EUROPEAN COAL AND STEEL COMMUNITY

Community Ergonomic Research

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Technical Report n° 13

DEVELOPMENT AND APPLICATION OF A COMPUTER PROGRAM FOR THE EVALUATION OF PHOTOGRAPHS OF BODILY POSITIONS IN UNDERGROUND WORKINGS

Source : Prof. W. ROHMERT, Advisor of the Community Ergonomic Research

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1. Introduction

The purpose of this report is to make available for further processing the diverse information which we can gain from the knowledge of working postures and bodily positions. For this it is necessary to work out a simple and practicable process for recording and processing data. While the previous procedure of filming or verbal job description entails a heavy outlay in time and money, it does not yield the degree of accuracy and reproducibility desired.

The further requirement of universal applicability makes it also necessary that it should be possible to describe bodily positions and postures over the widest range of degrees of accuracy while at the same time remaining realistic. For example, the description of a high-precision assembly workplace would attach importance to different dimensions than that of a workplace in a mine.

During a series of studies carried out by the Institut für Arbeitswissenschaft (industrial science) of the Darmstadt Polytechnic photographic records were obtained in a number of underground coal workings which so far it has not been possible to evaluate statistically. It is thus possible to test out the procedure to be developed against an original example.

This study is accordingly broken down into three main sections :

1) First the characteristics and definitions of human positions and postures are investigated and described in the light of studies of the literature (Chap. 2).

2) The positions and postures defined are grouped on the basis of a uniform coding for a classification, at the same taking into account a qualitative or quantitative description (Chap. 3).

3) Taking as an example the collection of photographs in coalmining, statistical processing is carried out with the aid of a computer program (Chap. 4).

It is not the purpose of this report to provide a far-reaching work on industrial science or a physiological interpretation of the characteristics found. For this the reader is referred to the appropriate literature and particularly to the study carried out by TEMMING (1969) in which bodily stress was assessed from the same study material for a number of workplaces.

Those studies were first made possible by the financial support of the Directorate-General for Social Affairs of the Commission of the European Communities, to which due thanks must be expressed.

2. Description of positions of the human body

2.1 General positions

Although the terms "bodily position" and "bodily posture" are used interchangeably in the literature, in this study the terms will be assigned the following meaning :

- the term bodily position will be reserved for the basic positions of standing, lying and sitting;

- possible variants of bodily positions will be covered by the term posture.

The external appearance of human life consists of a chain of postures and movements. There is a constant change in human movement. When a statistical approach geared to time is adopted, the postures adopted can be described as variations of the basic positions of standing, lying and sitting.

The starting point for a classification of human movements could be a classification by the type of organs carrying out the movements. A distinction could be made for example between arm, head, eye, hand and leg movements. Since, however, no organ performing a movement has an independent function - walking, for example, cannot be regarded as an isolated movement of the legs - very little significance can be attached to isolated observation of the movements of such organs. According to

BUYTENDIJK (1956) human movement has a threefold aspect, i.e. the way it is carried out, its cause and its significance.

The objectively perceptible method of expression can be described and is distinguishable by quantitatively varying peculiarities and the qualitative form of the pattern of movement.

The pattern of movement is greatly dependent on the individual and can under certain circumstances be regarded as the way the individual expresses himself. Observation from a typological point of view is therefore perfectly reasonable.

The way a movement is carried out is also linked with the attitude of the person to this movement. An inquiry into the cause of the movement throws light on the way it is carried out.

The significance of the movement presupposes knowledge of the circumstances in which it is carried out.

According to BUYTENDIJK (1956, p. 60) four classifications, setting out from the three points of view, are possible; of these two relate to the way the movement is carried out, one to the cause of the movement, and the other to its purpose. These classifications are as follows :

1) The intra-empirical classification by the directly perceptible manner of performance, its empirically given course and its pattern.

2) The typological classification in view of the relation between pattern of the movement and the person carrying it out.

3) The trans-empirical classification by the degree of freedom and necessity, i.e. related to the relationship to the subject, the "self".

4) The functional classification by the purpose of the movement.

