. (Another important parameter of stress for assessing work requiring physical effect, that is electrical activity from the electromyogram also behaves in this way - see LAURIG, 1970, and VREDENBREGT & RAU, 1971).

With work loads above the endurance threshold, the increase of pulse rate depends both on the level of work load and on the duration of the work load. However, since once the endurance threshold has been passed, pulse rate is only likely to return to the reference level very slowly (see Fig. 8), in practice, when measuring stress, various effects will be superimposed whenever load phases with work load levels above the endurance threshold alternate with cycles worked at lower load levels but which do not last long enough for the fatigue-induced rise to decline completely (see also ROHMERT, 1965).

As reference values suitable for determining the increase of pulse rate, TARRIERE [053] determined the lowest, smoothed instantaneous pulse rate during physical rest (in an arm-chair) at the workplace (ECG telemetry) in each case in a succession of special inactivity phases throughout the entire shift:

a) After preparing the worker for measuring pulse rate (≈10 minutes) before starting work

b) After standardized work on a bicycle ergometer before starting work (≈15 minutes)

c) Before and after the midday break lasting 45 minutes and other meal breaks

d) During organized rest breaks

e) After the end of the shift.

According to TARRIERE, determining the reference values at the workplace largely eliminates the effect of environmental factors on the increase in pulse rate caused by the activity. However, we cannot assume that the work load components activity and environment are superimposed, particularly in respect of stress due to working conditions (see BROUHA, 1960). Therefore, to estimate the superimposed effects, TARRIERE also carried out tests using the same standardized work load on an ergometer under "optimum" environmental conditions (by optimum he presumably means subjectively comfortable conditions).

Unlike TARRIERE, FAURE [03] used pulse beats counted at the wrist in the standing position, before and after the breakfast break for a period of 30 seconds. This choice of reference value was made on the basis of detailed laboratory tests with work on a bicycle ergometer and a defined sequence of different levels of work load before and after a meal break. These experiments showed that this reference value for the methods used by FAURE underground to determine "recovery pulse rates" (see Section 6.2.1.3.) is likely to demonstrate in the best way the differences in stress due to different levels of work load.

6.2.1.3. Determining the "recovery pulses"

As shown in Fig. 8, the pulse rate in a cycle in which the level of work load = 0 only returns to the reference value slowly, and the greater the increase of pulse rate in the preceding work phase, the slower is this fall. Thus, pulse rate during cycles in which the load level = 0 (i.e. inactivity phases) provides information about the preceding stress level; that is to say, the longer the pulse rate remains elevated during an inactivity phase (in a bodily posture which can be described as "resting"), the higher must have been the stress preceding the work break. KARRASCH & MÜLLER (1951) utilized this typical behaviour of pulse rate during recovery phases to derive a stress parameter, "summed recovery pulses" (= SRP). According to them, the sum of the recovery pulses is the number of beats occurring before the reference value used for calculating the increase of pulse rate is reached. KARRASCH & MÜLLER also showed that the sum of the recovery pulses recorded after the same period of work load are a measure of the stress due to the preceding work load, and the sum of the recovery pulses at work load levels above the endurance threshold increases both with level of work load and with duration of work load.

SIEBER (1971) showed that, for one-hour laboratory tests on a bicycle ergometer, there is a statistically significant, non-linear relationship between mean rise of pulse rate during loading and the sum of the recovery pulses. SIEBER found a linear relationship (statistical determination $B > 90\%$) between the sum of the recovery pulses calculated in the first five minutes after loading, and the mean rise of pulse rate during loading.

Using these results to evaluate work requiring physical effort, we can derive easily determined reference values for stress by recording the rise of pulse rate which persists in the inactivity phases. However, from the requirements in Section 6.1., these reference values cannot strictly be described as parameters of stress, since they are not measured continuously during loading, as a function of time.

In the first standardized method of this kind (JOHNSON et al., 1942) the course of recovery after loading is estimated from three 30-second pulse counts in the 1st, 2nd and 3rd minutes of the recovery phase. Since these "pulse counts" can be done at the wrist without measuring equipment, this is a particularly simple way of estimating stress.

FAURE /03/ modified this method slightly for his underground studies, by taking the pulse in the standing position (unlike BROUHA (1960)), since it was found impossible to provide a suitable place to sit down in the breast. Like BROUHA, FAURE measured recovery pulses three times, each time for 30 seconds. The first phase started 30 seconds after beginning an inactivity phase and, by doubling the beats counted, this gives an estimate of the mean pulse rate for the 1st minute (= P_1) of the inactivity phase. Values P_2 and P_3 were determined in a similar way for the 2nd and 3rd minutes. The first pulse count was always done at the end of the journey in the personnel train, after getting out of the carriage, and the last whilst waiting for the train at the end of the shift. For the remainder of the shift, the proposed counting cycle was about every

20 minutes, and the actual counting was to start when the worker spontaneously took a break. Another planned counting time was at the end of the breakfast break. Work load was studied by measuring the duration of the activity phases (rounded up to the nearest minute) and describing the load phases in them. The proposed counting cycle of about 20 minutes was to ensure as little disruption to the working cycle as possible, since the "spontaneous" work breaks had to be extended to at least 3 minutes 30 seconds because of the counts. On the other hand, the predetermined interval between two counts did not necessarily mean that the activity phases lasted at least 20 minutes, and so it is difficult to analyse the results, not least because of the difficulty in compiling comparable sequences of work load phases. The only way to compensate for this is to use a large number of replicated tests.

6.2.2. Recording the stress parameter "electromyogram"

It is still difficult to attribute, i.e."to analyse" the total stress on a worker, as shown by an increase of pulse rate, into the individual work load components which cause the increase (see RUTENFRANZ et al., 1971). Since the type of work load (activity, conditions etc.), the type of work (heavy dynamic, unilateral dynamic, etc.) and the share of these in the entire work (non-physical components) all have a part to play, it is difficult to obtain any information about the stress on a single muscle from the pulse rate. However, monitoring the electrical discharges (action potentials) which accompany muscular contraction provide a direct measure of the relative stress on a single muscle.

A recording of these action potentials (in the mV range with frequencies up to 1000 Hz) in muscles is called an electromyogram and the technique is known as electromyography. The surface electrodes for monitoring are about 1 cm in diameter and they are attached directly to the skin over the muscle with adhesive foil. Surface electrodes cannot be used for monitoring deeper muscles; this imposes a limitation since needle electrodes cannot be used for studies at workplaces, for the reasons discussed in 6.1. After amplification, the electromyogram can be recorded on direct recording equipment, thus providing an ordinal classification of different muscle tensions. To quantify the data, the electromyogram is generally rectified electronically and integrated over specific time segments (e.g. part of a load phase). The result of this processing

$$\int_0^t |EMG| \cdot dt = \text{electrical activity} \qquad (9)$$

is called electrical activity (= EA).

For static muscular work it has been shown (see, for instance, LAURIG, 1970) that there are reproducible relationships between electrical activity and muscular power measured isometrically. It can also be shown that, like pulse rate, where the work load level is constant, electrical activity increases as a function of time when the level of the work load exceeds the endurance threshold, and the gradient of this increase rises with the level of work load (see, for example, LAURIG, 1967, RAU & VREDENBREGT, 1970).

Thus the derived parameter of stress "electrical activity" can be used to assess the stress on different groups of muscles in different bodily postures (see SCHMIDT [005], OKADA, 1972) and to detect changes in muscular stress, as a function of time, during static and dynamic work. However, this method has hardly been used at all in industrial field work (see LAURIG, in print).

6.3. Possible approaches to determining stress by deductive methods

As shown in Section 3, the deductive approach to determining stress is based on the functional relationship between work load and characteristic values for individual capabilities, using equation 3. Therefore, for this deductive approach we must have an analytical description of the work load and suitable characteristic values for individual capabilities, and know the function linking the variables mentioned.

Based on ROHMERT's results (1962), the principal structure of this function depends on endurance threshold (a characteristic of individual capability):

$$\text{Stress} = C_1 \cdot (\text{work load level})^{C_2} \qquad \text{for level of work load} < ET \qquad (10\text{ a})$$

$$= C_1 \cdot (\text{work load level})^{C_2} \cdot (\text{duration of work load})^{C_3} \qquad \text{for level of work load} > ET \qquad (10\text{ b})$$

where the coefficients C_i depend on the size of the muscle mass used during the activity and the type of muscular work (static or dynamic).

The second equation, for stress at work load levels above the endurance threshold, was stated by ROHMERT as a numerical equation to describe the increase of pulse rate as a function of time, for different examples of muscular work; this was done by relativizing and standardizing the level of work load by relating it to individual endurance threshold.

Finally, if ROHMERT's formula (1960 b) for calculating supplementary recovery periods during static work is modified for calculating recovery periods+) then, assuming that the "recovery period necessary =

+) by expanding with t

measure of stress", we again have an equation of the 10b type with a standardized level of work load, but the coefficients of this for static work are independent of the size of the group of muscles since the endurance threshold for static work (15% of maximal muscular power, measured isometrically) is independent of the muscle group (MONOD, 1956, ROHMERT, 1960 b).

Thus, for the many cases of static holding work, the level of stress can be deduced for all work load levels above the endurance threshold by determining the recovery period necessary (see example in Appendix 3).

However, up to now there are no comparable practicable approaches for deducing stress due to other forms of work requiring physical effort since, in practice, this work is usually a mixed form of static and dynamic muscular work and this makes it more difficult to determine reproducible values for the coefficient C_i.

6.4. Determining the characteristics of "individual capability"

Although possible approaches to determining stress deductively have so far been confined to static holding work, we need to determine suitable characteristic values, independently of this, to describe individual capabilities, to enable us to interpret the interindividual scatter in stress studies analytically. For this "discussion by variance analysis" of the variation in stress parameters, the methodical problem of defining physical functional capacity by a single characteristic value (see, for instance, VALENTIN et al., 1971) is unimportant. All we need is an appropriate correlation between the stress parameter measured and the "individual characteristic value" to be defined, so that we can discuss interindividual variations in the stress parameter as a function of time.

However, characteristic values of this sort are also essential to characterize a group of workers under study, to supplement the usual characteristics of sex, age, height and weight. In addition to characterizing a group by selected characteristic values of this sort, we can also compare groups on the basis of the variation in their characteristic values. This is particularly important for checking that results obtained by sampling are applicable to larger populations. Generally speaking, unless characteristic values are determined for the workers being studied, we cannot draw any conclusions as to whether each subject is average or differs from the average (e.g. as regards age, height, weight etc.).

Besides muscular power, characteristic values for cardiopulmonary capacity are important for evaluating work requiring physical effort.

The muscular power available can be regarded as a direct measure of capability of doing tasks involving carrying or lifting. Muscular power here is generally determined as maximum power measured isometrically. Since muscular power can only be measured as physical strength produced, the considerable variation in measurable physical strength in different bodily postures and different limb postures must be taken into account. However, for the basic standing position there are a number of collections of data for arm strengths for all the important arm postures, (these could be described as "strength atlases": ROHMERT, 1960 c, ROHMERT & HETTINGER, 1963; ROHMERT, 1966b, ROHMERT & JENIK, 1972), and so it is not generally necessary to measure physical strength.

For assessing cardiopulmonary functional capacity, we have a number of standard test methods which take the variation in circulatory parameters as a function of a defined standard load as a measure of cardiovascular functional capacity for heavy dynamic muscular work.

According to VALENTIN et al. (1971), these methods are based on the idea that the less a person's physical functions at a specific output deviate from the resting or initial level, the more capable he is of performing predominantly muscular work.

For field studies, in some circumstances, methods which involve measuring the pulse rate as a circulatory parameter, are better than more complicated techniques since pulse rate is required in any case for the stress study and so the only extra work needed is to produce a standard work load.

The simplest method proposed for producing the standard work load is climbing steps ("step test", e.g. HETTINGER & RODAHL, 1960). However, this method is not yet sufficiently standardized and only of limited value as a circulatory function test because of the unavoidable effect of the test subject's body weight and other biomechanical factors (see HOLLMANN et al., 1965). A further disadvantage of the step test is the relatively high work load it imposes; this generally means that the work loads cannot be kept below the endurance threshold.

Since, for assessing workers, we are not so much interested in their maximum functional capabilities in the sporting sense, but rather their occupational functional capacities around the endurance threshold, it is better to use bicycle ergometers to produce standardized work loads. The method proposed by E.A. MÜLLER (1950) involving determining a capacity pulse index as a measure of occupational endurance works with test loads of up to 10 mkgf/sec on a bicycle ergometer, and this is very little above the endurance threshold of male workers. According to BLOHMKE's studies (1968), there are likely to be intra-individual scatters of 27% when calculating CPI. This simple technique is sufficiently accurate for ordinal assessment of workers in the context of stress studies. On the other hand, according to EHRENSTEIN & MÜLLER-LIMMROTH (1968), attempts to calculate maximal O_2 uptake (as a measure of maximal functional capacity) using the CPI's produced appreciable errors.

Other techniques for determining physical functional capacity (e.g. that of ASTRAND & ROHDAHL, 1970) certainly show much less intra-individual scatter than determination of CPI, but they are less suitable for determining endurance for assessing workers.

Table 7 shows a selection of familiar techniques for determining characteristic values of pulmonary functional capacity, which are also simple to use in ergonomic field studies in industry.

7. Results of a study of work load and stress during work requiring physical effort, with particular regard to the research project sponsored by the Commission of the European Communities.

7.1. General methods of ergonomic research in the field

Irrespective of specific problems in particular research projects, all research projects sponsored by the Commission of the European Communities which involve field studies (particularly the projects of FAURE [03], ROHMERT [007] and TARRIERE [053] are done by a general method for ergonomic scientific field study (see also ROHMERT et al., 1973a, b) which is illustrated by the flow chart in Fig. 9.

Technique from	Work load standardized by	Circulatory variables to be measured	Value characteristic of functional capacity	Remarks
HETTINGER, TH. and ROHDAHL, K. (1960) (modified step test)	Climbing steps 25/min for 2 minutes	Pulse rate and systolic blood pressure before and after loading	Calculation of index by equation, from measurements of pulse rate and blood pressure	Step height is selected according to leg length
MÜLLER, E.A. (1950) (capacity-pulse index)	Bicycle ergometer at 60 r.p.m. Work load increased by 1 mkgf/sec every minute for 10 minutes	Pulse rate by counting for one minute per minute of loading	Increase of pulse rate as loading is increased by 1 mkgf/sec = CPI (= increase of pulse rate per minute of work load)	CPI has a very suitable dimension: change of pulse rate as standardized work load is increased by 1 mkgf/sec
WAHLUND (1948) (physical working capacity) RUTENFRANZ's modification (1968)	Bicycle ergometer at 60 r.p.m. Work load increased by 1 mkgf/sec each minute until a specified pulse rate is reached e.g. 150/min	Pulse rate by counting one minute per minute of loading	By extrapolating the regression line between PR = f(capacity), a capacity corresponding to pulse rate of 170/min can be estimated and this is called PWC 170 (mkgf/min)	In the modification, the work load must not be increased until a pulse rate reaches 170/min. By extrapolation, systematic over-estimation of PWC 170 min by on average 180 mkgf/min
ASTRAND, P.O. and ROHDAHL, K. (1970) (indirect determination of maximal O_2 uptake	Bicycle ergometer set at constant work load between 300 and 1500 mkgf/min for 6 minutes under steady-state conditions	Pulse rate at constant working pulse rate (i.e. rise of PR/minute <5 beats/minutes)	Pulse rate in 5th and 6th minute with loads of 300, 600, 900, 1200 or 1500 mkgf/min is used to estimate O_2 max from the table	Correction factors are given to take account of age

Table 7: Synopsis of selected methods for determining characteristic values of pulmonary functional capacity

Generally speaking, unlike conventional laboratory experiments, in an ergonomic field study the planning, experimental and analysis phases, cannot be strictly defined either as regards time or subject matter. A field study in fact consists of a large number of related phases of study which represents only part of the total research project.

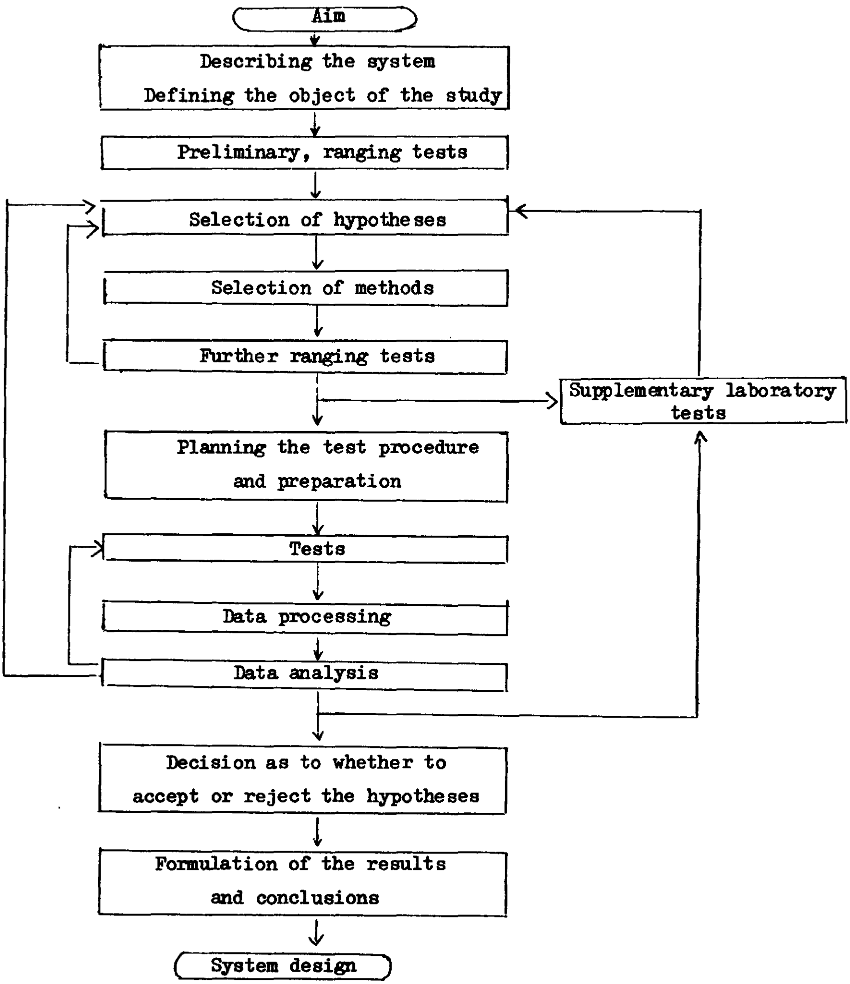


Fig. 9: Generalized flow diagram for an ergonomic field study

As can be seen from the list of named research projects in Tab. 8, the <u>system to be studied</u> and the object of the study are defined by the very titles of the projects. The <u>aim</u> of these three research projects is to describe, quantitatively, work load and stress by analysing the actual situation. The results are then assessed by evaluating examples of work requiring physical effort.

If the studies set out to answer problems over and above a general description of actual conditions, these problems nearly always contain hypotheses which can be accepted or rejected by the results of the studies. The <u>hypotheses</u> are generally formulated around the question of whether the stress can be regarded as tolerable. Thus, the following pair of hypotheses would be used for deciding the parameters to be studied:

The combination of work load parameters produce

a) tolerable stress

b) intolerable stress

where hypothesis a) is the null hypothesis and b) the alternative hypothesis.

Statistical tests have to be used to decide which of the hypotheses to reject, and the result of these tests is the statement of probability, for instance for accepting the null hypothesis because the alternative hypothesis is rejected. However since, in this case, the null hypothesis is accepted to some extent without evidence, it is very important to select a suitable alternative hypothesis in the light of the aim of the study. The above pair of hypotheses therefore has the advantage from the point of view of the method that even one case of demonstrable intolerance to the stress is evidence against accepting the null hypothesis. On the other hand, it is more difficult to reject the alternative hypothesis since this could only be done after testing a <u>large number</u> of possible combinations of work load parameters, which would <u>all</u> have to point to acceptance of the null hypothesis.

Subject of the research project Name of leader Report documentation No.; Index No.; Research No.	Methods used in the field study Work load study	 Stress study	Supplementary laboratory tests
Physical work load in a highly mechanized breast (mechanical working and mechanical filling, progressive lining) G. FAURE Doc. No. 3157/70d; 11/08 6242 / 23/03	Time studies for 56 shifts at five different workplaces. The following times were measured for each shift: a) travel and waiting b) walking, changing clothes c) activity and inactivity Classification by "work requiring effort" corresponds to classification by cycles as in Fig. 1.	Pulse taken manually in the inactivity phases, from 56 workers over 56 shifts. Between 93 and 9 pulse counts were analysed for 10 different cycles "requiring effort". The effects of age and environmental influences, conditions, noise and dust, are discussed.	Effect of standardized work load on the bicycle ergometer on the pulse rate in 9 TS to determine comparative data for the pulse measurements underground.
Transporting and handling of loads by miners in coalmining (Physical work load at different mechanized workplaces) W. ROHMERT Doc. No. 3029/70 d; 11/05 62-22-1-007	Time studies for 27 shifts with 15 different cycles of transporting and handling of loads. The following times were measured for each shift: a) travelling (cable car, walking, personnel train) b) activity, inactivity c) breaks for the tests Classified by cycles as in Fig. 1 Level of work load in terms of energy measured for activity phases. Photography of bodily postures. Climatic variables measured: dry and wet temperature, weather rate, air flow; determination of sound pressure level and the octave spectrum.	Pulse counted photo-electrically for the entire shift, divided into activity and inactivity phases, in 15 workers. Determination of the sweat loss during the shift by weighing before and after the shift and taking into account fluid intake and urine voided.	Clinical examination of all workers studied at their workplace: case history, ECG at rest and during exercise, lung function test, some x-ray examinations. Capacity-pulse index determined (see section 6.4.) Characteristic anthropometric values determined (somatotype according to SHELDON et al., 1954)

contd.../

Determining the physiological demands of work under actual working conditions (forging works, foundries, iron and steel works) C. TARRIERE Doc. No. 3031/70d, 11/04 6242-22-3-053	Description of cycles, time studies on 67 shifts at 32 workplaces; energy consumption during work calculated from tables; an "equivalent mechanical work load" determined with a bicycle ergometer by finding the work load on the ergometer which produced a pulse rate comparable to that measured during work at the workplace. Details of working conditions, sound pressure level and octave spectrum at each workplace.	Instantaneous pulse rate determined telemetrically as a function of time over the entire shift, in relation to the nominally described work load.	Methodical study to determine a standardized work load for tests at the workplace (20 TS-bicycle ergometer) Studies to determine a suitable reference value for pulse rate measurements. Attempts to determine the cardiac output by an external technique.

