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ORIGINAL PAPERS

AN ERGONOMIC SYSTEM FOR ASSESSING POSTURAL STRESS IN WORKPLACES

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Abstract. A new method has been developed to enable the ergonomic assessment of stress associated with posture at the workplace. It enables evaluations of the load resulting from working postures at workplaces where standing and walking postures dominate. The method also offers the possibility of estimating the preexisting load already at the stage of workplace designing. This may prove useful in evaluating both the global load and giving the designer an idea about the effect of individual design decisions on changes of the postural load. The method has been used to compare the postural stress at several workplaces in the texile industry and it seems to perform satisfactorily.

INTRODUCTION

Stress caused by an awkward working posture of the trunk, shoulders and legs can result in fatigue, musculoskeletal disorders and nerve entrapment syndromes. The association between awkward work postures and development of fatigue and musculoskeletal disorders has been widely discussed in recent literature on ergonomics (1, 7). In general, experimental laboratory testing and computer-assisted methods of collecting data on working posture have been highly developed (2). However, we still have insufficient capacity for evaluating and comparing postural stress in actual work performance.

The correct spatial design of a workplace should ensure a low level of postural stress in worker. The load connected with work posture is dependent not only on the specifications of the operated machines, but also on the methods of their operation (4). It is the work organization factor which determines how essential individual specifications are for operative comfort. For example, it is important to know how often a worker will need to reach an uncomfortably positioned manual during his work time. The difficulties in assessing postural stress in the workplace

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also lie in the fact that various activities may cause a great number of possible body positions which constitute the working posture.

THE METHOD

The working posture analysis system which is presented here has been developed to enable the ergonomic assessment of posture in the workplace. It relates to works performed predominantly in the standing and walking postures. The overall posture refers to the combined position of the back, arms, and legs. The analysis covered 144 body postures including 4 postures of the back, 4 postures of the arms and 9 postures of the legs. These standard postures were developed on the basis of possible deviations from the ergonomically neutral posture. The strenuousness of a particular posture was estimated on the basis of biomechanical investigation. The method is based on analyzing the force moments occurring at individual postures, as the investigations have revealed; that is, the force moments which determine the magnitude of load. The basic angles considered in the method are presented in Fig. 1.

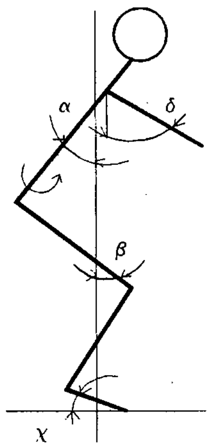


Fig. 1. Basic angles considered in the method.

Generally, the method is as follows:

The load of the workplace from the point of view of the working postures can be determined from the formula:

$$I_1 = \sum \frac{C_c \cdot t_c}{T}$$

where: I_1 – index of postural load for a work place,
C_c – coefficient of load in particular category,
t_c – duration of investigated posture,
T – duration of observation, e.g. 60 minutes.

The postures have been classified into 5 categories. The classification into individual categories is presented in Table 1. The coefficients associated with the categories are given in Table 2.

To assess a single posture occurring during work time, one should:

1. Note constituents of the posture, i.e. positions of the trunk, arms and legs.

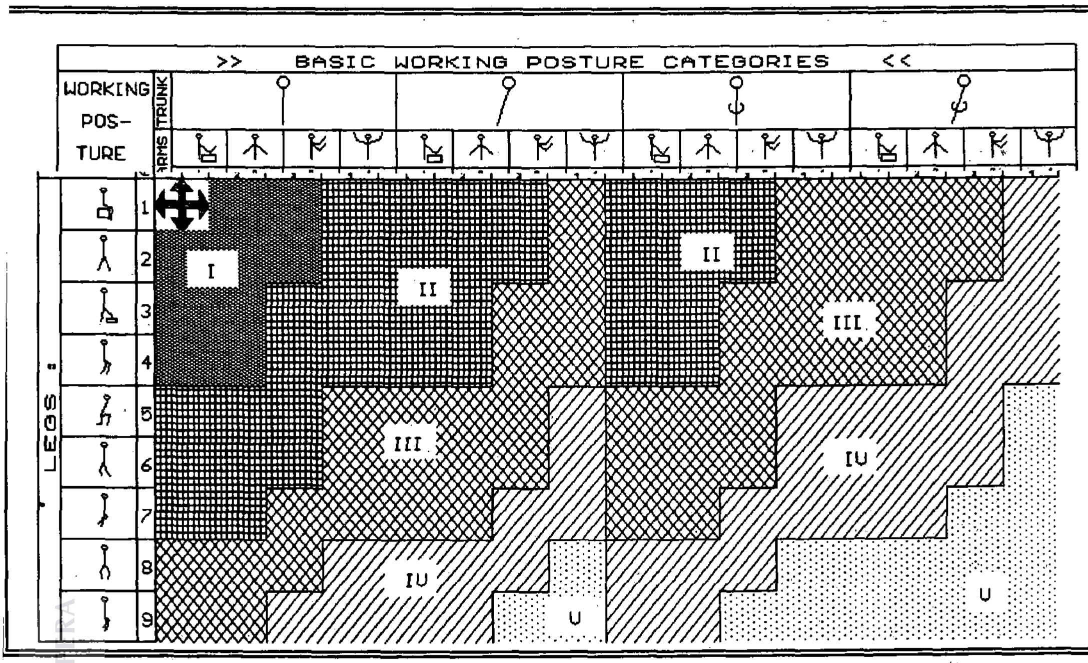
2. Find the investigated posture in the Table 1 giving the categories and note the category.

3. In Table 2, find the coefficient of load C, corresponding to the category of the investigated posture.

To evaluate workplace comfort attributable to the working posture, one should:

1. categorise all postures occurring at the workplace and determine the duration of these postures. The method of posture recording is of no consequence here (it is essential that a photograph, or video recording should show all these three elements, i.e. trunk, arms, legs).

Table 1. Basic working posture categories



Trunk : 1.straight, 2.flexed, 3.twisted, 4.flexed and twisted
Arms/shoulders : 1.arms supported, 2.both arms below the shoulder level, 3. one arm at or above the shoulder level, 4. both arms at or above the shoulder.
Legs : 1.sitting, 2.standing on both feet,legs straight, 3.standing on one foot,leg straight, 4.walking,moving, 5.kneeling on one or both knees, 6.standing on tiptoes,one foot, 7.standing on tiptoes,both feet, 8.standing or crouching on both feet,knees flexed,9.standing or crouching on one foot,leg flexed in knee.

2. multiply the duration times of the individual postures by the corresponding load coefficients.

The sum of all products $t_{1*}C_1 + t_{2*} C_2 + t_{3*}C_3 + \ldots$ divided by the nominal observation time gives the posture-related index of load for a given workplace.

The evaluation of a workplace, from the point of view of working posture, consists in comparing the obtained result with the indicators given below:

comfortable working posture	< 1.5
slightly uncomfortable working posture	$1.5 - 2.4$
very uncomfortable working posture	$2.5 - 3.4$
extremely uncomfortable working posture	$\geqslant 3.5$

Table 2. Coefficients of loads associated with the posture categories

posture category	I	II	III	IV	V
coefficient of load	1	2.3	4.2	7.0	11.2

ASSUMPTIONS OF THE METHOD

Posture assessment

Following a biomechanical analysis of forces and force moments occurring in each of the 144 postures resulting from various positions of the trunk, legs and arms, it has been found that:

1. Postural stress results in the first place from force moments, because they must always cause a corresponding reaction of muscles to keep the posture. Compressive forces (weight) are acting in each arrangement of posture and generally do not cause discomfort.

A numerical value corresponding to the occurrence of one moment has been assumed to be the measure of the discomfort. Each moment occurring in a given posture has been assigned the value of 1, this refers both to the moment resulting from gravity force and to the moment resulting from body twisting.