A classification of bodily positions will be based on the intra-empirical classification by movement pattern. The starting or end point of movements are the standing, lying and sitting positions. For example the standing position is the result of an action - standing or stopping - or the point of departure as the first phase of a new activity. These initial positions which, depending on their significance, can also be regarded as the starting point or end point of a movement as a rest position, can be attributed to three different bodily positions :

1) standing,
2) sitting,
3) lying.

Kneeling and squatting are also described as rest positions in the literature (BARDELEBEN, 1918). As in the European context these last two positions are to be regarded rather as transitional or intermediate positions, an attempt will be made to include them in the term "special forms of standing".

2.2 Standing position

2.2.1 General

In general, standing is regarded as the typically human posture. It lends itself to maximum scope for activity of the hands coupled with maximum freedom of movement of the head and the widest possible field of vision.

This position has the following peculiarities (DONSKOI, 1961, p. 188) :

1) The general centre of gravity of the body - c.g. - lies directly above a supporting surface.

2) Stability depends on the relation of the c.g. to the supporting surface.

3) The supporting surface consists of the surface area of the support and the area lying between the supports, i.e. the supporting surface depends on the posture of the legs adopted in standing.

4) Standing erect necessitates muscular work.

From the mechanical point of view, standing can be defined as follows (BUYTENDIJK, 1956) :

"The standing position is a labile state of equilibrium of a long narrow object made up of parts connected by highly mobile joints and resting on a small supporting surface."

For a better understanding of the factors involved the following concepts should be explained in greater detail :

1) Neutral standing position;
2) Body's c.g.;
3) Supporting surface;
4) Stability;
5) Relation between c.g. and muscular stress represented as a function of pelvic tilt;
6) Degree of freedom of extremities;
7) Range of motion of individual parts of the body.

A choice of three basic positions exists for the "neutral position", which is needed as reference quantity for the posture of individual parts of the body. These basic positions are discussed in detail in the literature (BRAUNE-FISCHER, 1890; FICK, 1911; BARDELEBEN, 1918; BUYTENDIJK, 1956; THÖRNER, 1959) : the normal, the military and the relaxed standing position.

2.2.2 The "normal position"

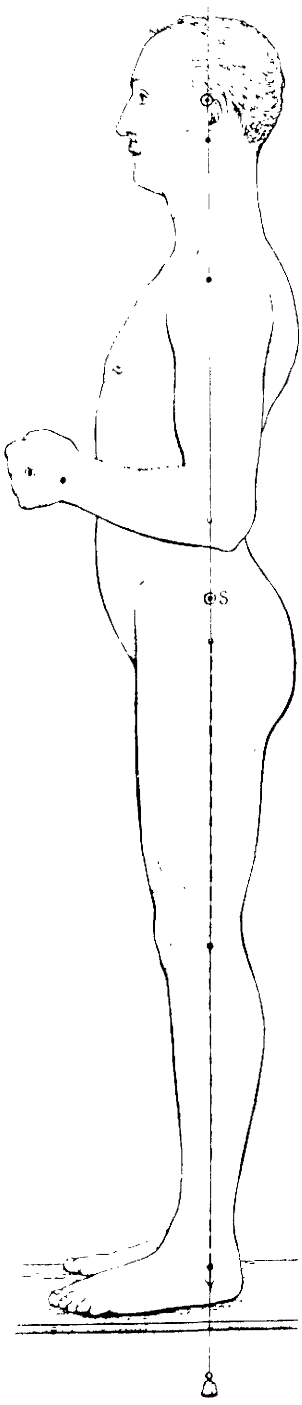


Fig. 1 - "Normal position" according to FICK (1911)

According to BRAUNE and FISCHER the normal basic standing position exists when the common c.g. of head, trunk and arms lies vertically above the common axis of the hip-joints. The common c.g. of the mass of the body lying above the knee lies vertically above the axis through both knee-joints, and the c.g. of the entire body cuts with its projection the axis of the ankle-joints. The description "normal standing" is to be attributed to the state of equilibrium which, resulting from the position of the c.g. is obtained in theory without any tension of muscles and ligaments. Any deviation has naturally to be compensated by the action of muscles and ligaments.