Tab. 8: Synopsis of field studies carried out to evaluate work requiring physical effort as part of the research work sponsored by the Commission of the European Communities.

Finally, when formulating the hypotheses, the consequences of any erroneous statistical decisions (see, for instance, SOKAL & ROHLF, 1969) must be borne in mind, since these are very important to the workers. For instance, with the pair of hypotheses selected above we could:

a) Reject a null hypothesis which is actually correct (= error of 1st type).
Acceptance of the alternative hypothesis would be of advantage to the workers concerned if measures were taken to reduce the work load where this is in fact unnecessary because the stress is actually tolerable.

b) Acceptance of a null hypothesis which is actually incorrect (= error of 2nd type).
There is a risk that the workers concerned will be overstressed since it does not appear necessary to reduce the work load, even though it is actually necessary.

The risk of detrimental effects due to erroneous statistical decisions may be increased further by the one-sided power inherent in some statistical tests. These tests depend on establishing that differences between samples are beyond the range of random variation at a certain probability level. If the null hypothesis is accepted, that is to say there is no difference as mentioned above, it does not mean that the null hypothesis has been proven correct, but simply that it will be accepted until there is evidence to the contrary. Therefore, the pair of hypotheses are suitable for testing the central ergonomic question of tolerability, and every effort must be made to minimize errors of the 2nd type when testing the hypotheses.

Therefore, for planning ergonomic field studies, it may be possible to avoid the laborious "randomization principle" in favour of a selective sample survey, since for studying tolerance to stress it is sufficient to study workplaces where, from experience, there is known to be a high work load.

There is another problem over and above the general hypothesis mentioned above for research projects sponsored by the Commission of the European Communities. The effect of mechanization on stress is examined in all three research projects. Here, the hypothesis must take the form: "mechanization alters (or reduces) stress".

The method selected depends on the hypotheses selected which, as shown in Table 8, necessarily meant that comparable methods were used in the sponsored research projects since, although different occupational tasks were studied, the same hypotheses were to be tested. After the hypothesis and method-selection phases, which generally had to be based on the results of preliminary ranging tests, as a rule the methods are tested to see that they are suitable in further preliminary tests under the particular conditions of the specific study. These preliminary tests may result in the hypotheses being reformulated and/or supplementary modification of test methods. This phase often demonstrates the need for supplementary laboratory tests to develop or check the methods (see also Table 8, or TEMMING & HAAS, 1969).

The primary requirement of planning and preparation for the actual (main) tests is giving an adequate explanation to the works (management) and workers to be used in the study. It is a good idea to hold short briefings in the works, sending out personal, written invitations. At these briefings (which may be held separately with the two groups to ensure that all the questions of interest are dealt with openly) the aims of the study should be explained and all the methods to be used should be demonstrated. Finally, all the members of the research team who will later be carrying out the tests at the workplace, should be introduced.

In addition to arranging to reimburse for working time lost because of the study, it may be expedient to agree on a single lump-sum bonus payment for all workers volunteering as test subjects (for instance, like an hourly wage). It is also an advantage and a good idea to provide photographs of working situation and workplace.

To minimize the chance of pathological factors affecting the physiological variables, it is advisable to give the workers to be studied, a clinical examination (see ROHMERT /007/ and Tab. 8).

As far as possible, the actual processing and analysis of the results should be done whilst the tests are in progress, since their outcome may suggest alterations to the tests themselves or even in selection of the hypotheses. They might also point to a need for laboratory tests to check and interpret the results, and this might well avoid follow-up tests.

The analysis also involves drawing a statistical conclusion by calculating the confidence limits for the results. This enables us to draw a conclusion, with a given probability, as to the applicability of the results obtained from the sample of an entire group of all the workers employed at comparable workplaces. This statistical formulation of the results may enable us to draw conclusions of more general application and should form the basis of an ergonomic system design. As the examples described by TARRIERE (053) show, the whole pathway right up to system design can be followed, even in an incomplete study, in order to be able to check the effectiveness of the proposed design measure by subsequent tests carried out as part of the overall project.

7.2. Results of studies on work requiring physical effort underground (studies by FAURE /03/ and ROHMERT /007/)

7.2.1. Results of work load studies

Comparison of the results obtained from time studies on the work load parameter "duration of work load" in Table 9 reveals significant+) differences between the groups of workers studied in the two investigations, as regards:

mean time present at the working point and total duration of the inactivity phases (at the working point)

However, we could not make a statistical comparison between the travel phases because some figures were missing. Where the train journeys were of comparable length there is liable to be a significant difference in the mean time spent on the footway, assuming a similar standard deviation. On the other hand, comparison of the mean

duration of the sum of the activity phases (at the working point)

did not reveal any significant difference.

+) a 95% significance level was regarded as significant.

Research leader:	FAURE (03)	ROHMERT (007)
Number of shifts studied	51 +)	27
Number of workers studied	28	15
Presence at the working point		
Mean (min)	329	345
Standard deviation (min)	33	28
Variation (%)	10	8
Total duration of the activity phases (difference not significant)		
Mean (min)	220	204
Standard deviation (min)	33	52
Variation (%)	15	25
Proportion of mean time present (%)	67	59
Total duration of the inactivity phases (including meal breaks)		
Mean (min)	105	142
Standard deviation (min)	33	49
Variation (%)	32	35
Proportion of the mean time present (%)	32	41
Time spent on footway walking from and to working point		
Mean (min)	70	41
Standard deviation (min)	not calculable	20
Variation (%)	"	48
Duration of train journeys (including waiting time, not including cable-car journeys)		
Mean (min)	70	70
Standard deviation (min)	not calculable	24
Variation (%)	"	34

+) (Not including coal cutter drivers, since the frequent stops made by the coal cutter mean that the driver would have a relatively high proportion of inactivity phases; also, the work hardly involves any work activity requiring physical effort)

Table 9: Comparison of the work load parameter "duration of work load" for underground work requiring physical effort.

Since both groups of workers studied were on the same standard shift of eight hours, the figures in Table 10 for proportion of the total shift time accounted for by the work load parameter duration of work load, can be compared. Comparison with the proportion figures calculated from SIEBER's results (1963) shows that, where time spent travelling is shorter, there are likely to be longer activity phases. The validity of this hypothesis can be checked by calculating the correlation coefficient between the relative proportions of travelling and activity phases for individual shifts; this was done for the studies by ROHMERT /007/ and SIEBER (1963). The calculations, done separately for each study, revealed negative correlation coefficients which are significant at $p > 0.10$ (for ROHMERT) and $p > 0.05$ (for SIEBER); an overall summary of the results also reveals a significant ($p > 0.05$) negative correlation, which confirms the assumption that duration of work activity at the workplace decreases as travelling time increases.

However, for evaluating work load we must remember that travelling time usually includes travelling on foot, which should not be regarded as an inactivity phase. ROHMERT /007/ also recorded some instances of work done during the journey to and from the workplace because of the special tasks of the group of miners he studied; these miners were mainly occupied in transporting and handling heavy loads. Thus, in this study for assessing work load, there is an important difference between the proportions of time in Table 10 spent at the working point and the distribution of the work load parameter "duration of work load" throughout the entire shift. The sum total of the inactivity phases accounted

Research leader	FAURE /003/	ROHMERT /007/	SIEBER (1963)
Total duration of the activity phases at the working point	46	43	56
Total duration of the inactivity phases at the working point	22	30	28
Presence at the working point	69	74	84
Duration of travel phases (excluding cable-car)	29	23	16 (including cable-car)

Table 10: Proportions of the work load parameter "duration of work load" (at the working point) in the shift period, from three different studies on underground work requiring physical effort (stated as percentages; since the means were calculated from individual data, they do not always add up exactly to 100%).

for, on average, 44% of the shift time and this increased the activity phases to 56%, thus achieving the figure quoted by SIEBER. According to ROHMERT's results, walking accounts for 8% of the shift time, but this is included as part of the activity phase; the coefficient of variance of 38% indicates a wide scatter in the proportion of walking (see also Tab. 9).

ROHMERT also found that the proportion of the inactivity phases deviates substantially from the mean of 44%, according to the time in the shift; inactivity per hour rises steadily from 33% in the 1st hour to 52% in the 5th hour, then falls to 35% in the 6th hour, then increases again to reach a maximum of 72% in the 8th hour (see Fig. 10). In absolute terms these figures certainly only apply to the tasks and working conditions studied by ROHMERT, but the trend they reveal (a monotonic rise up to the 4th and 5th hour of the shift and a renewed rise after a relative minimum in the 6th hour) are of general significance if we wish to draw conclusions about stress, from the variation in work load as a function of time.

As regards the level of work load during the activity phases, apart from nominal classification of each duty (= cycles in Fig. 1) FAURE only classifies these duties ordinally into "light, moderately heavy and strenuous" (= heavy). Analysis into these categories was based on the investigator's experience, i.e. operationally by cycles. This gave the percentage data, related to time present at the working point summarized in Tab. 11, from FAURE's results.

Operationally defined level of work load according to "cycles involving effort" — Workplace	Machine stall cutter foot of breast (n = 8)	Machine stall cutter head of breast (n = 7)	Cable attendant (n = 8)	Jerry man foot of breast (n = 8)	Jerry man head of breast (n = 8)	Lining cutter (n = 12)	Coal cutter driver (n = 5)
Loading with pick and shovel	35	25	5	11	20	11	-
Transporting heavy material	7	4	5	5	4	4	-
Hanging up cable	-	-	37	-	-	-	-
Operating compressed-air hammer	3	1	-	-	-	-	-
Working on steel lining	22	24	-	29	13	-	-
Total proportion of time present at workpoint	67	54	47	45	37	15	0
Variability index for duration of "cycles involving effort"	0.4	0.3	0.7	1.3	1.1	2.2	0.0
"Other cycles" (moderately heavy - light)							
Plate haulage unit, lining support, raise or restrain with chain pull	-	-	-	-	-	19	-
Wedging, timbering	-	-	-	20	26	4	-
Laying out coils of gobbing wire	-	-	-	-	-	5	-
Blasting (boring, loading, charging)	6	13	-	-	-	-	-
Hydraulic goaf stowage, conveyor, lining	-	-	-	-	-	27	-
Auxiliary work, coal cutter, repair work, chain scraper	-	6	-	-	-	-	16
Controlling coal cutter	-	-	-	-	-	-	34
Walking unloaded	-	-	-	5	2	-	-
Other work and various types of "light" work	2	4	17	10	8	5	7
Inactivity phases	24	22	36	22	25	24	43

Table 11: Mean percentage times for operationally defined levels of work load in relation to time present at working point for workplaces studied by FAURE /03/ (n = number of shifts studied)

The range of the total duration of "cycles requiring physical effort" related to the mean duration by the following equation, which FAURE called the variability index:

$$\text{Variability index} = \frac{\text{maximum duration} - \text{minimum duration}}{\text{mean duration}} \qquad (11)$$

provides additional information when comparing the mean proportions of cycles requiring physical effort (see Table 11). For example, from the low index of the machine stall cutter (head of breast) we would expect a low intra- and interindividual variation in the duration of cycles requiring physical effort, whereas the jerry man (foot of breast) is likely to have higher proportions of cycles requiring physical effort than is expressed by the mean.

Assuming a normal distribution in the overall group, if we use the more powerful calculation of confidence limits for the mean proportions of cycles requiring physical effort, then we can state the estimated scatter, also present in the variability index, quantitatively. Table 12 shows the statistical characteristic values in three cases:

Workplace	Mean proportion % (see Tab. 11)	Variab. index (FAURE)	Stand. deviation %	Variation %	95% confidence limits of the mean proportion (%)	
					upper	lower
Machine stall cutter (foot of breast)	67	0.4	6.4	9.4	73	61
Jerry man (foot of breast)	45	1.3	16.2	36.9	59	31
Lining cutter	15	2.2	12.4	80.6	23	7

Table 12: Confidence region for mean proportion of cycles requiring physical effort in the time present at the workplace for examples with a different variability index.

The confidence region between the upper and lower confidence limits shows the values we can assume for the unknown mean of the proportion of cycles requiring physical effort in 95% of all similar work tasks under comparable working conditions. For instance, for machine stall cutters at the foot of the breast this mean will probably be between 73% and 61% of the time present at the workplace in 95 out of 100 machine stall cutters.

The data for variation given in ROHMERT's results /007/ show that, on average, low variation is likely (see Tab. 13) for transport work underground. Since this transport work is comparable with the "cycles requiring physical effort" defined by FAURE, with this more homogeneous distribution about the mean, from these results we can estimate the maximum possible proportion for such cycles requiring physical effort; this is 87% for handling loads and thus exceeds the upper limits calculated for machine stall cutters (Tab. 12).

To determine the total work load for the time present at the working point, we can combine these estimates for <u>duration of work load</u> with data on level of work load (see also equation 6 in Section 5.1.).

However, this data for level of work load cannot be obtained from the qualitative categories used by FAURE ("requiring physical effort") and we must have at least ordinal data. As already explained in Section 5.2.2.2., energy consumed at work can be regarded as a parameter of level of work load. For all cases of heavy dynamic muscular work we can actually take the level on the proportionality scale for measured values of energy consumption at work, whereas we can only use an ordinal scale with mixed forms of different types of muscular work.

SIEBER (1963) and ROHMERT /007/ have given data on level of work load in terms of energy, for underground work. Work of transporting and handling heavy loads, only studied by ROHMERT, produced the distribution of energy consumption shown in Fig. 10.

Characteristic work involved	No. of shifts	Mean duration of the activity phases (min) at the working point	Variation (%)	Proportion of activity phases in the time present at the working point		
				Mean %	Confidence limits (95%) upper (%)	lower (%)
Handling loads	4	231	17.6	68	87	49
Loading and unloading	8	182	29.8	56	70	42
Reloading	15	208	24.8	57	66	50
Sum of all activity phases at the working point	27	204	25.4	59	65	53

Table 13: Characteristic statistical values and confidence regions for the mean proportion of time spent transporting, in the time present at the working point, from ROHMERT's study [007]

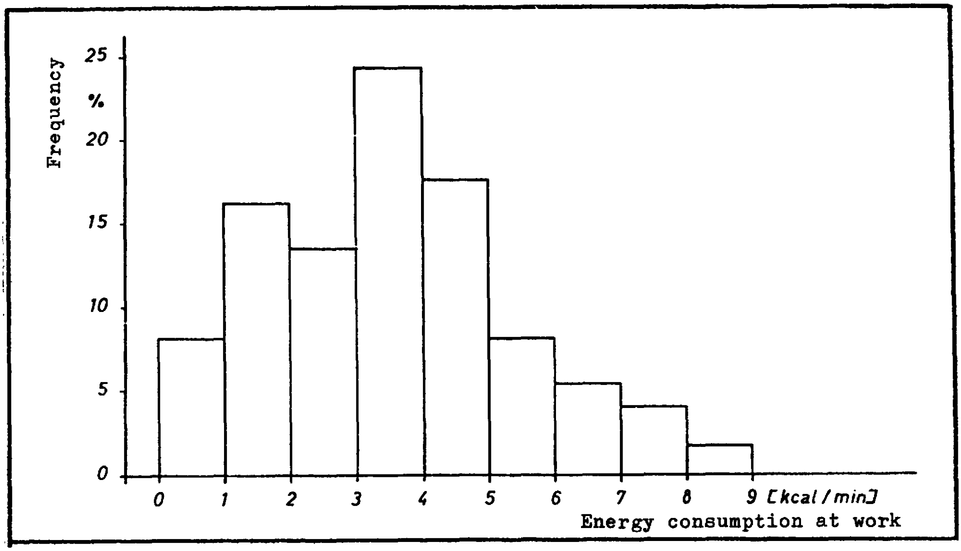


Fig. 10: Distribution of level of work load in terms of energy, for cycles of handling and transporting heavy loads underground.

Since, because of its positive skew, this distribution is probably not a normal distribution, it is advisable to estimate the maximum standard deviation from the range (SACHS, 1972), which gives S ≤ 4.5 kcal/min (with n ≈100). It would be necessary to know the mean energy consumption to determine the upper confidence limit; this would limit the results given in Fig. 10 in that the selection of cycles studied would be based on the work involved in handling and transporting heavy loads. Nevertheless, the mean of this distribution is certainly less than 4 kcal/min and hence below the mean of 4.9 kcal (per minute main time ≈ activity time at working point) for 97 workplaces with varying degrees of mechanization, reported by SIEBER (1963).

If the estimate of the upper confidence limit for the level of work load described in terms of energy is based on this mean of 4.9 kcal/min, the estimated maximum standard deviation gives an upper confidence limit of 5.8 kcal/min for the mean level of work load described in terms of energy for underground work (except for operating mining machines) for activity at the point of work. (The lower confidence limit is 4.0 kcal/min).

However, because of the high proportion of travelling time during the shift, this factor does affect the calculation of the range of variation of "work load in terms of energy". According to SIEBER's figures (1963), walking underground can produce levels of work load comparable to those shown for energy consumptions at work in Fig. 10. Walking in straight ways and cross-cuts without hindrance ($\approx$ 70 m/min) can result in energy consumptions of between 3.5 and 5.0 kcal/min, and with hindrance about 1 kcal/min more. Means of 9 kcal/min are likely for walking up sloping breasts ($\approx$ 10 m/min). The energy consumption per metre walked is twice as high in level breasts as in straight ways and cross-cuts, and six to fifteen times higher in sloping and steep situations (SIEBER, 1963).

Using these data on level of work load in terms of energy and the results for duration of work load (see Tab. 9), we can calculate the range of variation of the mean work load in terms of energy. This calculation has been done in Tab. 14, using the data on duration of work load from ROHMERT's studies (n = 27 shifts). However, the maxima and minima in this table refer to the mean values for shifts worked by a fairly large group of workers, and so they do not give the maximum work loads which can arise for the workers and activities studied by FAURE or ROHMERT in a single shift for one worker.

Characteristic cycles	Duration of work load (min) Mean	Confidence limits upper	lower	Work load level (kcal/min) Mean	Confidence limits upper	lower	Calculated mean work load (kcal) Mean	Maximum	Minimum
Activity phases at working point	204	224	184	4.9	5.8	4.0	1000	1300	735
Inactivity phases at working point	142	162	122	0.6+) standing	Extreme 0.8+) (standing bent)	Means 0.3+) (sitting)	85	130	40
Walking in straight ways	41	61	41	(SIEBER) 5.5 (with obstruction)	Extreme 9.0 (fairly steep)	Means 4.1 (no obstruction)	230	550	170
Train journeys	70	79	61	0.3+) (sitting)	—	—	20	25	20
Total mean work load, in terms of energy, during the shift from the sum of the calculated values							1335	2005	965

Table 14: Calculation of mean work load in a shift, in terms of energy, from data on duration of work load from ROHMERT and data on level of work load from SIEBER

+) from SPITZER & HETTINGER (1969)

Maximum work loads of this sort are a possibility if the duration of activity phases and/or the duration of the distance walked are appreciably different from the means given in Tab. 9 or if the times are comparable but cycles with high energy consumption are more frequent.

Therefore, to answer this question, the possible deviations of the individual readings must be estimated from the means given in Tab. 9. However, this estimate is made more difficult by the fact that, as has been shown, there is a negative correlation between the length of time present at the working point and the travelling time (including walking). However, since the duration of activity phases in the time present, and the duration of walking as part of the travelling time, are the parameters determining energy consumption, the maximum possible values for these two parameters must be determined separately and then related to one another.

If the time present at the working point is regarded as a dependent variable, then the possible maximum value for duration of walking must be determined first. Assuming a normal distribution, we can calculate from the standard deviation for duration of walking calculated from ROHMERT's results that the probability of positive deviations from the mean with a difference greater than $+2_{\sigma}$ is about $p = 0.05$. At this level of probability the maximum possible walking time is about 80 minutes. The mean of time present at the working point would therefore be reduced here by about 40 minutes. Table 9 shows that the activity phases represent just under 60% of the time present, so that in this instance about 210 minutes of the remaining approx. 305 minutes (345' - 40') of time present would be expected to be the duration of the activity phases.

In principle, the same approach could be used to estimate maximum energy consumptions at work. However, we must assume that the work load, in terms of energy, during the activity at the working point could possibly be related to the duration and level of work load of the walk, and so we could not validly estimate a maximum value simply from results obtained by analysing the actual situation. We must assume that work is not so intense at the beginning and end of the activity at the working point.

Independently of this, the distribution of the proportion of inactivity phases in terms of time shows an absolute maximum in the 8th hour of the shift in both SIEBER's and ROHMERT's studies, as shown in Figure 11.

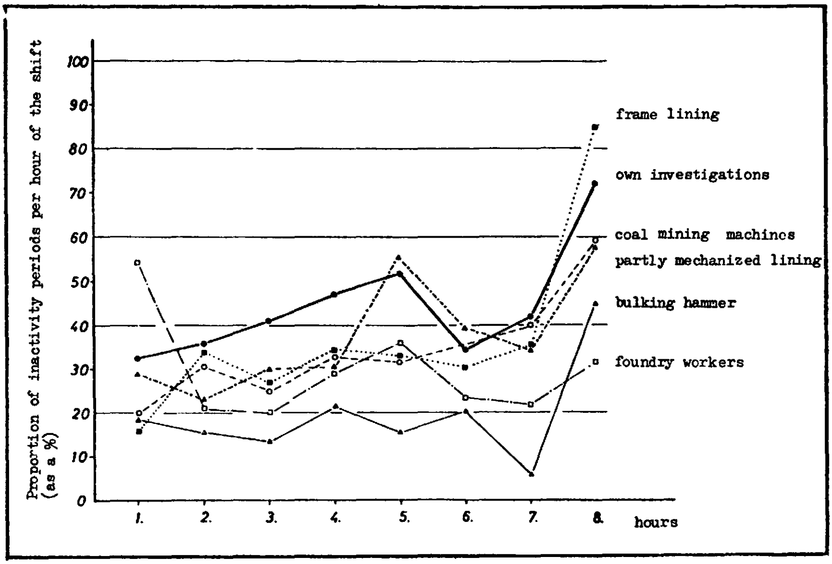


Fig. 11: Mean values for proportion of inactivity phases per shift hour from 27 separate studies by ROHMERT [007], compared with similar values (from SIEBER, 1963) for different activities.