2. Forces resulting from free posture, where the stress corresponding to the weight of the body is carried by the bones, generally do not cause discomfort. The only exception is the load on legs at occasions where the body weight is not evenly distributed to both legs and is carried by only one:

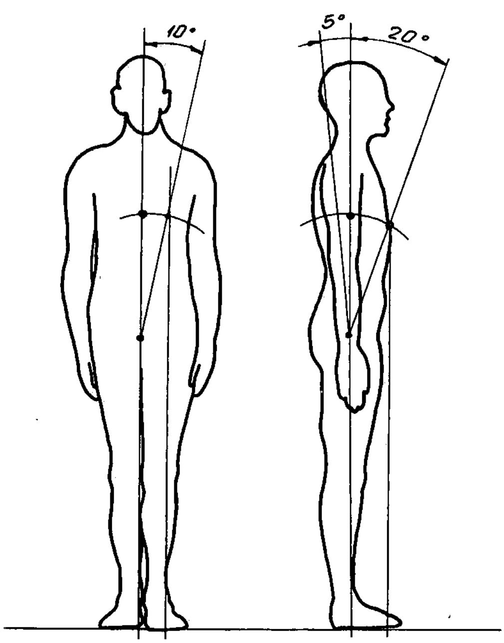


Fig. 2. Neutral postures of the trunk

– stress borne by two straight legs is assumed to cause no discomfort and should be neglected,

– stress borne when one leg carries over the weight of the body is uncomfortable and it has been assumed that the resultant discomfort is equal to 1/2 of the moment.

3. The position of arms at, or above, the line of the shoulders is uncomfortable and is assigned the value of 1. The position of one arm at, or above, the line of shoulders is assigned the value of 1/2.

4. It has been assumed that bending forward the trunk by up to 20° (5), to the sides up to 10°, and backward by up

to 5° constitutes the boundaries of free posture for the standing worker (Fig. 2). This results from the analysis of trunk inclination angles possible in the erect posture, since such deflection from the vertical does not produce a shift of the mass centre outside the limit determined by the outline of the feet (stable equilibrium without significant deflection of legs from the vertical). Trunk twisting by up to 5° has also been assumed to be comfortable . The value has been selected arbitrarily on the basis of the subjective feeling during twisting.

Adopting the number of force moments occurring as the basic indicator has enabled us to classify the individual postures into five comfort categories.

The classification of postures is presented in Table 1. Category I includes postures which have been assigned the values of 0 – 1.5, category II – the values of 1.0 – 1.5, category III – the values of 2.0 – 2.5, category IV – the values of 3.0 – 3.4, category V – the values of 3.5 and above.

Evaluation of a work place

The determination of the discomfort of a single posture is not sufficient to evaluate the workplace because usually various postures which often differ in their comfort category and duration, are assumed during work. To assess a workplace it is therefore necessary to determine which differences make up the distinction between the individual categories, i.e. to determine the function reflecting the change in load associated with shifting from one category to another (change in the number of moments of force present).

To that purpose, the range of angles occurring during the work has been analysed. From the analysis of work methods used to perform a job below the natural reach of the arms in the textile industry, it has been found that manual operations performed below the knees are carried out with legs bent in the knees. As a result of the study, the so-called range of "technologically justified" trunk inclination angles has been determined. It has been assumed to be 0 – 60° for women and 0 – 65° for men.

Force moments have been calculated, which occur during:

- trunk bending
- knee bending
- ankle bending.

The shares of individual parts of the human body in overall weight (3) have been assumed according to Table 3.

The determinations of force moments have been carried out assuming a rigid system with no external loads (such as those which could result from supporting or handling objects). Thus, some simplifications had been involved but it should be noted, however, that the loads appearing in a rigid system are maximal loads (actually, the force arm moment is shorter). It is also clear that, independent of the magnitude of the appearing force moments, the increase in their number results in an increased load.

To enable comparing the categories, simulated calculations of the loads which increase as a result of the increasing number of force moments occurring at a specified posture, have been performed. Only those loads resulting from force moments have been used in the calculations, for which the estimation seems to be proved. The moments resulting from raising the arms (the calculated moments do

Table 3. Default value for segments as proportions of body weight

Segment	Weight share
Trunk, Neck, Head	0.514
Thigh	0.200
Pelvis	0.064
Shank and Foot	0.122
Upper Arm	0.056
Lower Arm and Hand	0.044

not reflect the actual discomfort) and from the trunk twisting (load calculation is not possible because of the difficulties in determining the total force applied to produce and maintain trunk twisting and difficulties in determining the properties of material of the human body) have been, therefore, excluded from the calculations.