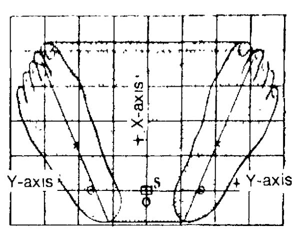
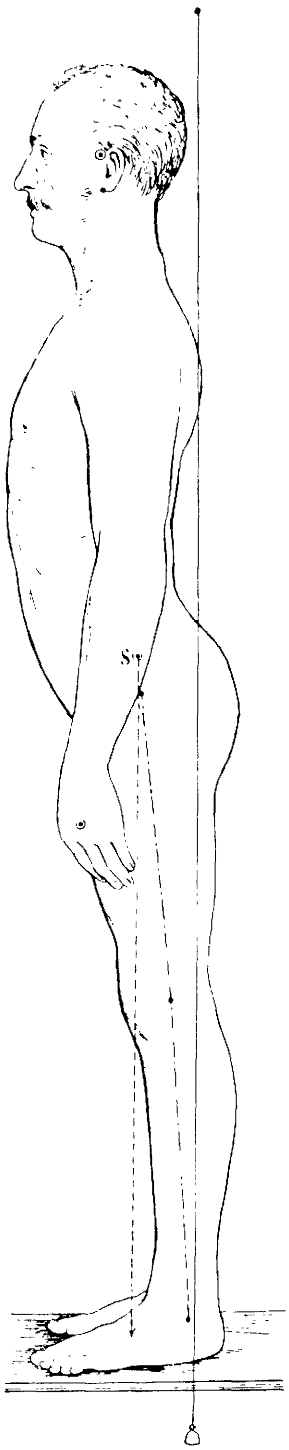


Fig. 2 - Supporting surface in the "normal position" according to FICK (1911)

2.2.3 The "military position"



The military position differs from the normal position in that the c.g. of the body is shifted forward. The chest is thrust upward and forward, the belly drawn in and the pelvis tilted forwards, i.e. lordosis of the lumbar region is accentuated.

In this position the c.g. of head, trunk and arms lies in front of the common axis of the hip-joints. This displacement leads to tensing of the extensors and of the hip and calf muscles.

Characteristic of the military position is the tensed posture which makes it possible, by releasing the tension, to react immediately with a forward movement. This can be described as an unnatural although highly "active" bodily position.

Fig. 3 - "Military position" according to FICK (1911)

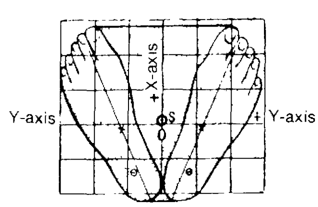
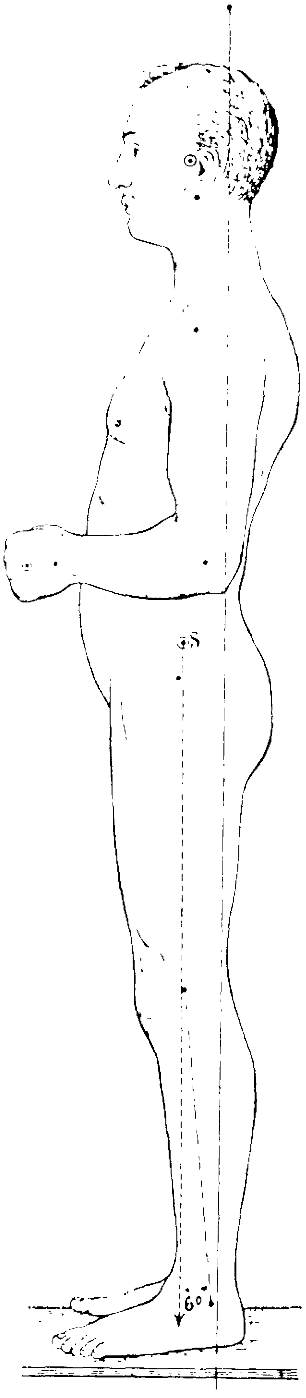