Comparison of the maximum value obtained for duration of work load during walking with the figures for mean duration of work load in Table 14 indicates that the calculated mean work load may be considerably higher for a single shift than the mean from all shifts.

Checks of the upper confidence limits for mean duration of activity for cycles with specific work contents shown in Fig. 13, indicate a similar situation. For the entire example of handling loads, the upper confidence limit for the mean proportion of activity phases in the time present at the working point gives a mean work load of 1300 kcal (87% of 345 min (see Tab. 9) = 265 min, 265 min . 4.9 kcal/min) or 1540 kcal (265 min . 5.8; see Tab. 14). So even this approach indicates that there may be higher work loads in individual shifts by individual workers, than would be expected simply from the means.

7.2.2. Results of stress studies

The two studies by FAURE [03] and ROHMERT [007] both set out to determine whether improved mechanization underground has reduced the stress on miners working at the time. We can compare the results of both these stress studies with the results of other underground studies by SIEDER (1963), because:

- all three studies examined the effects of mechanization on the stress on the worker;
- all three studies used the same stress parameters;
- since the studies were carried out in different countries and within a period of about 10 years in the development of mechanization, the results of stress measurements where work load (type of work load, level of work load, duration of work load) was also examined can be used to illustrate the different capabilities of each miner resulting from their different ages, and from the trend for the mining population to increase in age because of an inadequate intake of younger workers.

We have not considered work loading due to additional climatic environmental factors considered in discussing stress, since this is to be the subject of a report by the Commission of the European Communities.

FAURE reports that, in the French coalmining industry, the reservoir of young men who have always undertaken the physically strenuous underground work, is steadily dwindling (cp. Table 15).

	1952	1967	1969
Mean age of underground workers	32.9	36.4	37.8
Percentage of underground workers less than 35 years old	60	39	33

Tab. 15: Trend for the age of undergr und workers to increase in the French coalmining industry (FAURE)

The mean age of miners studied by ROHMERT was higher (40.3; range 28 - 48 years). On average, the men worked underground for 20.5 years (12 - 33 years). Comparing these figures with the group studied by SIEBER about eight to ten years earlier (1959 - 1961), the mean age at that time was only 31 years (range 21 to 41 years). There were two obvious findings:

- the general increase in the age of the underground mining population;
- younger workers are mainly employed in the breast region and pre-breast gallery (SIEBER), whereas the older men are frequently engaged in the transporting work (FAURE, ROHMERT).

This change in the type of job during a working life is only partly due to the miner's diminishing function performance. In fact, MÜLLER's capacity-pulse indices (CPI) are much the same in ROHMERT's and SIEBER's groups, although these figures for physical functional capacity are much worse than for other industrial workers or other homogeneous groups of personnel such as policemen (cp. Fig. 12).

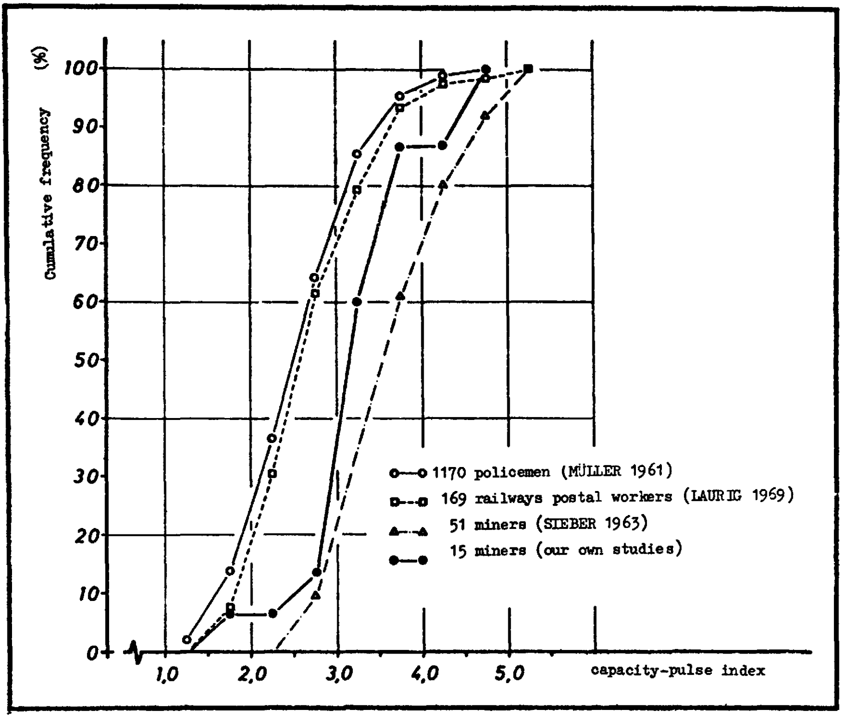


Fig. 12: Cumulative frequency for capacity-pulse index (CPI) of different types of workers.

The lower physical functional capacity does in fact correlate with a trend towards reduced stress, which can be attributed to lower work loads because of developments in mechanization. However, this only applies to the means of stress parameters. The means show considerable scatter, and so they can only be used to identify the trends. Completely the opposite may be found in a concrete example in considering a specific, non-mechanized workplace with a defined working point equipped with mechanical aids.

The different types of work done underground vary so much that we cannot really generalize in respect of stress due to "mining activity". Therefore we have to distinguish between different areas in the industry (e.g. winning, driving gallery, transporting materials). ROHMERT/007/ gives the stress parameter pulse rate (beats per minute: P/min) for three typical subgroups of workplaces for transporting materials, classified into mechanized and non-mechanized. Table 16 summarizes the results.

Workplace subgroup	Non-mechanized	Mechanized	Overall
Handling	87.0 (2.8) 22.0 (1.4) 4.5 (3.5)	98.5 (0.7) 24.5 (9.2) 9.0 (5.7)	92.7 (6.8) 23.3 (5.6) 6.8 (4.6)
Loading and unloading	95.9 (10.9) 26.6 (7.3) 3.8 (1.7)		95.9 (10.9) 26.6 (7.3) 3.8 (1.7)
Reloading	84.3 (3.1) 20.3 (3.3) 2.0 (2.3)	87.0 (6.5) 23.8 (9.3) 4.5 (1.9)	86.3 (5.8) 22.9 (8.2) 3.8 (2.2)
Total	91.3 (9.9) 24.1 (6.4) 3.4 (2.1)	88.8 (7.3) 23.9 (8.9) 5.2 (2.9)	90.1 (8.7) 24.0 (7.6) 4.2 (2.7)

Table 16: Means of characteristic values for cardiovascular stress in the workplace subgroups (from Rohmert)
(in brackets: standard deviation)
Each box shows:
1st line: overall pulse rate as a mean for shift
2nd line: work-induced pulse rate as mean for shift
3rd line: pulse rate elevation
(All data in P/min)

The mean of 90.7 beats per minute from all workplaces involving transporting materials indicates that, in general, there is no excessive cardiovascular stress on the miners. The differences in the means could be due to individual variations in the miners studied; this is confirmed by the fact that the mean work-induced pulse rate (2nd line in each box in Table 16) of 24.0 beats per minute is clearly not related to the level of mechanization of the workplaces or the type of task. Also, the lowest recovery pulse reading after the end of the shift (on average 4.2 P/min) is only slightly higher than the lowest initial pulse measured before the shift started (see 3rd line in each box in Tab. 16). This slight increase in pulse rate can be explained by the biological diurnal rhythm, a specifically dynamic effect which can increase metabolism and hence alter pulse rate after meals (KRAUT and KELLER, 1961, GLATZEL and RETTENMAIER, 1965), and also by a build-up of fatigue during the shift; however, all these factors should be so low as to be negligible.

The low mean stress tolerable over the shift as a whole does not mean there are no transient stress peaks. However, these peaks of up to 150 pulse beats per minute were immediately corrected since there were adequate opportunities for recovery in all shifts.

During winning, lining and mine-filling, SIEBER found higher stresses (on average 30 beats per minute) than during transport of materials. This is due particularly to difficult static holding work due to unfavourable bodily positions at these workplaces. The evaluations of stress are summarized in Table 17 for workplace sub-groups and different degrees of mechanization. The ratio of the work-induced pulse values exceeding a tolerable endurance threshold-stress of 35 work-induced beats per minute to lower work-induced pulse values is stated as a percentage. This shows that workplaces with non-mechanized bulking hammers in operation produce the highest stress, those with partly mechanized lining and mine filling produce medium stress and the fully mechanized workplaces for lining and winning produce the lowest stress. Since bulking hammer work has declined in importance in the last 15 years since SIEBER's studies, and climatic factors inducing additional stress were not referred to, we can also say in the fields of winning, lining and mine filling that the shift average shows tolerable stress.

Activity	Work-induced beats/min > 35	:	≦ 35
Bulking hammer	83	:	17%
Steel lining and mine filling	33	:	67%
Hydraulic single prop and frame	33	:	67%
Machine attendant	19	:	81%
Frame rack and stool	18	:	82%

Table 17: Percentage proportion of work-induced pulse rates of different levels in all shifts in different activity groups (from SIEBER)

All ROHMERT's and SIEBER's findings are evidently confirmed by FAURE's studies. However, in evaluating stress, FAURE points out the unfavourable trends with physical aptitude declining with the increasing age of the mining population, and other social problems due to the fact that further increases in productivity are often achieved by increased human output. Here we can easily encounter a bottle-neck produced by work requiring physical effort, which is difficult or impossible to do with machines.

7.2.3. Evaluation of the work load and stress imposed by underground work requiring physical effort

Some practical conclusions can be drawn from the results of all the stress studies examined:

- The age of the miners appears to be a cardinal problem of stress in mining; this cannot be solved by rigid technical structures. Technical development here must be specifically age-related, otherwise younger personnel would have to be given preference.

- In the areas of lining and mine filling (and to a certain extent also winning), generally speaking the stresses are greater than in the transporting of materials, not least because man is rigidly bound to the machine and organization. Care should be taken to provide optimum breaks and, where necessary, to use hopper attachments.

- The entire workforce should be given basic training (combined with continuous further education) in correct physical transport and handling techniques, which reduce the muscular strength used and reduce the risks associated with the work, as far as this is possible in the confined working area.

- Experimental work load, stress and functional capacity studies should be in progress all the time to ensure that the working methods are suitable for the men, even where there is increasing mechanization.

7.3. Results of the studies on work requiring physical effort in forging works, foundries and iron and steel works

7.3.1. Results of work load studies

TARRIERE /053/ carried out work load studies in iron and steel works. He used a standard technique which provided information about the work load parameters "level of work load", energy consumption and, to a certain extent, "duration of work load". 32 workplaces were studied, including 44 workers and 67 shifts.

The level of work load is stated by determining a mechanical work load (power, measured in watts) equivalent to a standard level of muscular effort. The standard muscular effort is determined whilst the subject is pedalling a bicycle ergometer with a progressively increasing work load. The variable measured is heart rate. Heart rate is introduced as a relative parameter so that the equivalent work load is not stated per individual, i.e. in person-specific terms. Any typological dimension of equivalent work load has deliberately been avoided, but a situative dimension has been purposely introduced into the determination by stipulating that the work load on the ergometer is imposed in the same environment in close proximity to the workplace and just before or after the equivalent mechanical work load to be determined.

In reports by POULSEN and ASMUSSEN (1962) equivalent work load is calculated by the following equation:

$$\frac{\text{Increase of heart rate during actual work}}{\text{Increase in heart rate during work on ergometer}} = \frac{\text{Equivalent mechanical work load}}{\text{Mechanical work load imposed by standard work on the ergometer}}$$

By equating the two sides of the equation, the dimension of the ergometer work load, (usually watts) becomes the dimension for the equivalent mechanical work load and this should enable us to compare very different human activities at different types of actual workplace. This method also excludes additional work load parameters, in particular specific dynamic effects of eating, the effects of diurnal rhythm or strain due to heat. Assessing strain due to heat will be the subject of another ergonomic report from the Commission of the European Communities.

Figure 13 shows an individual characteristic curve for heart rate as a function of ergometer work load in which a stabilized heart rate of 115 beats per minute was measured at an actual workplace, which in this example corresponds to an equivalent work load at the actual workplace of 45 watts.

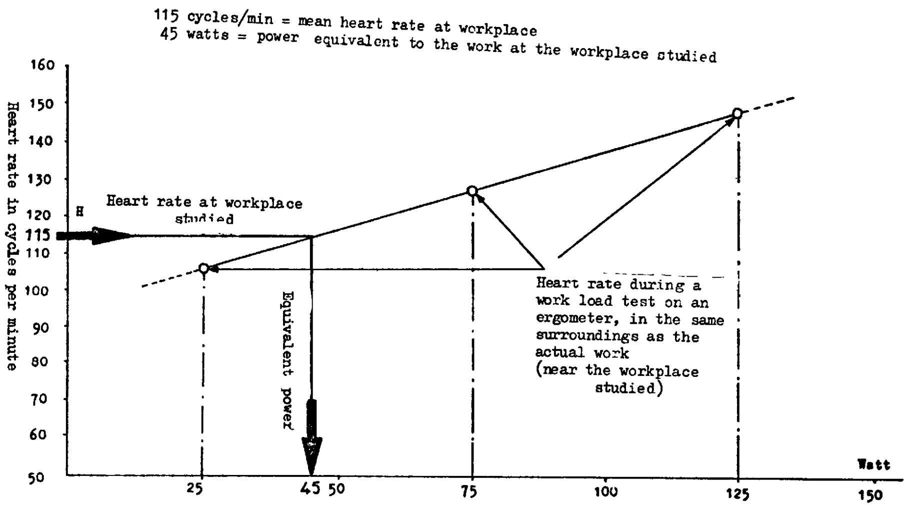


Figure 13: Determination of "equivalent work load" at a workplace using a bicycle ergometer (from TARRIERE)

Figure 14 is a further example illustrating two different test subjects in the same workplace. Here the equivalent work load is 58 watts. Irrespective of individual functional capacity (which differs here), we obtain a reading for the same work load at the same workplace.

Without going into a further physiological discussion about the approach chosen for determining work load, Tab. 18 is a summary of the results obtained from 20 workplaces from the iron and steel industry for five types of activity (including the car industry). The work load varies in the ratio of 1:6 between 19 and 108 watts, depending on the workplace. Since work requiring physical effort predominated at all the workplaces this is an impressive illustration of the different muscular work loads involved.

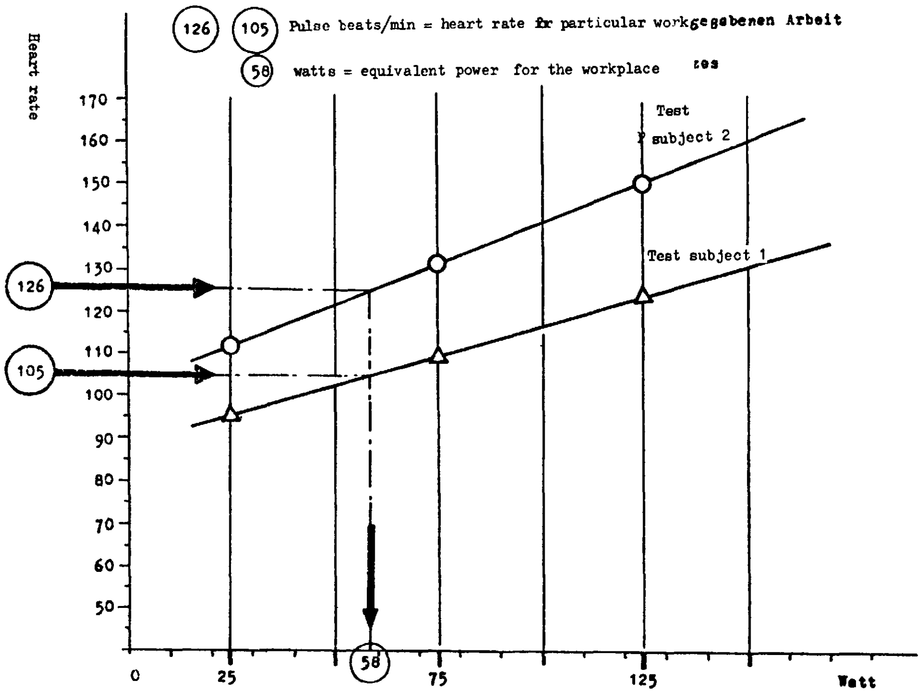


Fig. 14: Example of determining "equivalent work load" of a specific workplace for two different workers (from TARRIERE)

In figure 15 the results are summarized as histograms from which the following information can be obtained:

- 80% of the workplaces show a work load of less than 70 watts, which is a tolerable work load on a bicycle ergometer.
- At all workplaces in the forges and foundries the work load is greater than 50 watts. These are the most likely to produce intolerable working conditions.
- All workplaces in the machine shops and assembly plants are below 50 watts.
- Workplaces in the iron and steel works range through the whole gamut of work loads.

Type of activity	Description of workplace	Equivalent mechanical work load (watts)
Forges	Forging axle bearings 3000 t press	66
	Forging axle bearings 1800 kg hammer	108
	Forging steering-knuckle arms 680 kg hammer	50
Foundries	Moulding on a NICHOLLS moulding machine	76
Iron and steel works	Operating a 5 t hammer	28
	Operating a manipulator	22
	Hammersmith (1000, 250, 150 kg hammer)	70
	Grinding blocks and snagging	100
	Catching in rolling mill	25
	Controlling travelling gantry in rolling mill	
Machining (shaping by machining with removal of material by cutting tools)	Machining ball-and-socket joint	
	Machining brake drums	51
	Trimming threads with tap thread	19
	Machining small working parts on a turning lathe	
	Machining drive shafts	40
	Refinishing driven plates	48
Assembly plants	Sewing with sewing machine	
	Inserting piston rings	35
	Attaching rubber seals to doors etc.	
	Adjusting track	
	Mounting the right front wheel axle	67
	Suspending the engine	41
	Attaching the interior lining	52
	Assembling rocker arm and drive rod	
	Assembling starter	
	Connecting gear box	25
	Polishing car body 1. wet	60
	2. dry	40

Tab. 18: Equivalent mechanical work load (watts) at 20 different workplaces for five types of activity (from TARRIERE)

The summaries in Table 18 and Figure 15 correlate well with earlier findings by SCHOLZ (1963) in studies at foundries, and by LEHMANN, MÜLLER and SPITZER (1950) at drop forges. We can conclude from this that technical developments over 20 years have still not drastically reduced the work requiring physical effort in iron and steel works.

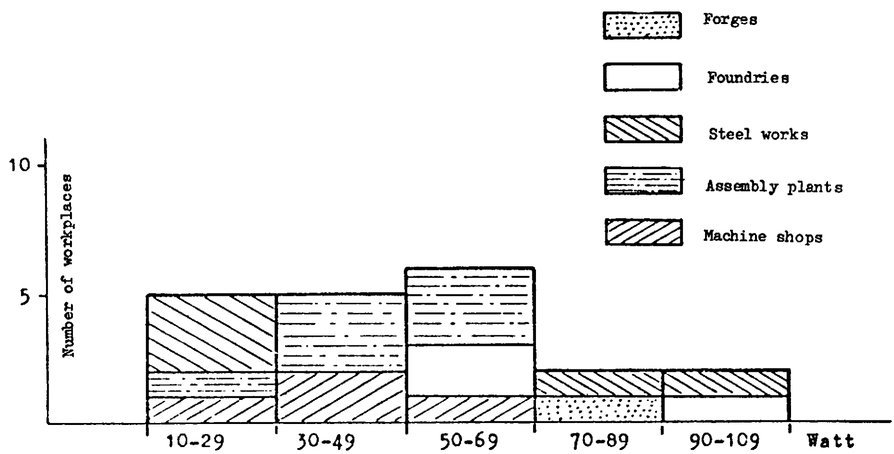


Fig. 15: Distribution of equivalent mechanical work load (watts) for 20 different workplaces (from TARRIERE)

7.3.2. Results of stress studies

At the 20 different workplaces studied by TARRIERE, work load showed a 1:6 scatter whereas stress, assessed by work-induced pulse rate was scattered in a ratio of 1:5. We can conclude that the differences in work load tend not to be completely relevant to stress since people with an individual functional capacity adequate to cope with extreme work loads tend to be employed in those areas. However, we cannot interpret this as meaning that the right man is always put in the right place. The range of work-induced pulse rates (11 to 55 beats per minute) is an indication that there are too few workers or the work loads are intolerable. Table 19 and Figures 16 and 17 show a differentiation of the results classified into the workplaces studied and the five types of activity.

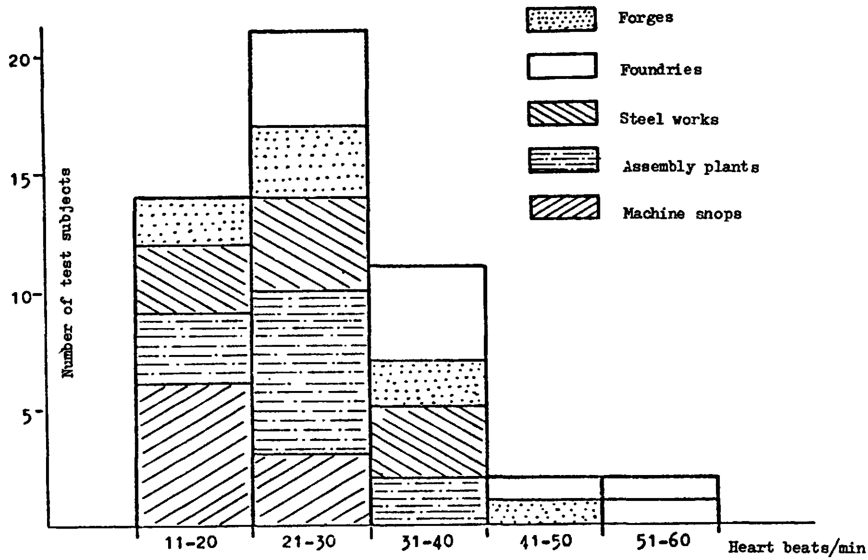


Fig. 16: Frequency distribution of the mean work-induced pulse rates for five types of activity (from TARRIERE)

It can be concluded from the summaries that:

- 70% of all mean work-induced pulse rates are below 30 beats per minute and hence within the physiological limits of tolerance.
- With two exceptions (workplaces with overhead work), the measured stress was tolerable, with work-induced pulse rates of < 30 beats per minute in the machine shop and assembly plants.