The number of posture variants is practically unlimited: 4 calculation variants have been tried, which may represent a wide spectrum of postures in which 1, 2, or 3 force moments occur in hips, knees and ankles.

Two basic variants represent the prevailing combination of working postures:

variant 1 — assuming trunk inclination within the average "technologically" reasonable movement range of the trunk (45°) and a corresponding bending of the knees (60°) to ensure reaching to 30 cm above the floor level,

variant 2 — averages resulting from the maximum and minimum loads within assumed movement ranges (20–70° trunk, 20–90° knee).

The values obtained in these two variants have been represented in a graph to show the growth of the load resulting from an increase in the number of occurring moments. For both variants a function has been matched: $y = x^{1+x/10}$ (Fig. 3).

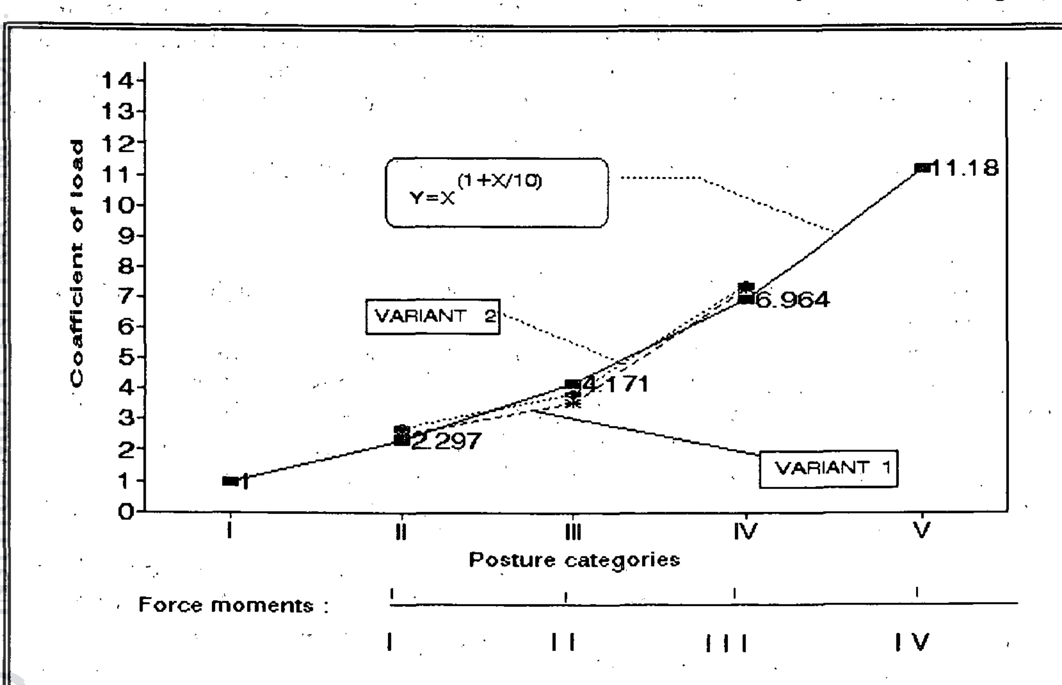


Fig. 3. Load increase vs. quantity of force moments acting in working posture.

The suitability of the obtained function for the assessment of discomfort resulting from a posture category has been additionally verified in two variants with mixed loads.

Verification calculations have demonstrated that the adopted function very well reflects the load relationship between the categories. The function remains in good agreement with the study performed in 1988 on the evaluation of the discomfort of individual posture categories according to the time elapsed until the first subjective sensations of fatigue appear (6).

From the adopted function it results that:

category II (1 moment) is related to the value of 2.297
category III (2 moments) is related to the value of 4.171
category IV (3 moments) is related to the value of 6.964
category V (4 moments) is related to the value of 11.180

The values obtained in this way have made it possible to determine the time equivalents of maintaining individual posture categories.

The time equivalents of work related to one hour of work at posture category I, based on this function are as in Table 4.

Table 4. Time equivalents of work in categories related to 1 hour of work at posture category I

posture category	I	II	III	IV	V
time equivalent, in minutes	60	26	15	8.5	5.5

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