Fig. 4 - Supporting surface in the military position according to FICK (1911)

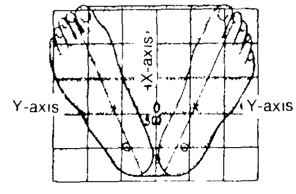
2.2.4 The "relaxed position"



In the comfortable or relaxed standing position the body's c.g. shifts, in relation to the normal position, backward. To prevent the body from tipping over backward, the gluteal muscles are relaxed and the ileo-femoral ligament tensed. It can be seen from Fig. 5 that the chest is drawn in, the belly pushed forward slightly and the tilt of the pelvis reduced. As the projection of the body's c.g. cuts the supporting surface in front of the ankle-joint axis, the calf muscles are tensed. The reason for the description "relaxed or comfortable standing" is that this posture is adopted particularly with the onset of fatigue. Minimum demands are made upon the extensors of the back and of the hip-joint.

Fig. 5 - "Comfortable posture" according to FICK (1911)

Fig. 6 - Supporting surface in "comfortable posture" according to FICK (1911)



2.2.5 The body's centre of gravity (c.g.)

The common c.g. of a number of interconnected moveable parts can be arrived at by adding the centres of gravity of the individual parts. The position of the c.g. of the human body depends on the posture adopted and can be determined by the following methods (DONSKOI, 1961, p. 170 ff) :

a) graphical (addition of forces)
b) analytical (addition of moments of force)
c) by weighing men or models.

In the graphic method parallel forces (forces of gravity of the various parts) are added. A prerequisite for this method is knowledge of the absolute and relative weight conditions as well as of the c.g. of each part. From the "radii of the centres of gravity" - distance of the c.g. from the proximal point of attachment, calculated on the overall length of the body part - it is possible to work out the coefficients, which according to FISCHER are 0.47 for the upper arm, 0.42 for the forearm, 0.44 for the thigh and 0.42 for the shank. The c.g. of the trunk when the backbone is held erect lies on the straight line connecting the middle of the shoulder and hip axes, i.e. at 0.44 of the length of this line calculated from the shoulder-axis.

The c.g. of the head lies in the middle of the line connecting the upper edges of the external ears. The weight ratios of the various bodily parts can, according to VON MEYER (1863), be given in a simplified form by the following ratios :

Table 1

Trunk the head	13 : 2
Trunk and head to both arms	9 : 2
Trunk, head and arms to both legs	2 : 1
Upper trunk to lower trunk	10 : 3
Upper arm to forearm and hand	6 : 5
Upper arm to forearm to hand	4 : 2 : 1
Hip to shank and foot	2 : 1

Relative weight ratios of parts of the body according to VON MEYER (1863)

The connection of individual centres of gravity through a straight line determines, with inverse proportional division of this line to the relative weight ratios, the position of the aggregate centre of gravity.

The application of the graphic method for determining the body's c.g. can be explained in the light of an example by VON MEYER (1863) in which the special positions assumed in standing are reflected. A similar application to photographs is possible.

Comments on Fig. 7 :

a) k = c.g. of head

r = c.g. of trunk

a = c.g. of arms

(VON MEYER has not drawn in the arms for the sake of simplicity)

rk = common c.g. of trunk and head

rka = common c.g. of trunk, head and arms

h = elbow-joint

u = elbow-joint

t = c.g. of shank

b = c.g. of legs

f = c.g. of thigh

G = c.g. of entire body

v = point of intersection of the centroidal axis of body's c.g. with floor

b) Comments on Fig. 7 :

A) Figure standing erect with marked forward bending of the backbone. The arms are to be thought of as pressed against the trunk.

B) Sitting figure with the maximum flexion of the hip-joint and knee-joint to be achieved by muscular action. The arms are to be thought of as crossed under the knees.

C) Sitting figure with maximum flexion of hip and knee joints achievable through external force; the bending force is provided by the arms which are clasped round the shanks, the elbow-joints lying at u.