Type of activity	Description of workplace	Test subject	Stress: Work-induced pulse rate beats/min	Stress: Pulse rate beats/min
Forges	Forging axle bearings on a 3000 ton press	A 1 B 1 C 1 D 1 E 1	46 36 37 36 22	108 111 108 118 113
	Forging axle bearings with drop forging hammer of 1800 kg	A 2 B 2 C 2	25 52 55	97 140 128
	Forging steering-knuckle arms with drop forging hammer of 680 kg	A 3 B 3 C 3	23 23 32	109 104 112
Foundries	Moulding on a moulding machine - Conveyor 1	A 4 B 4 C 4	32 27 19	113 109 94
	Moulding on a moulding machine - Conveyor 2	A 4 D 4	41 23	106 106
	Moulding on a moulding machine - Conveyor 3	A 4 E 4 F 4	33 21 20	105 107 105
Iron and steel works	Operating a 5-ton hammer	A 5	18	98
	Operating a manipulator	A 6	30	119
	Hammersmith 1000 kg hammer 250 kg hammer 150 kg hammer	 A 7 A 8 A 9	 35 18 26	 106 90 102
	Grinding blocks and snagging	A 10	38	110
	Catching in rolling mill	A 11 B 5 C 5	36 26 24	122 101 102
	Controlling travelling gantry in rolling mill	A 12	17	89

Tab. 19: Stress at different workplaces for five types of activity (from TARRIERE)

Table 19 continued:

Type of activity	Description of workplace	Test subject	Stress	
			Work-induced pulse rate beats/min	Pulse rate beats/min
Machine shops	Machining ball-and-socket joints	A 13 B 6	16 12	78 84
	Trimming threads with tap thread	A 15 B 7	11 15	82 82
	Machining drive shafts	A 16	20	97
	Machining small working parts on a turning lathe	A 17 B 8	25 16	105 95
	Refinishing driven plates	A 18	30	85
Assembly plants	Sewing with sewing machine	A 19	11	88
	Inserting piston rings	A 20	11	95
	Attaching rubber seals to doors etc.	A 21	25	103
	Adjusting track	A 22	12	97
	Mounting the right front wheel axle	A 23	26	109
	Suspending the engine	A 24	32	118
	Attaching the interior lining	A 25	33	109
	Assembling rocker arm and drive rod	A 26	24	77
	Assembling starter	A 27	29	119
	Connecting gear box	A 28	29	100
	Polishing car body 1 - wet	A 29 B 29	29 31	86 97
	2 - dry	A 30 B 10	19 28	111 102

- The overall mean pulse rates range between 77 and 140 beats/minute. The majority are between 100 - 109 beats/minute; 76% of all means are below 110 beats/minute.

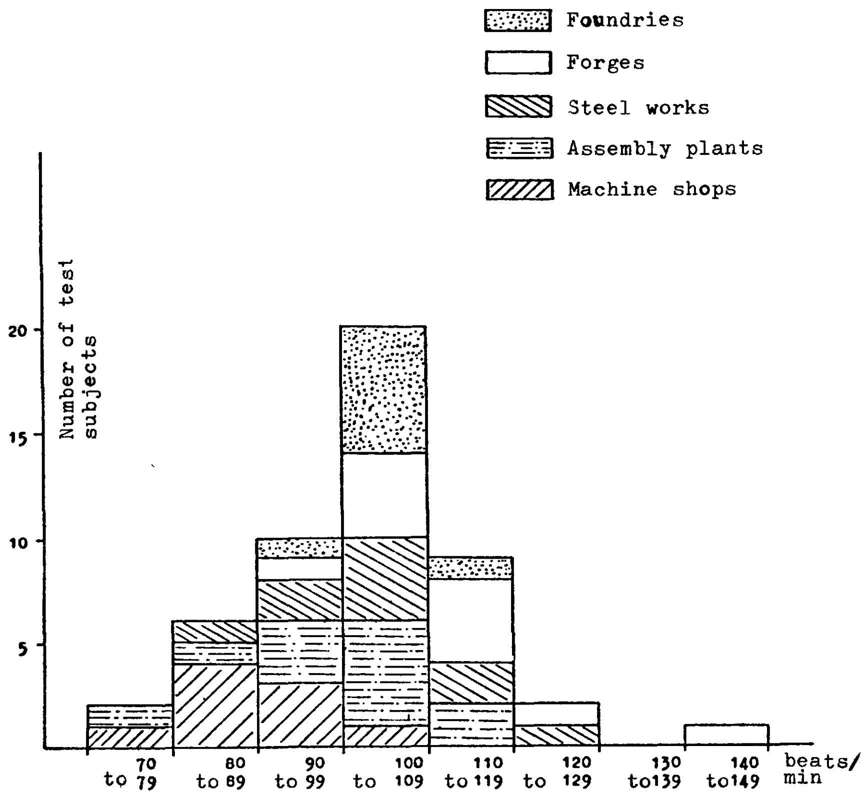


Fig. 17: Frequency distribution of the mean pulse rates of 50 workers in five types of activity (from TARRIERE)

If physical signs of fatigue are assessed by the increase of pulse rate between the beginning and end of work, Table 20 shows that work in forges and foundries is most unfavourable, although this is where workers with above-average functional capacity are in fact employed. In steel works, the signs of fatigue are distributed over the entire intensity scale. The fewer signs of fatigue here may well also be because recovery breaks are longer and better arranged than in other types of work. In the area of assembly work, greater signs of fatigue are also due to non-physical work load factors (for instance pressure of time, nervous strain). Because workers in machine shops are able to set their work rate themselves, they come out most favourably, despite occasionally heavy mechanical work loads.

Type of activity	Number of workplaces or test subjects studied		Number of workplaces or test subjects where signs of fatigue were observed				
			None	Slight	Moderate	Severe	Very severe
Forges	Work place	3	0	0	0	2	1
	Test subjects	10	0	0	3	2	5
Foundries	Work place	3	0	0	0	0	3
	Test subjects	12	0	0	0	0	2
Steel works	Work place	6	1	2	2	1	0
	Test subjects	12	1	3	2	1	1
Machining	Work place	6	4	2	0	0	0
	Test subjects	12	8	3	1	0	0
Assembly line	Work place	13	1	4	4	2	2
	Test subjects	15	1	5	5	1	3

Table 20: Comparison of signs of fatigue in five types of activity (from TARRIERE)

7.3.3. Evaluation of work load and stress due to work requiring physical effort in the iron and steel industry

We can draw the following general conclusions from the results of TARRIERE's studies in the iron and steel industry and in the car industry:

- The work load at various workplaces in forges and foundries is so high that the stress cannot be kept within physiologically tolerable limits even if the activities are carried out by selected workers with a particularly high functional capacity.

- Therefore, the worker should not be assigned a job until his physical functional capacity has been tested.
- At certain workplaces imposing particularly high work loads, work design improvements must always be impdemented. In any case, this is always better than using "skilled" workers! The improvements should be achieved by work design (reducing the work load level) and by organization (shortening the duration of work load in each case, optimal schedule of breaks, optimal shift schedule).
- Unsuitable body postures should be avoided. Figure 18 illustrates the great "value" of improving the bodily posture of a castings cleaner (assessed by the work load parameter energy consumption and the stress parameter work-induced pulse/minute) and Figure 19 illustrates the same for assembly work standing and sitting down (assessed by the stress parameter electromyographic activity).

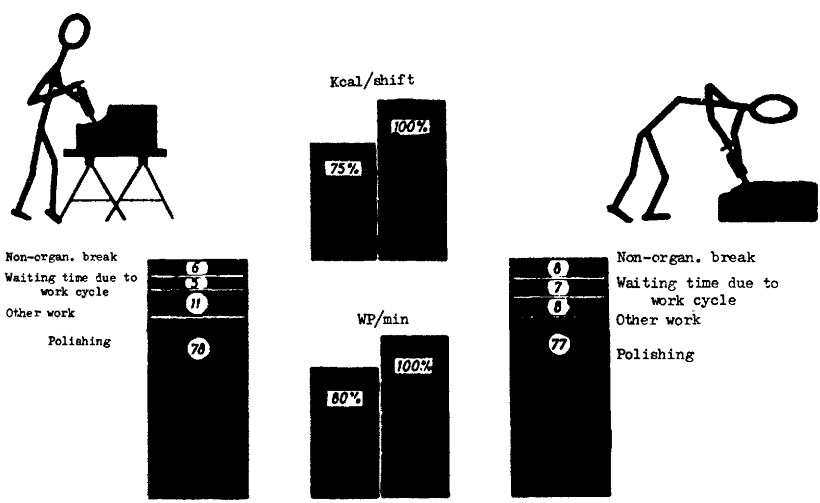
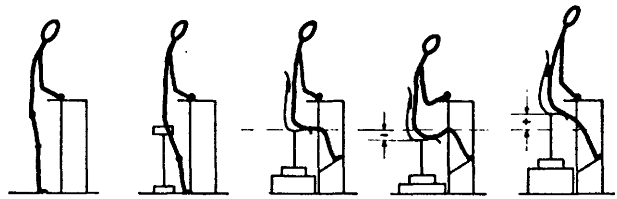


Fig. 18: Work load and stress on a castings cleaner working in an upright and bent posture, in the middle of a shift (from SCHOLZ)



Calf muscles	**	*	*	*	*
Back muscles	*	*	**	***	**
Arm muscle I (Biceps m.)	**	**	**	**	***
Arm muscle II (Deltoid m.)	**	**	**	***	*

Fig. 19: Electromyographic muscular tension in different bodily positions and bodily postures (the number of * indicates relative muscular tension)

7.4. Results of the laboratory studies on work requiring physical effort

In Section 7.1., in discussing the general methods of ergonomic field research, it was pointed out that it is nearly always necessary to carry out laboratory tests to supplement the field research. Supplementary laboratory tests are necessary:

- to select suitable work load and stress parameters.
- to develop or check methods.
- to practice using the methods (for the study team and possibly for the workers as well).
- for systematic variation of the variables affecting work load (work load parameters, work load factors from equation 2) and individual characteristics and capabilities (from equation 3) for determining how they affect stress.
- for working out the principles of ergonomic system design.

The penultimate reason usually gives rise to experimental simulations and to the development of simulators and simulated workplaces, which enables fundamental research work to be carried out on an ergonomic system design.

The Commission of the European Communities has given financial support to some exemplary laboratory research projects involving work requiring physical effort, and we shall now give a brief summary of the content and results of these projects. The research projects concerned were carried out by SCHMIDT /005/, SCHNAUBER /047/, MARGARIA* /017/, /040/ and LAVENNE* /056/. SCHMIDT (published by SÄMANN, 1970) analysed the characteristics and effects of unfavourable bodily postures, whilst SCHNAUBER (published by SCHNAUBER and MÜLLER, 1970) specifically studied particularly fatiguing overhead work and looked into the functional capacity of the hands doing work which has to be carried out at various levels above the heart. This was a typical ergonomic study of local muscular loadings on cardiovascular stress. On the other hand, MARGARIA's research team studied heavy physical work imposing work loads on large groups of muscles, and detailed worker selection for work requiring physical effort. Finally, LAVENNE's research work set out to define the optimum method for organizing work by studying the optimum arrangement of breaks and the effects of a change of work in reducing stress during work requiring physical effort.

SÄMANN classifies unfavourable bodily postures into those which are unavoidable, those which are partly avoidable and those which are avoidable. Fig. 20 shows the criteria used for classifying posture into one of these three groups. The classification is done by recording unfavourable bodily postures under the worker's specific working conditions. The author points out the detrimental effect of unfavourable bodily postures on health, and from an economic point of view.

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* The reports of MARGARIA and LAVENNE are not yet available.

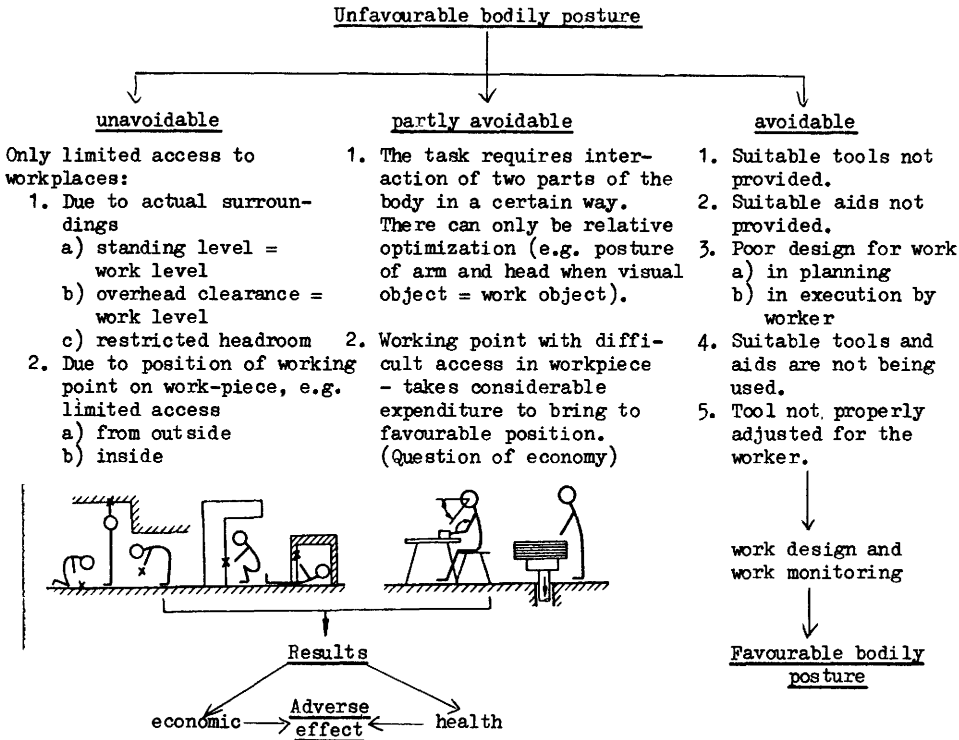


Fig. 20: Classification of bodily postures into three groups (from SÄMANN)

In order to assess a bodily posture as more or less favourable or as unfavourable, there are a number of analytical criteria by which the investigators expect to be able to assess bodily posture without carrying out detailed experimental measurements. The criteria are:

1. System: human body-body supporting surface.

   The state of equilibrium can be inferred from the type of body support. This affects the stiffening actions necessary to maintain the particular bodily position. The greater the number of supports, the further apart the supports, and the wider the supporting surface, the more stable is the position. Bearing these points in mind, we can compare, for example, standing, kneeling and lying positions.

   The size of the supporting surface also gives the surface pressure. This and the suitability of the supporting parts of the body to accept the forces to be borne are key factors in the sensing of surface pressure. For instance, the knee caps are much less suitable for bearing force than the supporting tissue of the feet.

2. Geometric height relating to bodily posture.
The hydrostatic pressure of the blood columns is produced by the difference between the level of the heart and lowest part of the body. The higher this pressure, the more blood can stagnate in the legs and the intracardiac pressure will fall. Pulse rate has to increase to maintain cardiac output.

From the difference between the level of the heart and the highest part of the body we can infer the increased work of the heart required to maintain an adequate supply of blood to the raised parts of the body against the force of gravity. This has to be borne in mind especially when assessing overhead work.

3. Position of the centre of gravity of the body.
The overall centre of gravity of the body must be vertically above the supporting surface to produce a posture which is stable and can be maintained. A specific expenditure of energy, which depends on the actual posture, is required to fulfil this requirement. The same applies to the position of individual parts of the body in association with the appropriate joints. For instance, very few muscles are being used when the arm is hanging down. When the arm is outstretched, the energy required for this posture can be calculated from the weight of the arm and the distance from the centre of gravity to the shoulder joint. Finally, the height of the body's centre of gravity above the floor also has a part to play. It affects the amplitude of swing of the body and hence the muscles required for balancing (e.g. standing).

4. Position of individual parts of the body within their natural area of movement.
Irrespective of gravity, any positioning of a body part away from the middle position increases the load on muscles, tendons and

ligaments. In the natural central position, for example, agonist and antagonist have equally little tension. An example here is extending the foot at the ankle when operating foot pedals.

5. Suitability of connecting and supporting tissue for transmitting forces arising in a posture.
   A specific flux of force occurs in the body in relation to posture. This gives the loading on each structural unit of the body, such as bones, tendons, ligaments and muscles, in relation to safe load.

   This list only contains objective criteria which enable a posture to be assessed.
   The following factors must also be considered:

1. Period over which the factors above are imposed.
2. Intensity of their effect
3. Individual capacity of the worker to tolerate a specific posture.

SÄMANN summarizes the conclusions from his research in seven key points:

1. A bodily posture is optimal physiologically when it demands a minimum of static holding work.

2. This can be achieved by ensuring that

   a) suitable aids are used (e.g. arm supports);

   b) the force flux is favourably arranged (shortest route);

   c) the work is carried out as close to the body as possible;

   d) the most passive postural mechanisms possible are used (supporting tissue, ligaments, tendons);

   e) parallel groups of muscles are used in active holding work.

3. Bodily posture must be considered when planning a workplace (design of working media and their working parts; dimensions of the workplace).

4. The worker should be able to change his posture so that the load can be taken alternately by different groups of muscles.

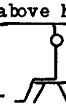
5. Accustoming and acceptance of an unfavourable posture does not reduce the measurable increase of loading on the body.

6. The position of equilibrium and hence the most favourable position for all the limbs and the head from the point of view of stress comes midway between the extreme positions.

7. The more static components there are in a bodily posture, the longer will be the additional time required for recovery.

Finally, Figures 21 - 24 show the overall assessments of the different bodily postures sitting, standing, kneeling, squatting and lying in their various forms.

Fig. 21: Overall assessment of sitting as a bodily posture (from SÄMANN)

Bodily posture / Assessment criterion	Normal sitting	Sitting bent	Sitting upright arms above head
			
Energy requirement compared with resting position (kcal/min)	0.06	0.15	0.16
Increase of pulse rate compared with resting rate (beats/min)	7	13	13
EMG findings without loading (points)	1	6 partic. back muscles	11 partic. back and shoulder muscles
Particularly bad features	Little force can be applied with restricted working area Superficial circulation in buttocks and backs of thighs is impaired in the long term.	Respiration and digestion impaired by abdominal compression	Long additional recovery time is necessary
Particularly good features	The provision of an armrest provides for a rapid transition between working and resting postures Relieves the supporting tissue of the legs Little stabilizing work necessary (good for precision motor activity) Circulatory and energy demands low Favourable working posture		
Range of application	Whenever conditions permit	Unjustifiable (work design!)	Only if working point is only accessible from below
Overall assessment (rank)	2	4	10

Bodily posture / Assessment criterion	Normal standing	Standing bent over	Standing very bent	Standing upright arms above head
				
Energy requirement compared with resting position (kcal/min)	0.16	0.38	0.56	0.30
Increase of pulse rate compared with resting rate (beats/min)	14	18	17	18
EMG findings without loading (points)	2	6 partic. back & thigh muscles	2 Partic. thigh muscles	12 Partic. back and shoulder muscles
Particularly bad features	Risk of blood stagnating in the lower extremities Constant bracing is necessary for stabilizing equilibrium Unsuitable for precision motor activities		Very high energy requirement	Long additional recovery necessary
Particularly good features	Rapid change of working area possible Wide reach possible Large forces can be exerted			
Range of application	When sitting is impossible but there is room for free deployment	Only justifiable in certain unavoidable circumstances	Only if standing level = working level, or where headroom is restricted	Only if work place is only accessible from below and it is not possible to sit
Overall assessment (rank)	3	5	8	11

Fig. 22: Overall assessment of standing as a bodily posture (from SÄMANN)

Fig. 23: Overall assessment kneeling as a bodily posture (from SÄMANN)

Bodily posture / Assessment criterion	Normal kneeling	Kneeling bent	Kneeling, arms above head
			
Energy requirement compared with resting position (kcal/min)	0.28	0.32	0.36
Increase of pulse rate compared with resting rate (beats/min)	21	22	26
EMG findings without loading (points)	2	2 Partic. back muscles	16 Partic. back and shoulder muscles
Particularly bad features	Severe load on knee-cap and knee joint Locomotion difficult High circulatory and energy demands		Long additional RT necessary
Particularly good features	Fairly high forces can be applied		
Pange of application	If headroom restricted Posture is synonymous with squatting and standing very bent	If standing level = working level	If workplace is only accessible from below and headroom is restricted
Overall assessment (rank)	7	9	14

Bodily posture / Assessment criterion	Rest position	On back, arms above head	Normal squatting	Squatting, arms above head
				
Energy requirement compared with resting position (kcal/min)	0	0.06	0.27	0.28
Increase of pulse rate compared with resting rate (beats/min)	0	3	10	14
EMG findings without loading (points)	0	7	8 Partic. calf and thigh muscles	18 Partic. calf, shoulder and thigh muscles
Particularly bad features		Very restricted freedom of movement, high local loading (back of neck), long additional recovery periods necessary	Locomotion difficult High level of stabilizing work to maintain equilibrium Circulatory disorders due to pressure: thigh-lower leg	Long additional recovery periods necessary
Particularly good features	Low bearing pressure on the body		Load on circulation is less than in comparable postures	
Range of application	Rest position	Only if workplace is only accessible from below and there is very little headroom	If there is restricted headroom Posture is synonymous with kneeling and standing very bent	If the workplace is only accessible from below and headroom is restricted
Overall assessment (rank)	1	12	6	13

Fig. 24: Overall assessment of lying and squatting as bodily postures (from SÄMANN)

The following conclusions have been drawn from research sponsored by the Commission of the European Communities:

- The detrimental effects of an unfavourable bodily posture on workers and industry, are to be avoided.

An unfavourable bodily posture always has a detrimental effect. Depending on how abnormal the posture is, the worker is subject to greater physical stress and hence is more fatigued, to achieve the same result. In time, the human body nearly always suffers specific functional impairment which, in especially predisposed cases, may turn into premature overstrain.

As far as the industry is concerned, the cases of this sort are always uneconomic since an unfavourable posture must be taken into account in the job evaluation and long additional allowances for recovery have to be granted for many postures, and in the case of illness or even complete incapacity of the worker. All these factors illustrate the key importance of "bodily posture".

- Unfavourable bodily postures cannot be evaluated by one method of measuring and testing.

A representative selection of all different types of posture was studied. It has not been possible to devise a universal technique for measuring all the physical effort required for a bodily posture because of the multiple effect of stress. Consequently several criteria were used for assessing each case and these were then combined to give an overall assessment. The most important results are shown in Figures 21 - 24.

It was found that total stress is unrepresentative in many cases, but that heavy local loading makes it impossible to assume a posture for a prolonged period (cp. also SCHNAUBER and MÜLLER, 1970).

- Unfavourable bodily postures can be improved by ergonomic work design.

The results obtained enable the designers to design workplaces for a favourable bodily posture. Classification was based on the extent to which it is possible to avoid an unfavourable bodily posture. This clearly showed that there are only specific circumstances in which an unfavourable posture is unavoidable (cp. Fig. 20). An unfavourable posture can usually be avoided by work design, particularly by use of suitable aids. Above all, it is important to appreciate the ergonomic principles involved, their far-sighted application and effective checking methods.

Several times in his studies SÄMANN pointed out the need to assess local muscle loadings imposed by bodily postures as well. SCHNAUBER and MÜLLER then implemented laboratory tests to study the stress involved in overhead work on a hand ergometer. They used four female and six male test subjects.

When assessing work load, the authors found that the higher the arms were held above the level of the heart, the greater was the energy consumption (due to the work of holding the arms up) for the same level of ergometer work performed by the hands. Thus, the efficiency of the work in terms of energy deteriorated accordingly. It was 13% when working at heart level, but it fell to only 2% when the arms were held up as high as possible. However, whereas the work load increased linearly as the arm level was raised, there was a much steeper, non-linear rise of stress. Pulse rate rose exponentially in relation to both level and duration of work load; this is due to the fatigue, which increased with the working level of the hands and the duration of overhead work. Simply holding the arms up as high as possible without simultaneous dynamic hand work was the most strenuous and tiring.

The results show that tiring static work due to positioning the arms affects the functional capacity of muscles working dynamically. Thus, the higher the working position of the hands above the heart, the greater was the decline of maximum functional capacity (assessed by perserverance with hand work above the head) and of endurance (assessed by the continuous level of the pulse rate during the loading).

If the muscles of the forearm are working above the level of the heart there appears to be a hydrodynamically-induced increase of resistance in the vascular system, which is not compensated for even by the work-induced vascular dilatation in the muscles during the dynamic work. There is increased muscular fatigue and the ability to do muscular work is impaired.

Therefore, overhead work with the hands is more demanding and more tiring than other forms of work, for two reasons:

- Only small groups of muscles are used for the dynamic work, and these have a comparatively low endurance threshold.

Both hands working on a hand ergometer together only achieved about 9% of the mechanical endurance of the large groups of leg muscles on a bicycle ergometer. Hand work only rates about 12% of the endurance of the calf muscles.

- The additional static muscular stress due to holding the arms during overhead work reduces the work capacity of the hands even further because fatigue increases as a function of work load level (level at which the hands are working above the heart and ergometric capacity) and duration of work load (duration of hand work).

In a further series of experiments, SCHNAUBER and MÜLLER studied the arrangement and duration of recovery breaks which have to be taken during overhead work of varying heaviness and duration, to prevent specific fatigue. They found that the higher the hands are working above the heart, the longer the recovery period required to relieve the fatigue (additional recovery period as a percentage of the preceding work period). If the additional period for recovery after tiring work at heart level is taken as = 100%, then this rises by about 34% when the hands are raised to half their highest possible level. For work at normal hand level, the additional period for recovery actually has to be raised by about 90%. In line with their lower functional capacity, in the women studied the recovery pulse rate for the same mechanical performance of arm work (= work load) was about three times greater than in the men studied. The working period did not seem to affect the recovery time required, possibly because the working period was not varied enough.

The following conclusions can be drawn from results obtained by SCHNAUBER and MÜLLER, who studied overhead work:

- Unfavourable working positions of the hands should be avoided if possible!

Since it was found that as working level increases, both the endurance threshold and the maximum achievable working time decline appreciably and the additional period for recovery are correspondingly longer, every effort should be made to avoid the hands working in such unfavourable positions. In practice, this is only possible to a limited extent. If such work is unavoidable, the first step to be taken to reduce the work load and increase work capacity is to reduce the working level of the hands in relation to the level of the heart, by raising the worker's sitting or standing position as far as possible. Results reported show that raising a position by, for instance, 20 cm at 0.6 mkgf/sec is likely to double the maximum possible period for continuous work or reduce the additional period for recovery by about 20%, with intermittent work.

- Less able workers and workers who are too short (e.g. women, foreign workers) should as far as possible not be used.

It is important to bear in mind individual functional capacity and, for example, women with a lower functional capacity under given working conditions may need three times the recovery period needed by men. Apart from this, the results indicate that, for a given distance between floor or sitting surface and hand working position, short people are worse off than taller people.

- In practice, overhead work is likely to be much harder than the overhead ergometer work studied. The results of the studies should therefore be looked on as having been obtained under "optimum conditions".

As regards the additional recovery periods, it must be remembered that they only obtain under the experimental conditions and so cannot be regarded as generally applicable. It should also be remembered that the experimental conditions of work, particularly the type of work on a hand ergometer described, were probably better than conditions found in practice. Whereas the test subjects were to some extent able to steady themselves on the ergometer and reduce their static holding work, in practice workers often have to hold equipment, parts etc. freely in their hands. This means that the stated recovery periods are probably minimum values, which would be exceeded by the same subjects doing the same dynamic work under practical working conditions. The discovery that pure holding work with arms free without support is particularly hard indicates that loads which have to be held in the hands during overhead work should be suspended, for instance by springs or counterweights close to the place where the hands are working.

LAVENNE's studies /056/ include research on intermittent work and experimental breaks. However, unlike SCHNAUBER and MÜLLER, the selected work load for the whole body was much higher, being 80% of the maximum O_2 uptake. The measurements were made on volunteer workers and both pulse rate and interior body temperature were measured. The results have not yet been published in full. Subjective tiredness was also assessed: the detachment of the working man from his working environment was considered, with self-regulation of the level and duration of work load by the workers.

It has been found in industry that workers usually rapidly adopt a higher work load spontaneously, in order to ensure they get through their day's output quota. For instance, the schematic assessment of results of experiments carried out by LEHMANN (1962) shows that, where the men are not bound to a fixed method of working, production plotted as a function of shift time always looks like the illustration in Figure 25.

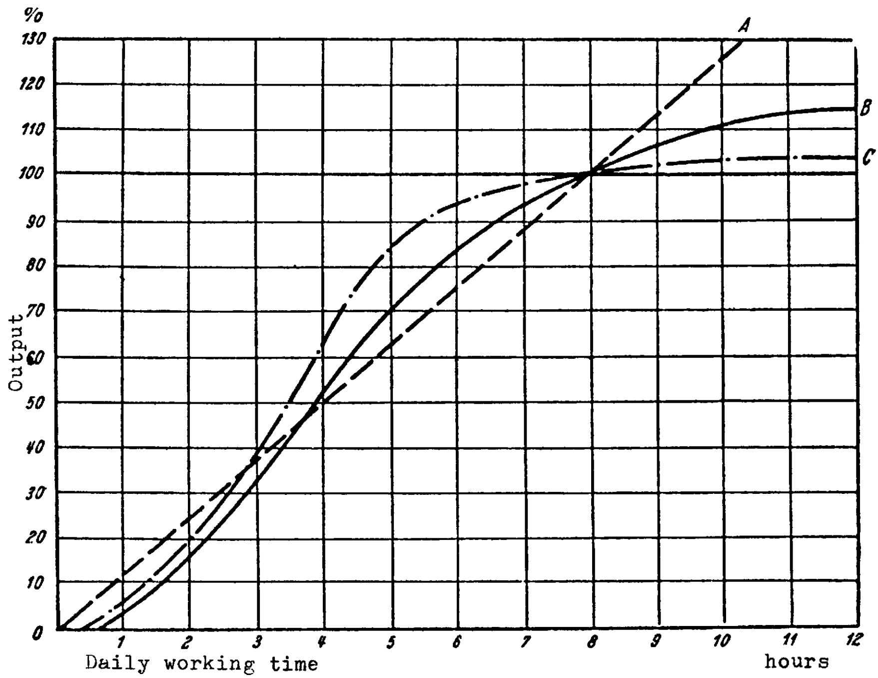


Fig. 25: Diagram of the relationships between working time and output; the output for 8-hours' work is taken as equal to 100% (from LEHMANN)

Plot A: working time proportional to output

Plot B: Output as a function of working time for work requiring a moderate effort

Plot C: Output as a function of working time where physical work load is high

Three conclusions can be drawn from this analysis of human behaviour:

- In practice, there is not a linear relationship between a person's work output and the shift time. The higher the physical work load, the greater the variation.
- Work output is slow at the start of the shift, but then half the shift output is done in less than half the shift time. The heavier the physical work load, the more this applies.

- Less than half the output is produced in the second half of the shift, and so output plotted as a function of shift time looks rather like a typical saturation curve at the end of the shift.

This typical human behaviour clearly shows that the worker will not of his own volition regulate the intensity of the work load in the best way; he would try to avoid the heavy work loads at the beginning of the shift which, as far as he is concerned, would cause a build-up of fatigue later in the shift.

This also indicates that voluntary breaks in self-regulated work would usually come too late. These breaks will not prevent fatigue. Also, if they are taken too late, the fatigue has often become so severe that the total time available for breaks is inadequate to relieve the fatigue. So the worker has an adverse effect on himself.

The cause of this apparent human failing seems to lie in the complexity of the physiological phenomenon of stress. This is expressed in equation 10 b. According to this equation, stress in an individual depends on the level of work load, and on the duration of the work load.The two factors influence stress in a different, exponential way. Both factors are also linked in a multiplicative way. Therefore, a specific level of stress can be produced by a low level of work load acting over a long period, or by a high work load of correspondingly shorter duration. Since man does not have a natural stress-warning system, and any protective effect afforded by feeling tired has been steadily eroded away from childhood by demands to improve performance, it is unlikely that a human being will be able to regulate his work load himself. Rather, the worker has to be protected against excessive, physiologically intolerable work loads by regulating work load and breaks in every way (i.e. in respect of level of work load, duration of work load and individual capabilities). This is achieved by work design in three areas:

1. working method design
2. ergonomic work design
3. organizational work design

The aim of working method design is to see that the functions expected of a work system are actually possible. The result of this initial stage of work design for the person working in a work system is that all functions are allocated either wholly or partially to equipment or tools (for instance machines, apparatus, computer) or to the workers. The functions allotted to the worker can be modified in subsequent stages of working method design in respect of the effect of the functions to be fulfilled on work load and stress imposed on the man. The aim of ergonomic adaptation is to take into account the anatomy, physiology, physiopsychology and social aspects of man both in the design of workplaces, working media and working methods and in the selection and instruction of staff, practice and training. Organizational work design covers the allocation of functions amongst different people (division of labour), regulation of working periods and breaks, and optimum arrangement of shift schedules.

Ergonomics only assume a midway position in the hierarchical system of work design. However, this does not rule out the possibility that working methods may have to be redesigned if the ergonomic aspects of existing or planned working methods are very unfavourable.

This report deals exclusively with work requiring physical effort. However, these limiting conditions do not only apply to this area. Therefore, there should be further reports providing a similar survey of research sponsored by the Commission of the European Communities into other problem areas of human work. All in all, there is an obligation for working methods design, which must be tailored to suit the workers, for the following reasons:

- technological:	materials representing a health hazard, methods, working hours, free time
- working method:	exceeding human capacities and capabilities
- labour economic:	availability of staff
- organizational:	working hours, free time
- ergonomic:	optimizing anatomical, physiological, bio-mechanical, psychophysical functional capabilities of man
- health:	dangerous work, laws and regulations, physical environmental factors
- psychological:	motivation of workers, requirements for managing staff
- sociological:	group composition, individual job satisfaction.

These examples may illustrate the complexity and complications of the problems involved in work design.

8. References

ASTRAND, P.O.; K. RODAHL

Textbook of Work Physiology,

Mc Graw-Hill, New York (1970)

BLOHMKE, M.

Vorteile und Nachteile einiger submaximaler Belastungsverfahren

in; ROHMERT, W. (Edit.)
Muskelarbeit und Muskeltraining
A. W. Gentner Verlag Stuttgart (1968)

BOUISSET, S.

Postures et mouvements

in: J. SCHERRER (Edit.)
Physiologie du Travail
Masson, Paris (1967)

BROUHA, L.

Physiology in industry

Pergamon Press, Oxford, London, New York, Paris (1960)

CHRISTENSEN, E.H.

Beiträge zur Physiologie schwerer körperlicher Arbeit

4th Communication: Die Pulsfrequenz während und unmittelbar nach schwerer körperlicher Arbeit
Arbeitsphysiologie 4 (1931) 453-469

DEMLING, L.; K. BACHMANN, (Edit.)

Biotelemetrie

Georg Thieme Verlag, Stuttgart (1970)

DURNIN, J.V.G.A.; R. PASSMORE

Energy, work and leisure

Heinemann Educational Books, London (1967)

EHRENSTEIN, W.; W. MÜLLER - LIMMROTH

Über die Zuverlässigkeit des Leistungspulsindex (LPI) nach E.A. Müller als Kriterium der körperlichen Leistungsfähigkeit

Int.Z. angew. Physiol. einschl. Arbeitsphysiol. 26 (1968) 189 - 204

GLATZEL, H; G. RETTENMAIER

Kreislaufregulation und Ernährung

Archiv für Kreislaufforschung 45 (1965) 195-212

HALLER-WEDEL, E.

Das Multimomentverfahren in Theorie und Praxis
Volume I

Carl Hanser Verlag, Munich 1969

HETTINGER, TH.; K. RODAHL

Ein modifizierter Stufentest zur Messung der Belastungsfähigkeit des Kreislaufes

Dtsch. med. Wschr. 85 (1960) 553 - 557

HETTINGER, TH.

Angewandte Ergonomie

Bartmann, Frechen (1970)

HOLLMANN, W; C. BOUCHARD, H. VENRATH, G. HERKENRATH

Vergleichende Untersuchungen über die Aussagekraft des Master-, Harvard-, Tuttle-, Schneider-, Hettinger- und Lian-Tests bezüglich der kardiopulmonalen Leistungsfähigkeit

Zeitschrift für Kreislaufforschung 54 (1965) 647 - 657

HOLLMANN, W.

Präventive Kardiologie mittels körperlichen Trainings

Arbeitsmedizin, Sozialmedizin, Arbeitshygiene 7 (1972) 3, 57-63

JENIK, P.

Biomechanische Analyse ausgewählter Arbeitsbewegungen des Armes

Beuth Vertrieb Berlin, Cologne, Frankfurt (1973)

JOHNSON, R.E.;; BROUHA, L.; DARLING, R.C.

A Test of Physical Fitness for Strenuous Exertion

Rev. Canad. Biol. 1(1942) 491ff
quoted from BROUHA (1960)

KARRASCH, K.; E.A. MÜLLER

Das Verhalten der Pulsfrequenz in der Erholungsperiode nach körperlicher Arbeit

Arbeitsphysiol 14 (1951) 369-382

KATZUKI, S.

Relative Metabolic Rate of Industrial Work in Japan

Metabolic Rate, Food and Nutrition Committee-Japan (1960)

KIMMICH, H.; P. VOSS (Edit.)

Biotelemetry

Meander N.V. Leiden (1972)

KRAUT, H.; W. KELLER

Arbeit und Ernährung

In: Handbuch der gesamten Arbeitsmedizin, Vol.I Arbeitsphysiologie
Verlag Urban und Schwarzenberg, Berlin-Munich - Vienna (1961)

KROEMER, K.H.E.

COMBIMAN - COMputerized BIomechanical MANmodel

Conference Report from the IFU Colloquium 1972, 73-88, Verlag TÜV - Rhineland Cologne (1973)

LAURIG, W.

Erweiterung der Methoden des Arbeitsstudiums durch Einsatz telemetrischer Meßverfahren

Refa Reports 22 (1969)1, 19-22

LAURIG, W.

Elektromyographie als arbeitswissenschaftliche Untersuchungsmethode zur Beurteilung von statischer Muskelarbeit

Beuth-Vertrieb Berlin, Cologne, Frankfurt (197(

LAURIG, W.

Beurteilung einseitig dynamischer Muskelarbeit

Beuth-Vertrieb Berlin, Cologne, Frankfurt (in the press)

LEHMANN, G.

Energetik des arbeitenden Menschen
in BAADER, W.E. et al. (Edit.)
Handbuch der gesamten Arbeitsmedizin
I. Band: Arbeitsphysiologie
Urban und Schwarzenberg, Berlin, Munich, Vienna (1961)

LEHMANN, G.

Praktische Arbeitsphysiologie

Georg Thieme Verlag, Stuttgart (1962)

LEHMANN, G.; E.A. MÜLLER, H. SPITZER

Der Kalorienbedarf bei gewerblicher Arbeit

Arbeitsphysiologie 14(1950) 166- 235

LEHMANN, G.; F. STIER

Mensch und Gerät
in: BAADER, W.E. et al. (Edit.)
Handbuch der gesamten Arbeitsmedizin
Vol. I: Arbeitsphysiologie
Urban und Schwarzenberg, Berlin, Munich, Vienna (1961)

MONOD, H.

Contribution a l'étude du travail statique

Institut National de Sécurité, Paris(1956)

MÜLLER, E.A.

Ein Leistungs-Pulsindex als Maß der Leistungsfähigkeit

Arbeitsphysiologie 14(1950) 271-284

MÜLLER, E.A.

Die Beziehung zwischen Pulsfrequenz und Muskelarbeit als Test der Herzfunktion

Fifth Freiburg Symposium: Die Funktionsdiagnostik des Herzens, 252-263
Berlin, Göttingen, Heidelberg (1957)

MÜLLER, E.A.

Die physische Ermüdung
in: BAADER, W.E. et al. (Edit.)
Handbuch der gesamten Arbeitsmedizin
Arbeitsphysiologie
Urban und Schwarzenberg, Berlin, Munich, Vienna (1961)

MÜLLER, E.A.

Physiologie der körperlichen Leistungsfähigkeit
in: Landois-Rosemann. Lehrbuch der Physiologie des Menschen
28th Edition, Munich, Berlin (1962)

MÜLLER, E.A.; H. FRANZ

Energieverbrauchsmessungen bei beruflicher Arbeit mit einer verbesserten Respirations-Gasuhr

Arbeitsphysiologie 14(1952) 499 - 504

MÜLLER, E.A.; W. HIMMELMANN

Geräte zur kontinuierlichen fotoelektrischen Pulszählung
Arbeitsphysiologie 16(1957) 400-408

OKADA, M.

An Electromyographic Estimation of the Relative Muscular Load in Different Human Postures

Journal of Human Ergology 1(1972) 75-93

PORNSCHLEGEL, H. (Edit.)

Verfahren vorbestimmter Zeiten
Arbeits-und betriebskundliche Reihe Volume 8/9
Bund Verlag, Cologne (1968)

POULSEN, E.; E. ASMUSSEN

Energy requirements of practical jobs
from pulse increase and ergometer test

Ergonomics 5 (1962) 33-36

RAU, G.; VREDENBREGT, J.

The electromyogram and the force
during static muscular Contractions

Inst. Perc. Onderzoek, Eindhoven
Ann. Progr. Rep.5 (1970) 174-178

REFA (Edit.)

Methodenlehre des Arbeitsstudiums
Part 2 Datenvermittlung
2nd Edition
Carl Hanser Verlag 1973

ROHMERT, W.

Statische Belastung bei gewerblicher Arbeit
Forschungsbericht des Landes Nordrhein-Westfalen No. 793
Westdeutscher Verlag Cologne and Opladen (1959)

ROHMERT, W.

Statische Haltearbeit des Menschen

Reprint of Refa Reports
Published by the Verband für Arbeitsstudien Refa e.V. Darmstadt (1960a)

ROHMERT, W.

Ermittlung von Erholungspausen für
statische Arbeit des Menschen

Int. Z. angew. Physiol. einschl. Arbeitsphysiol. 18(1960b), 123-164

ROHMERT, W.

Die Armkräfte des Menschen im Stehen
bei verschiedener Körperstellung

Int. Z. Physiol. einschl. Arbeitsphysiol.
18(1960 c) 175-190

ROHMERT, W.

Untersuchung statischer Haltearbeit
in achtstündigen Arbeitsversuchen

Int. Z. Physiol. einschl. Arbeitsphysiol.
19(1961)

ROHMERT, W.

Untersuchungen über Muskelermüdung und Arbeitsgestaltung

Beuth-Vertrieb , Berlin, Cologne, Frankfurt (1962)

ROHMERT, W.

Arbeitswechsel und Muskelermüdung

Ergonomics, Proceedings of 2nd I.E.A. Congress Dortmund (1965) 17-21

ROHMERT, W.

Determination of Relaxation Allowances in Industrial Operations

The Production Engineer (1966a) 578-589

ROHMERT, W.

Maximalkräfte von Männern im Bewegungsraum der Arme und Beine

Research report No. 1616 of the Nordrhein-Westfalen Region, Westdeutscher Verlag
Cologne and Opladen (1966b)

ROHMERT, W.