D) Maximum bending of the trunk against legs stiff at the knees. The arms are allowed to hand downwards vertically so that their c.g. lies at a.

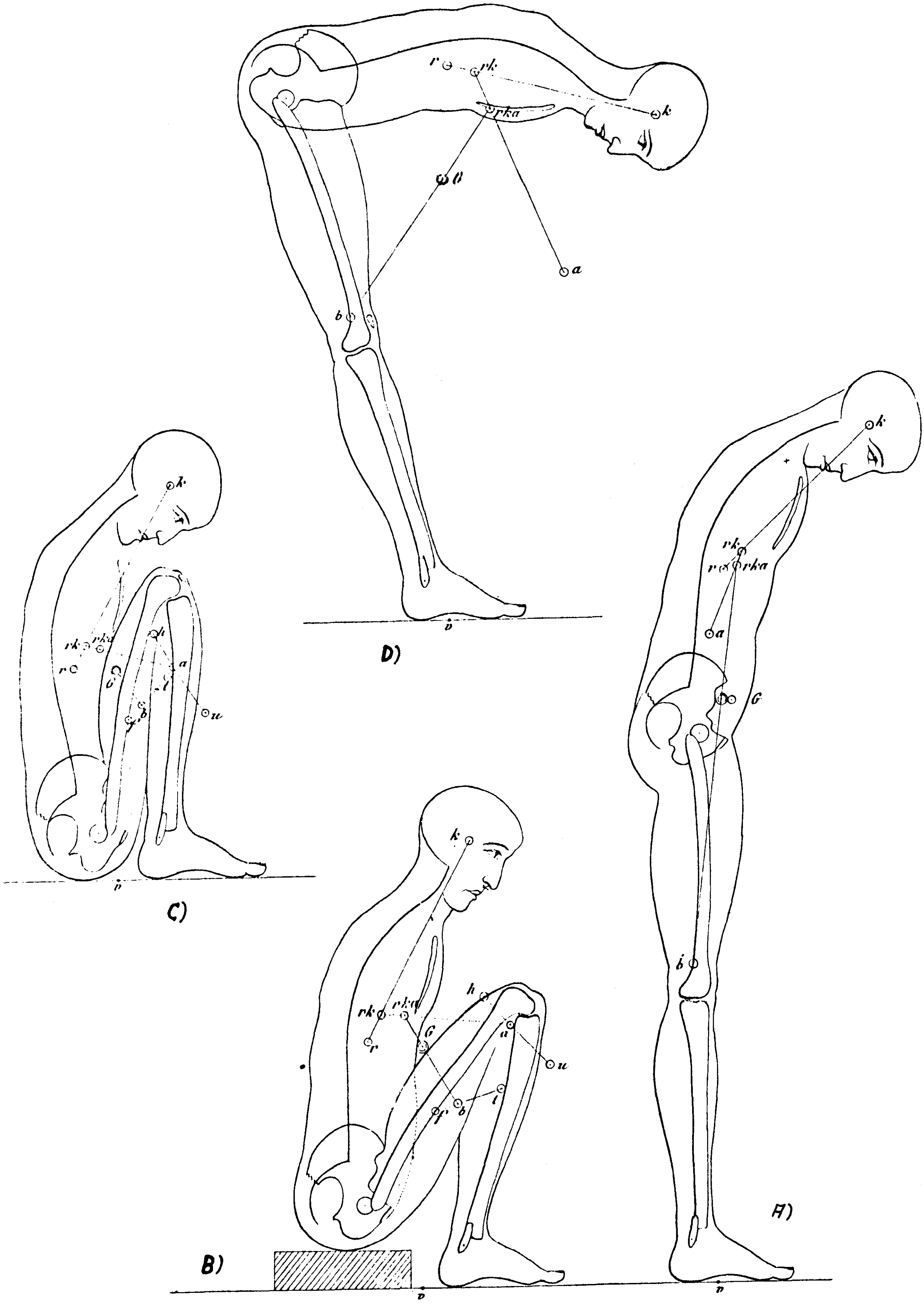


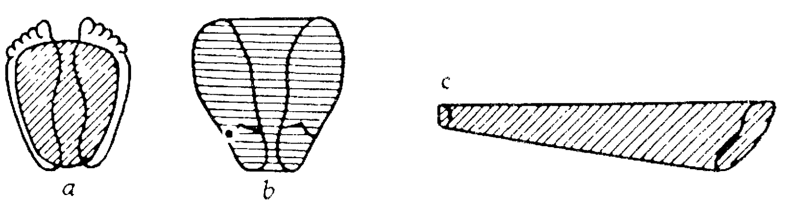
Fig. 7 - Graphic method for determining body's c.g., taken from VON MEYER (1863)

In the analytical method, before the body's c.g. can be calculated the coordinates of the various centres of gravity must be determined. The coordinate axes can be arbitrarily chosen. As the moment of the sum of all forces, calculated on the axis chosen, corresponds to the sum of the moments of all individual forces, it is fairly simple to calculate the body's c.g. A proposal for the most favourable sequence for the calculation is contained in DONSKOI (1961).

The method of determining the position of the centre of gravity by weighing men or a model will not be gone into further. A brief description was provided by DONSKOI (1961).

2.2.6 The supporting surface

In the standing position the supporting surface consists of the surface area of the supports (sole or shoes) and the area lying between the supports. The form and size of the supporting surface depend on the posture taken up by the legs.



a) standing barefoot

b) standing in ski-boots

c) "scissor stand" - position during weight-lifting

Fig. 8 - Leg posture and supporting surface according to DONSKOI (1961)

For simplicity's sake the shape of the supporting surface can be regarded as a quadrangle of variable form and area.

2.2.7 Stability

In standing, the body's c.g. lies above the supporting surface so that a labile equilibrium exists.