Aufgaben und Inhalt der Arbeitswissenschaft

Die berufsbildende Schule
24 (1972) 1 3-4

ROHMERT, W.; HETTINGER, TH.

Kräfte im Bewegungsraum

RKW-Schriftenreihe
Arbeitsphysiologische Hinweise für die Praxis
Beuth-Vertrieb Berlin, Cologne, Frankfurt (1963)

ROHMERT, W.; SCHOTT, R.; TEMMING, J.; FRIESS, K.

Entwicklung und Anwendung eines Rechenprogramms zur Auswertung von fotografisch aufgezeichneten Körperstellungen bei Untertagearbeiten

Research report for the European Coal and Steel Community, Luxembourg (1970)

ROHMERT, W.; JENIK, P.

Maximalkräfte von Frauen im Bewegungsraum der Arme und Beine

Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1972)

ROHMERT, W. et al.

Psycho-physische Belastung und Beanspruchung von Fluglotsen

Schriftenreihe Arbeitswissenschaft und Praxis Volume 30, Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1973 a)
Schriftenreihe"Arbeitsmedizin, Sozialmedizin, Arbeitshygiene" Volume 52
A.W. Gentner Verlag Stuttgart (1973)

ROHMERT, W.; W. LAURIG, P. JENIK

Ergonomie und Arbeitsgestaltung - dargestellt am Beispiel des Bahnpostbegleitdienstes

Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1973 in the press)

ROHMERT, W.; W. LAURIG; U. PHILIPP, H. LUCZAK

Heart rate variability and work load measurement
Ergonomics 16(1973) 33-44

ROSENBROCK, F.; W. ROHMERT

Multidimensional coding for telemetric transmission of work load factors in ergonomics research
in: KIMMICH, H.P.; J.A.VOSS (Edit.)
Biotelemetry
Meander N.V. Leiden (1972)

RUTENFRANZ, J.

Die Beurteilung der Leistungsfähigkeit Heranwachsender mit chronischen Erkrankungen; in ROHMERT, W. (Edit.)
Muskelarbeit und Muskeltraining
A.W. Gentner Verlag (1968)

RUTENFRANZ, J.; W. ROHMERT; A. ISKANDER

Über das Verhalten der Pulsfrequenz während des Erlernens sensomotorischer Fertigkeiten unter besonderer Berücksichtigung der Pausenwirkung
Int. Z. angew. Phsiol. 29(1971) 101-118

SACHS, L.

Statistische Auswertemethoden

Springer Verlag, Berlin, Heidelberg, New York
3rd Edition (1972)

SÄMANN, W.

Charakteristische Merkmale und Auswirkungen
ungünstiger Körperhaltungen
Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1970)

SCHARDT, R.

Über Belastung und Beanspruchung in der
Mechanik
in: W. ROHMERT (Edit.) Muskelarbeit und Muskeltraining

Schriftenreihe:Arbeitsmedizin, Sozialmedizin
Arbeitshygiene Volume 22 (1968)
A.W. Gentner Verlag, Stuttgart

SCHLAICH, K.;J. BREDEMEYER

Starke Belastung der Fingermuskulatur
bei einer Montagearbeit

Arbeitswissenschaft 5(1966) 91-92

SCHLAICH, K.

Vergleich von vorbestimmten und beobachteten
Elementarzeiten manueller Willkürbewegungen
bei Montagearbeiten
Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1967)

SCHNAUBER, H.; E.A. MÜLLER

Die Leistungsfähigkeit der Hände bei
Arbeit in verschiedener Höhe über dem
Herzen

Int.Z. angew. Physiol. 28 (1970) 135-154)

SCHOLZ, H.

Die physische Arbeitsbelastung der Gießereiarbeiter
Westdeutscher Verlag, Cologne, Opladen (1963)

SCHOTT, R.

Experimentelle Untersuchung der Struktur
von Gelenkbewegungen im Bewegungsraum der
Arme, des ganzen Körpers und Darstellung
in einem menschbezogenen Grundsystem
Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1972)

SHELDON, W.H.; C.W. DUPERTIUS; E. MC DERMOTT

Atlas of men: A guide for somatotyping the adult men at all ages

Harper, New York (1954)

SIEBER, W.

Die Bedeutung der Mechanisierung von Gewinnung, Ausbau und Versatz für die körperliche Belastung des Bergmannes im Steinkohlenbergbau.

Westdeutscher Verlag, Cologne, Opladen (1963)

SOKAL, R.R.; F.J. ROHLF

Biometry

W.H. Freeman and Company
San Francisco (1969)

SPITZER, H; TH. HETTINGER

Tafeln für den Kalorienumsatz bei körperlicher Arbeit
Beuth-Vertrieb, Berlin, Cologne, Frankfurt (1969)

TEMMING, J.; E. HAAS

Konstruktion eines widerstandsarmen Atemventils
Int. Z. angew. Physiol. 28(1969) 49-54

TEMMING, J.; W. ROHMERT

Untersuchungen über die körperliche Belastung der Bergleute
Schriftenreihe: Arbeitsmedizin, Sozialmedizin Arbeitshygiene Volume 48:
A.W. Gentner Verlag, Stuttgart (1972)

TORGERSON, W.S.

Theory and Methods of Scaling

John Wiley & Sons Inc. New York, London (1958)

VALENTIN, H.; W. KLOSTERKÖTTER, G. LEHNERT,
H. PETRY, J. RUTENFRANZ, H. WITTGENS

Arbeitsmedizin
Georg Thieme Verlag, Stuttgart (1971)

VREDENBREGT, J.; G. RAU

Surface Electromyography in relation to Force, Muscle Length and Endurance
4th Intern. EMG Congress Brussels 1971
Manuscript Nr. 217 of Instituut voor perceptie onderzoek, Eindhoven

WAHLUND, H.

Determination of the physical working Capacity
A physiological and clinical study with special reference to standardisation of cardiopulmonary functional tests

Acta. Med. Scand. 132, Suppl. 215(1948)
Quoted from Rutenfranz (1968)

WOITOWITZ, H.-J.; SCHÄCKE, G.; WOITOWITZ, R.;
EICHINGER, H.

Die Untersuchung von Herzschlagfrequenz und Elektrokardiogramm während der Arbeitsschicht mit Hilfe der Radiotelemetrie oder Magnetbandspeicherung
Ärztliche Forschung XXIV (1970) 46-58

9. Appendices

Appendix 1: FORTRAN program for computing the energy consumption at work and control sheet for checking the analytical results

Appendix 2: FORTRAN program for evaluating data on bodily posture obtained from photographs

Appendix 3: Example of deductive determination of stress during static holding work

9.1. Appendix 1: FORTRAN program for calculating the energy consumption at work and control sheet for checking the analytical results

Explanation of computer program

The program version in the list uses FORTRAN IV as the programming language and it was tested on the Telefunken TR 440 computer of the German Computer Centre in Darmstadt.

The series of data cards to be read contains

a) Data on the test series (up to two cards)
b) Data on the worker and a brief description of the particular cycle or activity
c) All data read from the gas meter, the duration of the recording, barometric air pressure, time until it was analysed (where the sample was stored in a rubber bag) and the result.

The sequence of punching and the punch formats are given in the program notes Formats 1001 - 1004. An example of the output is attached.

Explanation of the control sheet for respiratory tests

In order to show up any errors in analysis, it was advisable to divide the sample of expired air in half to enable a double determination to be made. The two must be close together when entering the results of the analysis in the control sheets. If the two results are linked and these linked lines are parallel to the "RQ lines" entered where there is a considerable discrepancy between individual readings, there is a danger that the sample was contaminated by fresh air. This could occur for example, whilst sealing the glass containers, where the air samples are not analysed at once. Entering the data into control sheets may in some cases clearly show up marked intraindividual scatter, since intraindividual results must be close together for comparable cycles.

```
3XBA,BEN=2076  LAURIG,FKZ=ENUM,
BG=9$
 3 XUM,COD=KC3$
UE., SOURCE=/

                PROGRAMME FOR CALCULATING VENTILATION PARAMETERS
                ************************************************

                ENUM = ENERGY CONSUMPTION OF MALE TEST SUBJECTS
                                  ===========

                *************************************************************

                ENUM03 VERSION FOR DIRECT ANALYSIS FROM RUBBER BAG WITH
                       MAGNOS AND URAS (HB,
                       SURPLUS PROPOSITIONS FROM ENUM02 WERE SIGNIFIED BY *C*
                       RE-INTRODUCED PROPOSITIONS BY C***

                NOTES FOR ANALYSIS WITH URAS (Infrared absorption recorder)
                ---------------------------
                       ACCORDING TO THE OPERATIONAL INSTRUCTIONS, THE VALUE
                       FOR CO2 ANALYSES MUST BE REDUCED BY 2.5 0/0 OF THE
                       READING - THIS CORRECTION IS DONE IN THE PROGRAMME -
                       THEREFORE FEED IN DIRECT READING

                       (LAURIG, IAD - DARMSTADT, JULY 1972)
                *************************************************************

                I. LIST OF ABBREVIATIONS AND SYMBOLS
                ------------------------------------

                1. ABBREVIATIONS ON THE FIRST DATA CARD
                UREIH = TEST SERIES (MAY INCLUDE A DESCRIPTION OF THE WORKING POINT)

                2. ABBREVIATIONS ON THE SECOND DATA CARD

                VP     = TEST SUBJECT (CHRISTIAN NAME, SURNAME)
                A      = AGE OF VP
                W      = BODY WEIGHT OF VP
                H      = HEIGHT OF VP
                VERS1  = DESCRIPTION OF TEST (ACTIVITY PERFORMED BY VP)
                FF     = INSTRUCTION TO CONTINUE (TEST CONTINUES ON NEXT CARD)
                VERS2  = IF NECESSARY, DESCRIPTION OF VP'S ACTIVITY CONTINUED
                KUZEI1= BRIEF DESCRIPTION OF TEST

                3. ABBREVIATIONS ON THE THIRD DATA CARD

                GE     = FINAL READING ON GAS METER
                GA     = INITIAL READING ON GAS METER
                GK     = GAS METER CORRECTION FACTOR
                GT     = GAS METER TEMPERATURE
                B      = BAROMETRIC PRESSURE
                VD     = DURATION OF TEST
                AZ     = FILLING TIME
                ZD     = CYLINDER PRESSURE AFTER FILLING
                ZVO2   = O2 - CONTENT OF FULL CYLINDER (ANALYTICAL RESULT)
                ZVCO2  = CO2 - CONTENT OF FULL CYLINDER (ANALYTICAL RESULT)
                ZLO2   = O2 - CONTENT OF EMPTY CYLINDER (NONE AFTER FLUSHING)
                ZLCO2  = CO2 - CONTENT OF EMPTY CYLINDER (NONE AFTER FLUSHING)
                EINO2  = O2 - CONTENT OF INSPIRED AIR (NOT  FOR EXTERNAL AIR)
                EINCO2= CO2 - CONTENT OF INSPIRED AIR (NOT  FOR EXTERNAL AIR)
```

KUZEI12 = BRIEF DESCRIPTION OF THE TEST

4. ABBREVIATIONS USED IN THE CALCULATION CYCLE AND IN THE RESULTS OUTPUT

PD	= SATURATED VAPOUR PRESSURE AT GT
GD	= GAS METER DIFFERENCE = VENTILATION READING
GDK	= CORRECTED VENTILATION = ACTUAL VENTILATION
REDF	= REDUCTION FACTOR (FOR NORM. DRY AIR, 0 DEGREES C)
RV	= REDUCED VENTILATION = GDK * REDF
RVM	= REDUCED VENTILATION PER MINUTE
XKO21	= O2 - CORRECTION FOR RUBBER BAG DIFFUSION
XKO22	= O2 - CORRECTION FOR CONTENTS OF CYLINDER ZLO2
O2K	= CORRECTED = ACTUAL O2 CONTENT OF RESPIRED AIR
XKCO21	= CO2 - CORRECTION FOR RUBBER BAG DIFFUSION
XKCO22	= CO2 - CORRECTION FOR CONTENTS OF CYLINDER ZLCO2
CO2K	= CORRECTED = ACTUAL CO2 CONTENT OF RESPIRED AIR
TW	= TABULATED VALUE FOR VOLUME REDUCTION
C2D	= O2 DIFFERENCE = ABSORBED VOL. 0/0 CARBON DIOXIDE
CO2D	= CO2 - DIFFERENCE = EXPIRED VOL. 0/0 CARBON DIOXIDE
RQ	= RESPIRATORY QUOTIENT = CO2D / O2D
VO2	= OXYGEN CONSUMPTION
VQ	= VENTILATION QUOTIENT
CALW	= CALORIC VALUE OF OXYGEN CONSUMED
BU	= GROSS ENERGY CONSUMPTION
GU	= BASAL CONSUMPTION (CALCULATED ACCORDING TO BENEDICT)
AU	= CONSUMPTION DUE TO WORK = BU - GU
FORTFA	= INSTRUCTION TO CONTINUE (WHERE TEST ON 2 DATA CARDS)
ZD2	= AIR PRESSURE IN TEST CYLINDER BEFORE FILLING (WITHOUT FLUSHING)
VO2N2	= RATIO O2N2 IN
VO2N2	= RATIO OF O2 TO N2 IN INSPIRED AIR
VCO2N2	= RATIO OF CO2 TO N2 IN INSPIRED AIR
EINN2	= N2 CONTENT OF INSPIRED AIR

II. PROGRAM SEQUENCE

A) INSTRUCTIONS ON DIMENSIONS AND DATA

```
      DIMENSION UREIH1 (15), UREIH2(15), VP(6), VERS1(6 ), VERS2(15)
      DIMENSION KUZEI1 (3), KUZEI2(3)
      DATA END /4HENDE/
      DATA CONTINUE /4HWEIT/
      DATA FF /2HFF/
```

B) READ IN INPUT DATA

```
   50 CONTINUE
      READ (5,1001) UREIH1
      READ (5,1001) UREIH2
 1001 FORMAT (15A4)
   60 CONTINUE
      READ(5,1002) VP, A, W, H, VERS1, FORTFA, KUZEI1
 1002 FORMAT(6A4,3F6.0,6A4,A2,3A4)
      IF(VP(1).EQ.CONTINUE) GOTO 50
      IF(VP(1).EQ. END ) GOTO 99
      IF(FORTFA.NE.FF) GOTO 10
      READ(5,1003) VERS2
 1003 FORMAT (15A4)
   10 CONTINUE
```

```
      READ(5,1004) GF, GA, GK, GT, B, VD, AZ, ZD, ZVO2, ZVCO2, ZLO2, ZLC
     1O2, EINO2, EINCO2, KUZEI2
 1004 FORMAT(F5.1,F5.1,F5.3,F4.1,F5.1,F5.2,F4.1,F4.1,F5.2,F4.2,F5.2,F4.2
     1,F5.2,F4.2,4X,3A4)
C
C     C)  CALCULATION OF THE SATURATED VAPOUR PRESSURE      PD = F(GT)
C         FROM VDI WATER VAPOUR TABLES, COMPILED BY E. SCHMIDT
C         SIXTH EDITION, SPRINGER- UND OLDENBOURG-VERLAG 1963
C
      FKQUER = 2.937 * (10. ** 5.)
      FAQUER = 5.426651
      FBQUER = (- 2005.1)
      FCQUER = 1.3869 * (10. ** (-4.))
      FDQUER = 1.1965 * (10. ** (-11.))
      FEQUER = (- 0.0044)
      FFQUER = (- 0.0057148)
      FTE    = (GT + 273.16)
      FX     = (FTE ** 2.) - FKQUER
      FY     = 374.11 - GT
      FTAU   = (GT + 273.16) / 647.3
      FALFA  = FAQUER + FBQUER / FTE + ((FCQUER * FX) / FTE) * (10. ** (
              (FDQUER * ((ABS(FX)) ** 2.)) - 1.)) + FEQUER * (10. ** (
              FFQUER * FY ** (5. / 4.)))
      FPC    = 1.01325 * (10. ** FALFA) + (FTAU - 0.422) * (0.577 - FTAU
     1        ) * (EXP((-12.) * (FTAU ** 4.))) * 9.80665 * (10. ** (-3.
     2        ))
      PD     = 750. * FPC
C
C     D)  CALCULATION OF VENTILATION PARAMETERS
C
      GD     = GF - GA
      IF(GD.LT.0.) GD = GD + 1000.
      GDK    = GD * GK
      REDF   = (B - PD) / (273. + GT) * (273. / 760.)
      RV     = GDK * REDF
      RVM    = RV / VD
C     ZD2    = B / 760.
      XKO21  = (0.04 * AZ) / (RV * 0.6)
C     XKO22  = (ZVO2 - ZLO2) * (ZD2 / ZD)
C     O2K    = ZVO2 - XKO21 + XKO22
C*    CORRECTION FOR URAS READING     ( - 2,5 O/O OF THE READING)
      ZVCO2 = ZVCO2 - 0.025 * ZVCO2
C
      XKCO21 = (0.20 * AZ) / (RV * 0.6)
C     XKCO22 = (ZVCO2 - ZLCO2) * (ZD2 / ZD)
C     CO2K   = ZVCO2 + XKCO21 + XKCO22
C***
      O2K = ZVO2 - XKO21
      CO2K = ZVCO2 - XKCO21
C***** CALCULATION CYCLE FOR WANIT WITH 21 O/O O2 EXTERNAL AIR
      EINO2 = 0.
C ***************************************************************
C
C         CALCULATION FOR FRESH-AIR INSPIRATION
C
      IF(EINO2.GT.0.) GOTO 12
      TW     = (100. - (O2K + CO2K)) * 0.264
      O2D    = TW - O2K
      CO2D   = CO2K
      GOTO 14
C
```

```
C           CALCULATION WHERE COMPOSITION OF AIR IS ALTERED
C
   12 CONTINUE
      EINN2  = 100. - (EINO2 + EINCO2)
      VO2N2  = EINO2 / EINN2
      VCO2N2 = EINCO2 / EINN2
      TWO2   = (100. - (O2K + CO2K)) * VO2N2
      O2D    = TWO2 - O2K
      TWCO2  = (100. - (O2K + CO2K)) * VCO2N2
      CO2D   = CO2K - TWCO2
C
   14 CONTINUE
      RQ     = CO2D / O2D
      VO2    = O2D * RVM * 10.
      VC     = RVM / (VO2 / 1000.)
      CALW   = 3.817 + 1.23 * RQ
      GU     = (66.473 + 13.7516 * W + 5.0033 * H - 6.7550 * A) / 1440.
      BU     = VO2 * CALW / 1000.
      AU     = BU - GU
C
C       F)  OUTPUT INSTRUCTIONS
C
 2000 FORMAT(1H0)
      WRITE(6,2001)
 2001 FORMAT(1H1)
      WRITE(6,2002)
 2002 FORMAT(10X,52HINSTITUT FUER ARBEITSWISSENSCHAFT DER T.H. DARMSTADT
     1/10X,52H****************************************************)
      WRITE(6,2000)
      WRITE(6,2003)
 2003 FORMAT (17X,35H CALCULATION OF VENTILATION PARAMETERS)
      WRITE(6,2003)
C
C           CHECK OUTPUT OF INPUT DATA
C
      WRITE (6,3001) REIH1
 3001 FORMAT (5X,20H TEST SERIES...  .... ,15A4)
      WRITE (6,2999) REIH2
 2999 FORMAT (5X,15A4//)
      WRITE(6,3002) VP
 3002 FORMAT(5X,4HVP. ,6A4/)
      WRITE(6,3003) A
 3003 FORMAT(15X,15HAGE                ,F6.0,2X,5H YEARS)
      WRITE(6,3004) W
 3004 FORMAT(15X,15H BODY WEIGHT       ,F6.0,2X,2HKG)
      WRITE(6,3005) H
 3005 FORMAT(15X,15HHEIGHT             ,F6.0,2X,2HCM//)
      WRITE(6,3006) VERS1
 3006 FORMAT(5X,12HACTIVITY        ,6A4)
      IF(FORTE A.EQ.FE) GOTO 16
      WRITE(6,3007) VERS2
 3007 FORMAT(17X,12A4)
   16 CONTINUE
      WRITE (6,3008) KUREIL
 3008 FORMAT(/5X,25HABBREVIATED DESCRIPTION OF TEST 3A4, 2X, 3A4)
      WRITE(6,2000)
      WRITE(6,3009)
 3009 FORMAT(5X,12HINPUT DATA   /5X,12H***********/)
      WRITE(6,3010) E
 3010 FORMAT(15X,25HGAS METER - FINAL READING    ,F7.1,2X,5HLITRES)
      WRITE(6,3011) CA
```

```
3011 FORMAT(15X,25HGAS METER - INITIAL READING    ,F7.1,2X,5HLITRES)
     WRITE(6,3012) CN
3012 FORMAT(15X,25HGAS METER - CORRECTION FACTOR ,F7.3,2X)
     WRITE(6,3013) CT
3013 FORMAT(15X,25HGAS METER - TEMPERATURE       ,F7.1,2X,6HDEGREES C)
     WRITE(6,3014) F
3014 FORMAT(15X,25H BAROMETRIC PRESSURE          ,F7.1,2X,4HTORR)
     WRITE(6,3015) VC
3015 FORMAT(15X,25H DURATION OF TEST             ,F7.2,2X,7HMINUTES)
     WRITE(6,3016) FT
3016 FORMAT(15X,25H FILLING TIME                 ,F7.1,2X,7H MINUTES/)
     WRITE(6,3017) Z
3017 FORMAT(15X,25H CYLINDER PRESSURE (FULL)     ,F7.1,2X,4H ATMOS)
     WRITE(6,3018) ZVO2
3018 FORMAT(15X,25HO2 - ANALYTICAL RESULT        ,F7.2,2X,10HVOL. - 0/0)
     WRITE(6,3019) ZVCO2
3019 FORMAT(15X,25HCO2 - ANALYTICAL RESULT       ,F7.2,2X,10HVOL. - 0/0/)
     IF(EINO2.GT.0.) GOTO 18
     GOTO 20
  18 CONTINUE
     WRITE(6,3020) EINO2
3020 FORMAT(15X,25HO2- CONTENT OF INSP. AIR      ,F7.2,2X,10HVOL. - 0/0)
     WRITE(6,3021) EINCO2
3021 FORMAT(15X,25HCO2- CONTENT OF INSP. AIR      F7.2,2X,10HVOL. - 0/0/)
     GOTO 22
  20 CONTINUE
     WRITE(6,3022)
3022 FORMAT(15X,45HO2-  CONTENT OF INSP. AIR       21.03  VOL. - 0/0 /)
     WRITE(6,3023)
3023 FORMAT(15X,45HCO2-CONTENT OF INSP. AIR         0.03  VOL. - 0/0 /)
  22 CONTINUE
```

RESULTS OUTPUT

```
     WRITE(6,4001)
4001 FORMAT(5X,10H RESULTS   /5X,10H**********/)
     IF(KUZEI1(1).EQ.KUZEI2(1).AND.KUZEI1(2).EQ.KUZEI2(2)) GOTO 24
     WRITE(6,4002)
4002 FORMAT (/////15X,32H THE BRIEF DESCRIPTION OF TEST//15X,32H IS DIFFERENT ON
     THE INPUT CARDS //15X,32H.   THE RESULTS ARE //20X,21H NOT GIVEN.)

     GOTO 60
  24 CONTINUE
     WRITE(6,4003) RV
4003 FORMAT(15X,25H   REDUCED   VENTILATION      ,F7.2,2X,5HLITRES)
     WRITE(6,4004) RVM
4004 FORMAT (40X,F7.2,2X,12HLITRES/MINUTE/)
     WRITE(6,4005) O2D
4005 FORMAT(15X,25H OXYGEN DIFFERENCE            ,F7.2,2X,10HVOL. - 0/0/)
     WRITE(6,4006) RQ
4006 FORMAT(15X,25H RESPIRATORY QUOTIENT         ,F7.3,2X)
     WRITE(6,4007) VQ
4007 FORMAT(15X,25H VENTILATION QUOTIENT         ,F7.2,2X,11H LITRES/LITRE/)
     VO2 = VO2 / 100.
     WRITE(6,4008) VO2
4008 FORMAT(15X,25H OXYGEN CONSUMPTION           ,F7.3,2X,12H LITRES/MINUTE/)
     WRITE(6,4009) GU
4009 FORMAT(15X,25H GROSS ENERGY CONSUMPTION     ,F7.3,2X,11HKCAL/MINUTE/)
     WRITE(6,4010) GU
4010 FORMAT(15X,25H BASAL CONSUMPTION            ,F7.3,2X,11HKCAL/MINUTE//)
     WRITE(6,4011) AU
```

```
4011  FORMAT(15X,25H NET ENERGY CONSUMPTION    ,F7.3,2X,11HKCAL/MINUTE//)
 111  CONTINUE
      GOTO 60
  99  CONTINUE
ENERGY CONSUMPTION WHEN PROCESSING ASBESTOS
                                  CEMENT (WANIT,WANNE-EICKEL,1972)
SEFCYK, R.                          46  75   171 CUT    5 SECTION    WANIT01 VP1
7098 6952  1004 210 7660   730  90  0.   1590 455 2050  3 2050  3    WANIT01 VP1
STRATMANN, F.                       38  77   183 MOULDING 300*200    WANIT02 VP2
1295  959   994 230 7670   900 120  0.   1565 500 2050  3 2050  3    WANIT02 VP2
END
```

0049*2076 LAURIG ENUM -DARMSTADT TR 440 DRZ 21.07.72 MV

INSTITUT FUER ARBEITSWISSENSCHAFT, T.H. DARMSTADT
****

CALCULATION OF THE VENTILATION PARAMETERS

TEST SERIES ENERGY CONSUMPTION WHEN PROCESSING ASBESTOS CEMENT (WANIT, WANNE-EICKEL, 1972)

VP. STRATMANN, F.

AGE	38 YEARS
WEIGHT	77 KG
HEIGHT	183 CM

ACTIVITY MOULDING 300*300 1,60 M

BRIEF DESCRIPTION OF TEST WANIT08 VP2

INPUT DATA
****

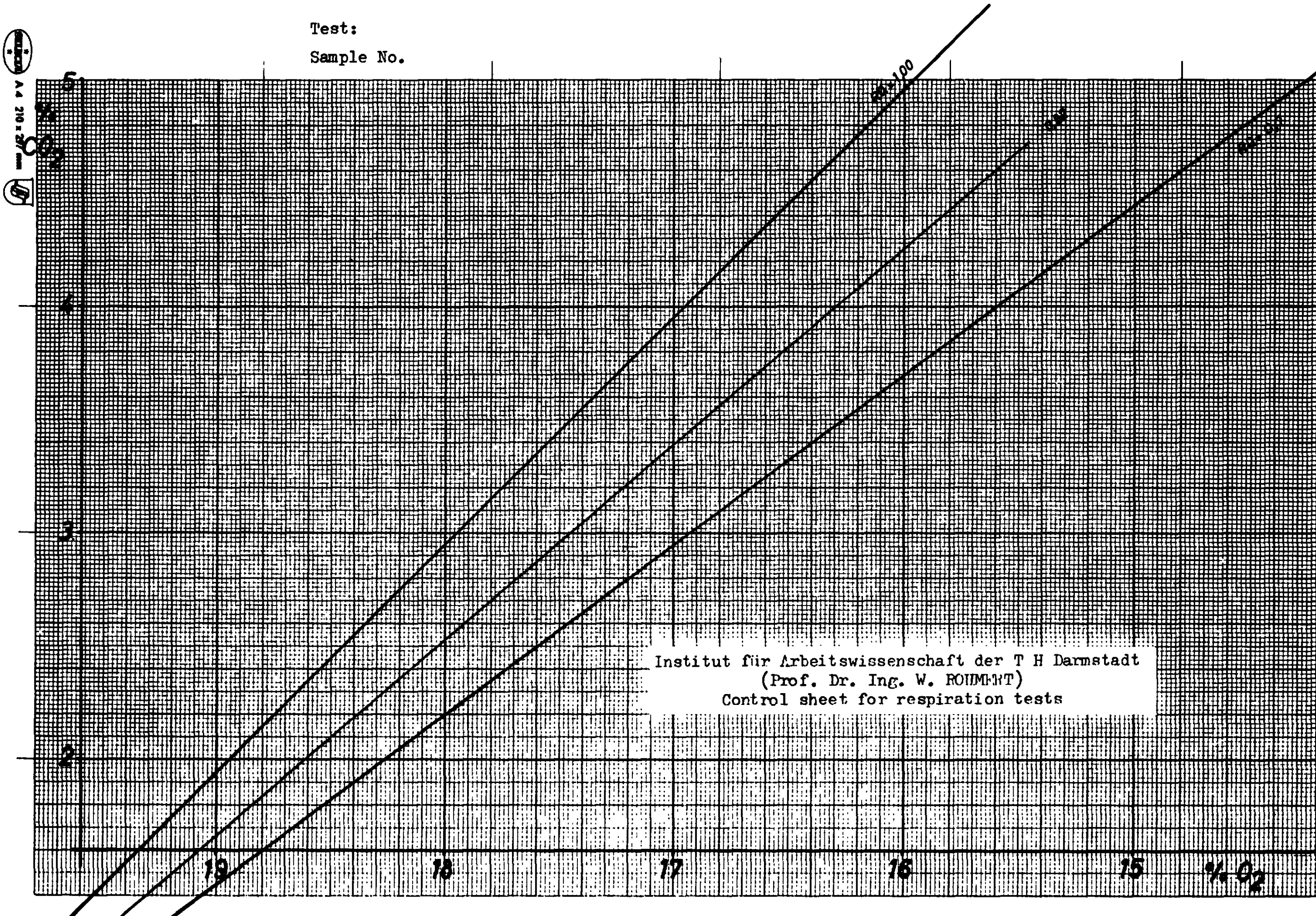
GAS METER - FINAL READING	7873.0	LITRES
GAS METER - INITIAL READING	7607.0	LITRES
GAS METER - CORRECTION FACTOR	1.004	
GAS METER - TEMPERATURE	23.0	DEGREES C
BAROMETRIC PRESSURE	769.0	TORR
DURATION OF TEST	6.45	MINUTES
FILLING TIME	8.0	MINUTES
O2 ANALYTICAL RESULT	16.05	VOL. - 0/0
CO2 ANALYTICAL RESULT	4.73	VOL. - 0/0
O2 CONTENT OF INSP. AIR	21.00	VOL. - 0/0
CO2 CONTENT OF INSP. AIR	0.03	VOL. - 0/0

RESULTS
****

REDUCED VENTILATION	238.83	LITRES
	37.03	LITRES/MINUTE
OXYGEN DIFFERENCE	4.87	VOL. - 0/0
RESPIRATORY QUOTIENT	0.969	
VENTILATION QUOTIENT	20.53	LITRE/LITRE
OXYGEN CONSUMPTION	18.033	LITRES/MINUTE
GROSS ENERGY CONSUMPTION	9.032	KCAL/MINUTE
BASAL CONSUMPTION	1.239	KCAL/MINUTE
NET ENERGY CONSUMPTION	7.793	KCAL/MINUTE/

Test:

Sample No.



A 4 210 x 297 mm

9.2. Appendix 2: FORTRAN program for evaluation of data on bodily posture obtained from photographs

General explanation

The version of the program in the list uses FORTRAN IV programming language and it was tested on the IBM 7040 computer of the Darmstadt Technische Hochschule. The program consists of three separate parts:

1. PHOTOGRAPH Ø1 with program parts 1 (see Statement No. 2004) and 2 (see Statement No. 2007).

   Purpose: To read-in the data cards and prepare a control output - classification of data cards

Column 1	Coding of bodily position 1 = standing 2 = sitting 3 = lying 4 = squatting 5 = kneeling
2 - 40	Coding of bodily posture according to a predetermined system (See enclosed extract of a coding for underground transport activities)
Column 51 - 56	Film No., Photograph No., Person No.
Column 58	Job (ARBART): 1 = handling 2 = loading and unloading 3 = reloading
Column 60	Degree of mechanization (GRADME - DEG.MEC.) 1 = mechanized 2 = non-mechanized

Program part 1 serves for the control output of all read-in data.

In program part 2, the frequency of the code numbers is decoded for columns 1 - 37.

2. PHOTO Ø3 and the 3rd program part brings together the code numbers by workplace groups, corresponding to the combination of code numbers for task (ARBART, see above) and degree of mechanization (GRADME, see above).

3. PHOTO Ø4 and the 4th program part provides the possibility of breaking down the frequency of coincidence of all posture characteristics (corresponding to columns 1 - 37). The breakdown is given in absolute and percentage frequency of each column characteristic with all other column characteristics.

Results

Fig. 26 shows examples of the results for frequency of bodily positions (column 1 program PHOTO Ø 1, 2nd program part) in the form of column groups for different industrial workplaces (= code numbers ARBART and GRADME) from SCHOTT (1972).

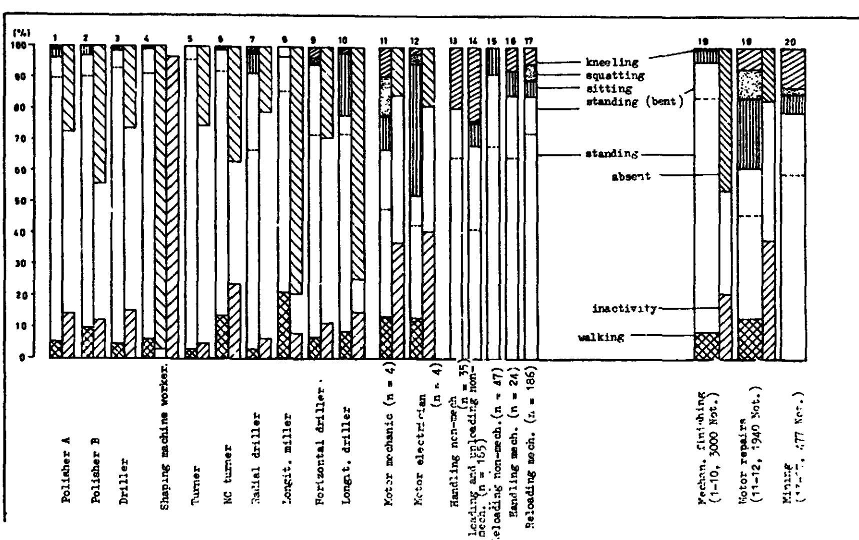


Fig. 26: Percentage frequencies of bodily positions in industrial workplaces

Supplement to Appendix 2:

Example of coding of bodily posture on data cards

Column	Code	Content of column and line
8		Trunk position: bending and stretching in sagittal plane
	1	Bent forwards
	4	Normal position
	7	Bent backwards
9		Qualitative determination of column 8:
	1	Marked forward bending
	2	Medium forward bending
	3	Slight forward bending
	4	Normal position
	5	Slight bending to rear
	6	Medium bending to rear
	7	Marked bending to rear
10		Position of trunk: lateral bending in frontal plane
	1	Bending to left
	4	Normal position (no bending)
	7	Bending to right
11		Qualitative determination of column 10:
	1	Marked bending to left
	2	Medium bending to left
	3	Slight bending to left
	4	Normal position
	5	Slight bending to right
	6	Medium bending to right
	7	Marked bending to right
12		Position of trunk: rotation ~~of trunk~~ in horizontal plane
	1	Rotation to left
	4	No rotation (normal position)
	7	Rotation to right