Stability depends on the projection of the c.g. and the adjacent limit of the supporting surface, i.e. if the distance between the projection of the c.g. and the limit of the supporting surface in one direction is smaller than in another, the centroidal axis can be displaced more easily beyond the supporting surface.

A statement can be made about the stability of the bodily posture in the various directions by making use of the "stability angle" - the angle between the projection of the c.g. and of the line connecting the c.g. to a point on the boundary of the supporting surface (corresponding to the tilting angle in mechanics).

Fig. 9 - Stability angle as a function of leg posture according to DONSKOI (1961)

In dealing with stability in standing the human body was treated as the rigid body of mechanics. This of course is not really the case : for example, the human body can never be absolutely still; moreover the position of its c.g., unlike that of rigid bodies, can be shifted by compensatory movements. The significance of the stability angle should not therefore be overrated. Nevertheless the relative stability in relation to the various directions can be very satisfactorily described by means of it.

2.2.8 Connection between position of the c.g. and muscular stress

In the erect standing position the body's c.g. lies above the transversal axis of the hip-joints. If the position of the c.g. is displaced by a change in posture, it displays torque in relation to the hip-joint axis and this must be compensated by a counteracting force. If the pelvis is regarded as an angle lever (SCHOBERTH, 1962, p. 28 ff.) the position and point of application of the muscular forces opposing the torque can be represented diagrammatically.

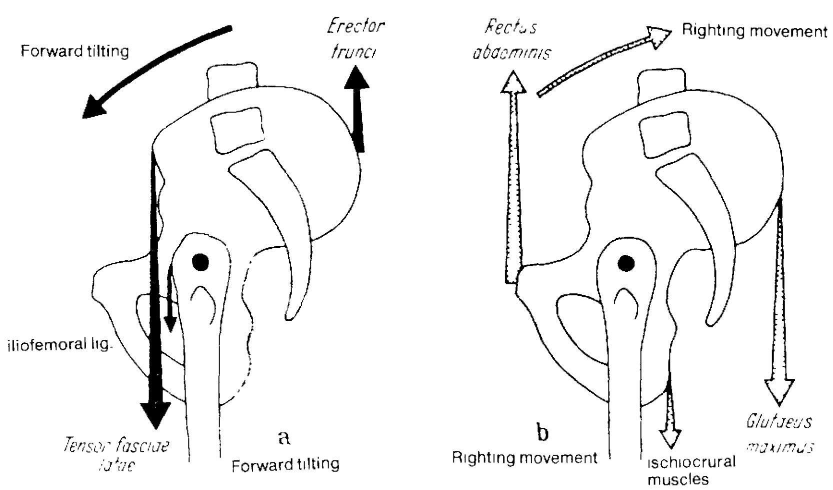


Fig. 10 - Diagram of pelvic tilting and the forces causing it, according to SCHOBERTH (1962)