Column	Code	Content of column and line
13		Qualitative determination of column 12:
	1	Marked rotation to left
	2	Medium rotation to left
	3	Slight rotation to left
	4	Normal position
	5	Slight rotation to right
	6	Medium rotation to right
	7	Marked rotation to right
14		Right arm: reach of arm in % of max. reach
	1	Right arm up to 50%
	2	Right arm up to 75%
	3	Right arm up to 100%
	9	No conclusion can be drawn from the photograph for the right arm
15		Left arm: reach of arm in % of max. reach
	1	Left arm up to 50%
	2	Left arm up to 75%
	3	Left arm up to 100%
	9	No conclusion can be drawn from the photograph for the left arm
16		Height of the righthand relative to the mid-point of the right shoulder-joint
	1	Above mid-point of shoulder-joint
	4	Level with the shoulder joint
	7	Below mid-point of shoulder-joint
	9	No conclusion can be drawn from the photograph

```
ØJOB    WATFOR    943   TEMMING   PHOTO = EVAL  T E T E T E T E T E T E T
ØTIME             4
ØLINE             1000
ØIBJOB
ØIBFTC  PHOTOO1
        DIMENSION TEXT(20,12)
        DIMENSION K(10,40)
        DIMENSION FILM(10), PHOTO(10), PERS(10), JOB(10), DEG.MEC(10)
        DIMENSION TOT(10)
        DIMENSION N NUMBER (10,40)
        DATA BEGIN /6HBEGIN/
        DATA MEND /6H END /
        DATA NBLANC /2H /
        DO  2  1  = 1.10
        DO  1  J  = 1.40
        N NUMBER(1,J) = 0
      1 CONTINUE
      2 CONTINUE
        NUMBER = 1
        NLINE = 1
        M  =  1
        NINSGE  =  0
      5 CONTINUE
        READ(5,1001) (TEXT(M,N), N = 1.12)
   1001 FORMAT(12A6)
        IF(TEXT(M,1).EQ.BEGIN) GOTO 10
        M  =  M + 1
        GOTO 5
     10 CONTINUE
   2000 FORMAT (1H0)
   2001 FORMAT(1H1)
        WRITE(6,2001)
        WRITE(6,2002)
   2002 FORMAT(30X,50HINSTITUT FUER ARBEITSWISSENSCHAFT DER TH DARMSTADT
        /3 10X,50(1H*))
        WRITE(6,2000)
        WRITE(6,2003)
   2003 FORMAT(30X,50HEVALUATION OF POSITION STUDY (UNDERGROUND PHOTOS)/3
        10X,50(1H-))
        WRITE(6,2000)
        WRITE(6,2004)
   2004 FORMAT(5X,56HPROGRAMPART 1 CONTROL OUTPUT OF INPUT DATA/
        5X,56(1H=))
        WRITE(6,2000)
        WRITE(6,2005)
   2005 FORMAT(2X,5HCARD,40X,41HC O N T E N T  OF  COL No. 1/)
        WRITE(6,2006)
   2006 FORMAT(2X,5H No. , 121H  1  2  3  4  5  6  7  8  9 10 11 12 13
        14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
        35 36 3  27  58  60)
        WRITE(6,2010)
     15 CONTINUE
        READ(5,1002) (K(No.I), I = 1,37), FILM(NO.), PHOTO(NO.),
        PERS(NO.), JOB(NO.), DEG.MEC(NO.), TOT(NO.)
   1002 FORMAT(37(11),13X,5F2.C,12X,F3.0)
        IF(K(NO.1).EQ.9) GOTO 500
        NINSGE  =  NINSGE  =  1
        DO - 20  NS = 1,37
        NC  = K(NR,NS)
        IF(NC.LT.1)  K(NR,NS) = NBLANC
        IF(NC.LT.1) GOTO 20
        NNUMBER(NC,NS)  =  NNUMBER(NC,NS) + 1
```

```
   20 CONTINUE
      IF(NLINE.GT.9)  GOTO 25
      WRITE(6,3001) TOT(NO.), (K(NO.I), I = 1,37), JOB(NO.), DEG.MEC(NO.)
 3001 FORMAT(2X,F5.0,37(1X,12),2F5.0)
      NLINE =  NLINE + 1
      GOTO 15
   25 CONTINUE
      WRITE(6,3002) TOT(NO.), (K(NO.I),I = 1,37), JOB(NO.), DEG.MEC(NO.)
 3002 FORMAT(2X,F5.0,37(1X,12),2F5.0)
      WRITE(6,2010)
 2010 FORMAT92X,126(1H-))
      WRITE(6,2006)
      WRITE(6,2010)
      NLINE = 1
      GOTO 15
  500 CONTINUE
      WRITE(6,2010)
      WRITE(6,2006)
      WRITE(6,2010)
      WRITE(6,2000)
      WRITE(6,2011) NINSGE
 2011 FORMAT(2X,40HNUMBER OF CODED BODILY POSTURES = ,115)
    0 CONTINUE
      WRITE(6,2001)
      WRITE(6,2002)
      WRITE(6,2000)
      WRITE(6,2003)
      WRITE(6,2000)
      WRITE(6,2007)
 2007 FORMAT(5X,70HPROGRAMPART 2. SUM TOTAL OF CODE - NUMBERS BY
      POSITION CHARACTERISTIC/5X,70(1H=))
      WRITE(6,2000)
      WRITE(6,2008)
 2008 FORMAT(10X,6HCOL,30X,34HNUMBER OF CASES FOR CODE NO.,34X,15HTOTAL/)
      WRITE(6,2009)
 2009 FORMAT(10X,2X,3HNO.,9X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5.9X,1H6,9X,1
      1H7,9X,1H8,9X.1H9,9X,5H1 - 9)
      WRITE(6,2012)
 2012 FORMAT(10X,111(1H-))
      NLINE = 1
      DO  100 NS = 1,  37
      NSTOT = 0
      DO 110 NC = 1,9
      NSTOT = NSTOT = NNUMBER(NC,NS)
  110 CONTINUE
      WRITE(6,3003) NS,(NNUMBER(NC,NS), NC 2 1,9), NSTOT
 3003 FORMAT(10X.15,9(1110),9X,115)
      IF(NLINE.GT.4) GOTO 50
      NLINE = NLINE = 1
      GOTO 100
   50 CONTINUE
      WRITE(6,2012)
      NLINE = 1
      GOTO 100
  100 CONTINUE
      WRITE(6,2012)
      WRITE(6,2000)
      WRITE(6,2011) NINSGE
  770 CONTINUE
      READ(5,1003) CHARACTERISTIC
 1003 FORMAT(1A6)
      IF(CHARACT.EQ.HEND) GOTO 780
```

```
      GOTO 770
  780 CONTINUE
      END
```

```
$JOB    WATFOR      943    TEMMING    PHOTO EVALUATION  T E T E T E T E T E T E T
$TIME               3
$LINE               500
$IBJOB
$IBFTC  PHOT003
        DIMENSION TEXT(15,12)
        DIMENSION K(40)
        DIMENSION NNUMBER(40,10,10)
        DIMENSION CHARACTERISTIC(40,12)
        DATA BEGIN /6HBEGIN/
        DATA MEND /6H END /
        DO   3   NS = 1,40
        DO   2   NC = 1,10
        DO   1   NG = 1,10
        NNUMBER(NS,NC,NG) = 0
      1 CONTINUE
      2 CONTINUE
      3 CONTINUE
        M  =  1
     10 CONTINUE
        READ(5,1001) (TEXT(M,N), N = 1,12)
   1001 FORMAT(12A6)
        IF(TEXT(M,1).EQ.BEGIN) GOTO 15
        M = M + 1
        GOTO 10
     15 CONTINUE
          M = M - 1
C
C       READ IN AND FILE CODE DIGITS
C
        NINSGE = 0
     25 CONTINUE
        READ(5,1002) (K(I),I = 1,40), FILM, PHOTO, PERS, JOB, DEG.MEC,
        TOT 1NO.
   1002 FORMAT(40(1I1),10X,5F2.0,12X,F3.0)
        IF(K(1).EQ.9) GOTO 500.
        NINSGE = NINSGE + 1
        IF(DEG.MEC.EQ.1.) GOTO 120
        IF(JOB.EQ.2.) GOTO 111
        IF(JOB.EQ.2.) GOTO 112
        NG = 4
        GOTO 200
    111 CONTINUE
        NG = 1
        GOTO 200
    112 CONTINUE
        NG = 3
        GOTO 200
    120 CONTINUE
        IF(JOB.EQ.1.) GOTO 121
        NG = 5
        GOTO 200
    121 CONTINUE
        NG = 2
        GOTO 200
    200 CONTINUE
        DO 210 NS = 1,40
        NC = K(NS)
        IF(NC.LT.1) GOTO 210
        NNUMBER(NS,NC,NG) = NNUMBER(NS,NC,NG) + 1
    210 CONTINUE
        GOTO 25
    500 CONTINUE
```

```
      DO 520 NS = 1,40
      DO 510 NC = 1,10
      NNUMBER(NS,NC,6) = NNUMBER(NS,NC,1) + NNUMBER(NS,NC,2)
      NNUMBER(NS,NC,7) = NNUMBER (NS,NC,4) + NNUMBER(NS,NC,5)
      NNUMBER(NS,NC,8) = NNUMBER(NS,NC,1) + NNUNBER(NS,NC,3) + NNUMBER(NS.
      NC,4 1)
      NNUMBER(NS,NC,9) = NNUMBER(NS,NC,2) + NNUMBER(NS,NC,5)
      DO 505 NG = 1,5
      NNUMBER(NS,NC,10) = NNUMBER(NS,NC,10) + NNUMBER(NS,NC,NG)
  505 CONTINUE
  510 CONTINUE
  520 CONTINUE
C
C     READ IN CHARACTERISTIC DESCRIPTIONS
C
      NS = 1
  525 CONTINUE
      READ(5,1003) (CHARACTERISTIC(NS,NM), NM = 1,12)
 1003 FORMAT(12A6)
      IF(CHARAC(NS,1).EQ.MEND) GOTO 530
      NS = NS + 1
      GOTO 525
  530 CONTINUE
C
C     PRINT OUT HEADING LINES
C
 2000 FORMAT(1H0)
 2001 FORMAT(1H1)
      WRITE(6,2001)
      WRITE(6,2002)
 2002 FORMAT(30X,50HINSTITUT FUER ARBEITSWISSENSCHAFT DER TH DARMSTADT/3
      10X,50(1H*))
      WRITE(6,2000)
      WRITE(6,2003)
 2003 FORMAT(30X,50HEVALUATION OF POSITION STUDY (UNDERGROUND PHOTOS)/3
      10X,50(1H-))
      WRITE(6,2000)
      WRITE(6,2004)
 2004 FORMAT(5X,66HPROGRAMPART 3. CODING ANALYSIS BY WORKPLACE
      GROUPS/5X,66(1H=))
      WRITE(6,2000)
      WRITE(6,2005)
 2005 FORMAT(50X,35HSIGNIFICANCE OF GROUPS - IDENT.NUMBERS/50X,35(1H-)/)
      DO 20 I = 1,M
      WRITE(6,2006) (TEXT(I,N), N 2 1,12)
 2006 FORMAT(50X,12A6)
   20 CONTINUE
      WRITE(6,2000)
C
C     READ OUT DIGITS - COUNTS
C
      WRITE(6,2007)
 2007 FORMAT(22X,58HNUMBER OF CODE NUMBERS WITHIN WORKPLACE GROUPS/)
      WRITE(6,2012)
      DO 800 NS = 1,40
      DO 540 NC = 1,9
      IF(NNUMBER(NS,NC,10). GT.0) GOTO 550
  540 CONTINUE
      GOTO 800
  550 CONTINUE
      LINES = 1.
      WRITE(6,2008) NS, (CHARACTERISTIC(NS,MN), MN = 2,12
```

```
2008 FORMAT(2X,12HCHARACTERISTIC NO. ,13,2H..,11A6)
     WRITE(6,2009)
2009 FORMAT(2X,117(1H-))
     WRITE(6,2010)
2010 FORMAT(4X,10HGROUP NO.,4X,1HI,4X,1HI,4X,1HI,4X,1H2,4X,1HI,4X,1H3,
     14X,1HI,4X,1H4,4X,1HI,4X,1H5,4x,1HI,4X,1H6,4X,1HI,4X,1H7,4X,1HI,4X,
     21H8,4X,1HI,4X,1H9,4X,1HI,3X,2H10,4X,1HI)
     WRITE(6,2009)
     DO 600 NC = 1,10
     IF (NNUMBER(NS,NC,10).LT.1) GOTO 600
     IF(LINES.EQ.2.) GOTO 560
     WRITE(6,3001) NC, (NNUMBER(NS,NC,NG), NG = 1,10)
     LINES = 2.
     GOTO 600
 560 CONTINUE
     WRITE(6,3002), NC, (NNUMBER(NS,NC,NG), NG = 1,10)
 600 CONTINUE
3001 FORMAT(4X,10HCODE NO.  ,I2,2X,1HI,10(16,3X,1HI))
3002 FORMAT(14X,12,2X,1HI,10(16,3X,1HI))
     WRITE(6,2012)
2012 FORMAT(2X,117(1H=)/)
 800 CONTINUE
     WRITE(6,2000)
     WRITE(6,3003) NINSGE
3003 FORMAT(10X,38HNUMBER OF EVALUATED CODINGS = ,115)
     END
```

```
$JOB     WATFOR  943  TEMMING  PHOTO EVALUATION T E T E T E T E T E
         T E T
$TIME              10
$LINE              5000
$IBJOB
$IBFTC PHOTO04
       DIMENSION K(40)
       DIMENSION NNUMBER(40,10,10)
       DIMENSION CHARACT(40,12)
       DIMENSION PERC(10)
       DIMENSION NPERC(10)
       DIMENSION NUMBER(10)
       DIMENSION NUMBER(10)
       DATA BEGIN /6HBEGIN/
       DATA MEND /6H END /
C
C      SCAN GROUP DESCRIPTIONS
C
     5 CONTINUE
       READ(5,1001) TEXT
  1001 FORMAT(1A6)
       IF(TEXT.EQ.BEGIN) GOTO 10
       GOTO 5
    10 CONTINUE
C
C      READ IN CODE DIGITS
C
       NINSGE = 0
       REWIND 1
    15 CONTINUE
       READ(5,1002) (K(I), I = 1,40)
  1002 FORMAT(40(1I1))
       NINSGE = NINSGE + 1
       WRITE(1) (K(I), I = 1,40), NINSGE
       IF(K(1)EQ.9) GOTO 500
       GOTO 15
   500 CONTINUE
C
C      READ IN CHARACTERISTIC DESCRIPTIONS
C
       N = 1
   505 CONTINUE
       READ(5,1003) (CHARACTER(N,NM), NM = 1,12)
  1003 FORMAT(12A6)
       IF(CHARACTER(N,1).EQ.MEND)  GOTO 510
       N = N + 1
       GOTO 505
   510 CONTINUE
C
C      FILE AND PRINT RESULTS
C
       DO 873 NOSP = 31,37
       REWIND 1
       DO 3 NS = 1,40
       DO 2 NC = 1,10
       DO 1 NG = 1,10
       NNUMBER(NS,NC,NG) = 0
     1 CONTINUE
     2 CONTINUE
     3 CONTINUE
    20 CONTINUE
       READ(1) (K(I), I = 1,40), NINSGE
       IF(K(1).EQ.9) GOTO 30
       DO 25 NS = 1,40
```

```
      NC = K(NS)
      NO = K(NOSP)
      IF(NC.LT.1) GOTO 25
      IF(NO.LT.1) GOTO 25
      NNUMBER(NS,NC,NO) = NNUMBER(NS,NC,NO) + 1
   25 CONTINUE
      GOTO 20
   30 CONTINUE
      NINSGE = NINSGE - 1
C
C     PRINT OUT HEADING LINES
C
 2000 FORMAT(1H0)
 2001 FORMAT(1H1)
      WRITE(6,2001)
      WRITE(6,2002)
 2002 FORMAT(30X,50HINSTITUT FUER ARBEITSWISSENSCHAFT DER TH DARMSTADT/3
      10X,50(1H*))
      WRITE(6,2000)
      WRITE(6,2003)
 2003 FORMAT(30X,50HEVALUATION OF POSITION STUDY (UNDERGROUND PHOTOS)/3
      10X,50(1H-))
      WRITE(6,2000)
      WRITE(6,2004)
 2004 FORMAT(5X,77HPROGRAMPART 4.  CODING ANALYSIS BY INDIVIDUAL
      POSITION CHARACTERISTICS/5X,77(1H=))
      WRITE(6,2000)
      WRITE(6,2005) (CHARACT(NOSP,N), N = 1,12)
 2005 FORMAT(22X,31HORDERING CRITERION = CHARACT NO.,12A6/22X,17(1H*))
      WRITE(6,2000)
      WRITE(6,2006)
 2006 FORMAT(25X,69H(GROUPING OF POSITION DESCRIPTIONS BY  /25X,70H
      IN ACCORDANCE WITH CODE DIGITS OF ORDERING CRITERION (OC). GROUPS -
      NO. /25X,52HAND CODE DIGIT OF OC ARE S 30 THEREFORE IN AGREEMENT).
      //25X,70HTHE TABLE CONTAINS THE NUMBERS OF CASES PER SUBGROUP AS
      WELL AS THE  /25X,70HQUOTA OF THESE CASES A 5N OF THE SUM TOTAL
      WITHIN THE GROUP (IN 0/0). )
      WRITE(6,2000)
C
C     PRINT OUT DIGITS - COUNTS
C
      WRITE(6,2008)
  008 FORMAT(1X,8(1H+),1HI,10(11(1H=),1HI)/)
      DO 800 NS = 1,40
      DO 540 NC = 1,9
      DO 535 NO = 1,9
      IF(NNUMBER(NS,NC,NO).GT.0) GOTO 550
  535 CONTINUE
  540 CONTINUE
      GOTO 800
  550 CONTINUE
      LINES = 1.
      WRITE(6,200  NS, (CHARACT(NS,MN), MN = 2,12)
 2009 FORMAT(2X,12HCHARACT NO. ,I3,2H..,2X,11A6)
      WRITE(6,2010)
 2010 FORMAT(1X,8(1H-),1HI,10(11(1H-),1HI))
      WRITE(6,2011)
 2011 FORMAT(1X,10HGROUP NO.,4X,1HI,5X,1HI,5X,1H2,5X,1HI,5X,1H3,5x,1HI,
      15X,1H4,5X,1HI,5X,1H5,5X,1HI,5X,1H6,5X,1HI,5X,1H7,5X,1HI,5X,1H8,5X,
      21HI,5X,1H9,5X,1HI,3X,5HTOTAL,3X,1HI)
      WRITE(6,2010)
      DO 600 NC = 1,9
      DO 570 NO = 1,9
```

```
      NNUMBER(NS,NC,10)  =  NNUMBER(NS,NC,10) + NNUMBER(NS,NC,NO)
  570 CONTINUE
      IF(NNUMBER(NS,NC,10).GT.C) GOTO 580
      GOTO 600
  580 CONTINUE
      DO 585  NO = 1,9
      COUNT(NO) = FLOAT(NNUMBER(NS,NC,NO))
      NUMBER(NO) = FLOAT(NNUMBER(NOSP,NO,NO))
      PERC(NO)  = ((COUNT(NO) / NUMBER(NO)) *  100.) + 0.5
  585 CONTINUE
      TOTAL = FLOAT(NOVERALL)
      NUMBER(10) = FLOAT(NNUMBER(NS,NC,10))
      PERC(10) = ((NUMBER(1C) / TOTAL)* 100.) + 0.5
      DO 586  NO = 1,10
      NUMBERPERC(NO) = INT(PERC(NO))
  586 CONTINUE
      IF LINES.EQ.2) GOTO 590
      WRITE(6,3001) NO, (NNUMBER(NS,NC,NO), NPERC(NO), NO = 1,10)
      LINES = 2.
      GOTO 600
  590 CONTINUE
      WRITE(6,3002) NC,  (NNUMBER(NS,NC,NO), NPERC(NO), NO = 1,10)
  600 CONTINUE
 3001 FORMAT(1X,5HCODE ,112,1X,1HI,10(114,1X,1H(,113,1H),1X,1HI))
 3002 FORMAT(6X,112,1X,1HI,10(1I4,1X,1H(,113,1H),1X,1HI))
      WRITE(6,200')
  800 CONTINUE
      WRITE(6,3003) NIKSGE
 3003 FORMAT(10X,38HNUMBER OF CODINGS EVALUATED = ,115)
  850 CONTINUE
  873 CONTINUE
      END
```

9.3. Appendix 3: Example of the deductive determination of stress during static holding work

Task: To determine the stress during: "Electric welding, standing upright, welding at about shoulder-level"

Hypothesis: Stress in excess of the endurance threshold is equal to the necessary recovery period

Approach to solution: Determine the recovery period by ROHMERT's equation (1960 b):

Additional recovery period (EZ) as a percentage of duration of work load

$$EZ = 18 \cdot \left(\frac{t}{T}\right)^{1.4} \cdot \left(\frac{k}{K} - 0.15\right)^{0.5} \cdot 100\%$$

with T = maximum possible holding time in minutes

t = duration of work load in minutes

K = maximum holding strength in kgf

k = level of work load in kgf

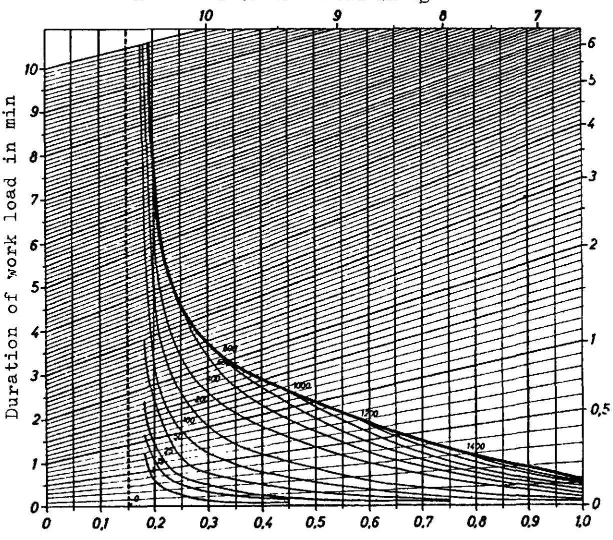


Fig. 27: Additional recovery period as a function of work load during static holding work (from ROHMERT)

Fig. 27 shows this equation expressed as a graph with EZ as a curve parameter.

Method of solving: To apply this equation or the nomogram in practice, level of work load, duration of the work load and maximum holding strength must be known. The following procedure would appear suitable:

1. Determine level of work load, that is the weight of the object to be held

   here: e.g. 2 kgf for electric welding

2. Describe bodily posture

   here: standing arms roughly parallel to the sagittal plain on a level with the shoulder-joint, centre of gravity of the hand about 50% of the arm reach

3. Estimate the additional weight components produced by positioning the limbs

   here: weight of arm, see also Fig. 3, Sect. 5.2.3.

4. Calculate the total effective work load

   here: sum of the weights of the electrode holder and accessories plus weight component from Point 3 where direction of force required is upwards (downwards the weight component acts positively!)

5. Determine the maximum displacement strength of the working limbs, by place and direction depending on the task

   here: place: 50% reach of arm, approximately sagittal plane on a level with the shoulder-joint
   direction: vertically upwards

6. Calculate the level of work load as a fraction of maximum strength from Point 5.

7. Determine the additional recovery period by combining level of work load with duration of work load derived from task

Re. Points 3 and 4

In this case, which is a bodily posture frequently found in practice, the total level of work load acting on an arm can be read directly from the following Fig. 28 (corresponding to problem set under Point 6)

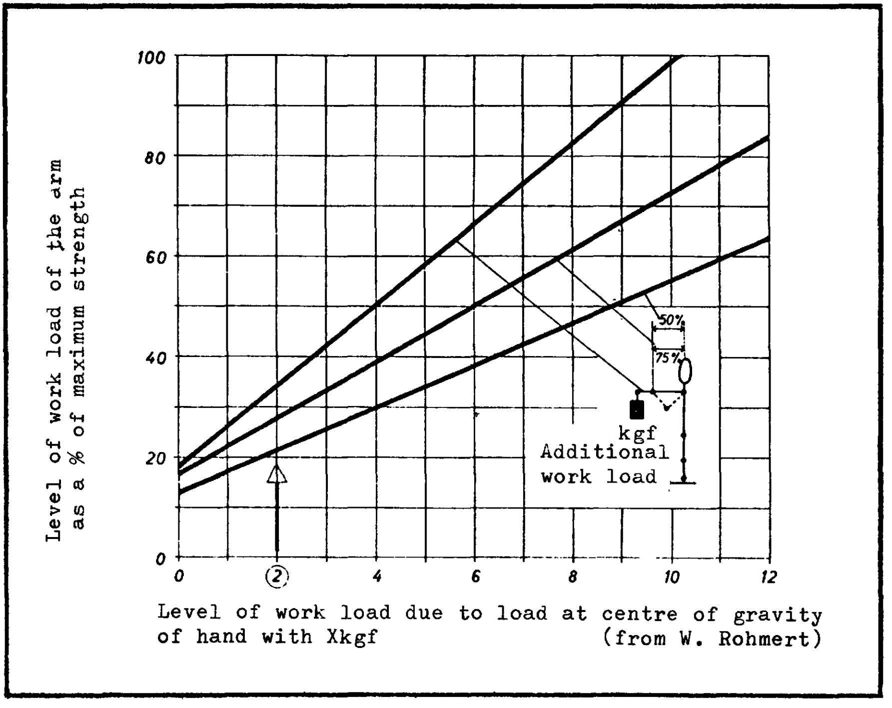


Fig. 28: Level of work load when holding parts for assembly, with arm stretched or bent

Therefore, in the example the work load is about 0.21 of the maximum strength.

For the general case of arm posture (not in the sagittal plane and above or below the level of the shoulder-joint) the additional weight component due to holding the arms can only be estimated. A mean of 10 - 20% of the maximum strength in the particular bodily posture is obtained from ROHMERT's results (1962). (For men: 10% for reach $\leq$50%, 20% for reach $>$ 75%)

Re. Point 5

For the general case of arm posture mentioned above, it is advisable to use the strength atlases of ROHMERT & HETTINGER (1963), ROHMERT (1966) and JENIK (1972 b). Figure 29 is an illustration from a strength atlas relevant to this example; it shows that the bodily posture described under Point 3 (β = 0 corresponds to work in the sagittal plane elevation angle α = 0° corresponds to shoulder level) leads to a maximum positional strength of about 15 kgf (figure top left).

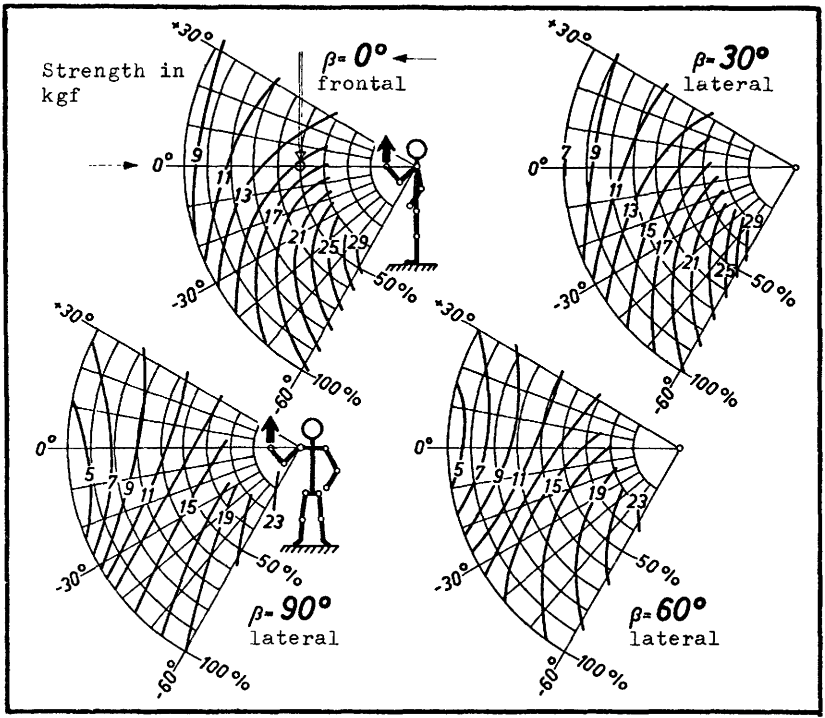


Fig. 29: Arm strength vertically upwards (from ROHMERT)

The weight component for the weight of the arm is 10% of this maximum strength ≈1.5 kgf. Therefore the total effective work load (see Point 4) is ≈3.5 kgf.

Results: For Point 6, by calculation we obtain a value of 0.23 for level of work load as a fraction of maximum strength; this correlates well with the figure derived from Fig. 28. The additional recovery period necessary can be obtained from Fig. 27 corresponding to the particular duration of work load, i.e. for a welding time of one minute it is about 50%, i.e. 0.5 minutes recovery period.

9.4. Appendix 4: Synopsis of the results referred to in this report

Research project number 22/...	Name	Contents or title
056 11/01	LAVENNE	Arrangement of breaks, change of work; laboratory tests, bicycle ergometer; response of physiol. variables
017 11/02	MARGARIA	Determination of max. oxygen consumption as a criterion for selecting workers to do heavy work Effect of heavy work on O_2max
040 11/03	MARGARIA	Anaerobic metabolism, determination of lactic acid concentration
053	TARRIERE	Contribution to study of the physiol. demands of work under actual working conditions
007 11/05	ROHMERT	Transporting and handling loads by miners in the coalmining industry
005 11/06	SCHMIDT	Characteristics and effects of unfavourable bodily postures
047 11/07	SCHNAUBER	Functional capacity of the hands when working at different levels above the heart
23/03 11/08	FAURE	Physical work load in a highly mechanized breast
Ergonomic Community Research	ROHMERT, SCHOTT, TEMMING, FRIESS	Development and application of a computer program for evaluating photographs of bodily postures during underground work

9.5. Synopsis of tables

14 Calculation of mean work load in a shift, in terms of energy, from data on duration of work load from ROHMERT and data on level of work load from SIEBER

15 Trend for the age of underground workers to increase in the French coalmining industry (FAURE)

16 Means of characteristic values for cardiovascular stress in the workplace subgroups
(in brackets: standard deviation). Each box shows:
1st line: overall pulse rate as a mean for shift
2nd line: work-induced pulse rate as mean for shift
3rd line: pulse rate elevation
(All data in P/min)

17 Percentage proportion of work-induced pulse rates of different levels in all shifts in different activity groups (from SIEBER)

18 Equivalent mechanical work load (watts) at 20 different workplaces for five types of activity (from TARRIERE)

19 Stress at different workplaces for five types of activity (from TARRIERE)

20 Comparison of signs of fatigue in five types of activity (from TARRIERE)

9.6. Synopsis of figures

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