The righting movement is prevented on the ventral side by the tensor fasciae latae. Further torques opposing it are produced by the dorsal muscles acting on the upper iliac crest and the broad strands of the iliofemoral ligament.

The pelvis is hindered from tilting forwards by the straight abdominal muscles and the glutaeus maximus. The ischiocrural flexors of the knee-joint support the torque to be applied.

From the example of pelvic tilting it can be seen that the minimum muscular work occurs when the centroidal axis lies directly above the appropriate joint-axis, i.e. when no torque occurs.

2.2.9 Range of motion of the extremities

The upper and lower extremities of the human body can be compared with kinematic chains. This approach yields a classification of the possible types of joints according to the range of motion and enables the number of degrees of freedom of the kinematic apparatus to be determined in terms of formulas (DONSKOI, 1961, p. 83). The kinematic chain is a movable system of individual members connected via joints. Depending on whether these members are endlessly connected or not, one speaks of a closed or open kinematic chain. In humans the upper extremities represent an open, the lower extremities a closed kinematic chain when, in the standing position, the legs are connected by the floor or some other supporting surface.

Open and closed chains are distinguishable by the number of degrees of freedom. For example, a closed kinematic chain first becomes mobile when more than three members are connected via joints. In open chains the degree of freedom of a chain member is made up of the total degrees of freedom of all preceding members.

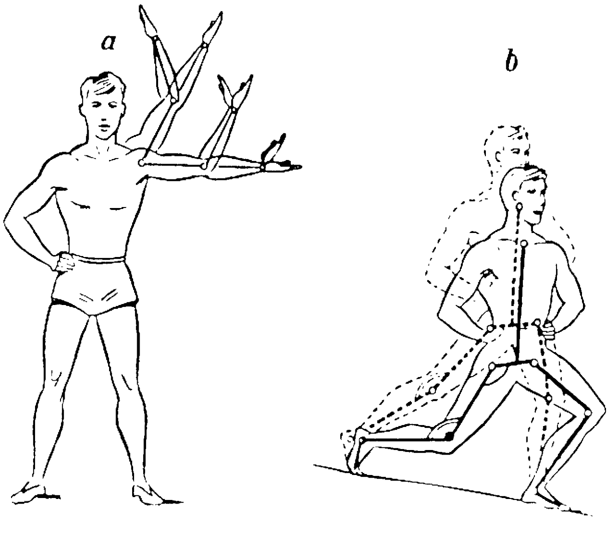


Fig. 11 - Kinematic chains, a) open, b) closed, according to DONSKOI (1961)

Thus the hand, as compared to the trunk which is assumed to be immobile, has 13 degrees of freedom although it is only able to exploit 6. If we regard the upper and lower extremities as kinematic chains, the wide range of motion of members can be inferred from the number of degrees of freedom. Moreover this approach brings out clearly the dynamic and static action of the muscles which move the member connected by joints ("muscles as driving force") or block the joint ("muscles as joint blockers") (HOCHMUTH, 1969, p. 87 ff.).

In specifying the extent of movement of the joint the following factors must be taken into account :

1) Movement in degrees from the neutral position
2) Definition of the neutral position
3) Specification of the extent of movement of the other members of the extremity or of the extent of movement in relation to the neutral position
4) Definition of the bodily posture in which the measurement was carried out.

2.2.10 Description of postures in the standing position

The different postures assumed during standing as a result of the position in space of the different members can be described and determined if the given position of the bodily parts is resolved into distance components in three planes about three basic axes lying perpendicular to each other.

Thus, movements about the vertical axis occur in the horizontal plane. Examples are the rotation of the head, twisting of the vertebral column, supination (turning outwards) and pronation (turning inwards) of the forearm hanging down in the standing position. For movement analysis the transverse axis (frontal axis) and te axis running from front to back (sagittal axis) must be selected from all horizontally lying axes.

Movements about the transverse axis - e.g. the flexion and extension of the vertebral column, the head and the extremities - take place in the sagittal plane, movements about the axis running from front to back - for example, abduction and adduction of the extremities and lateral bending of the trunk - take place in the frontal plane.

Of the large number of possible vertical planes, the frontal and sagittal, which are perpendicular to each other, are chosen as the basic planes.

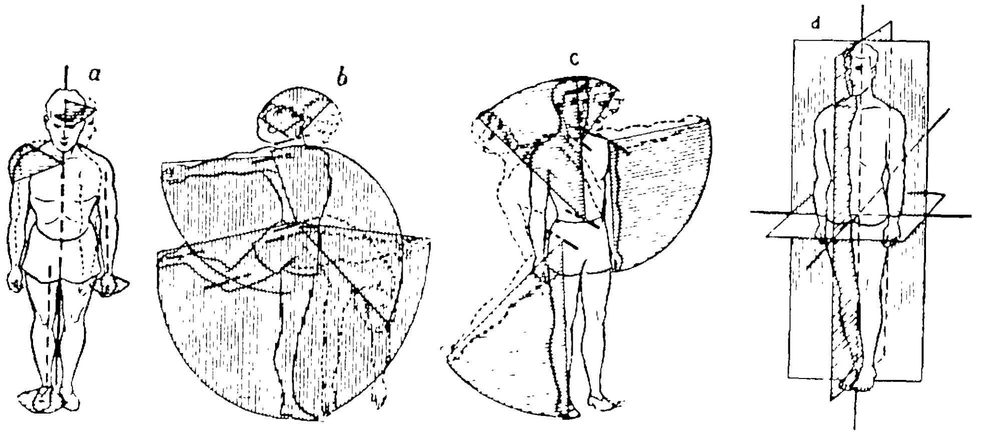
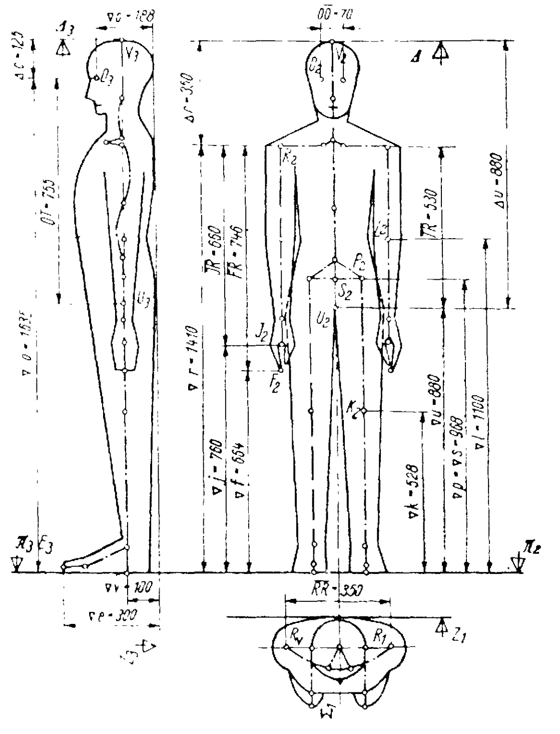


Fig. 12 - Movements about the basic axes according to DONSKOI (1961)

The postures of the human body can also be determined by means of somatography. According to JENIK (1963), somatography is a field of study concerned with the construction of pictures of the human body in various positions making use of all norms and procedures of technical drawing and the rules of descriptive projection in all three views. Somatography is based above all on human anatomy and anthropometry, on the basis of which it makes use of a system of position-describing elements as well as a system of basic skeletal, profile and functional measurements grouped into a "canon".



For the description of postures, somatography makes use of a system of position-describing elements and a system of basic skeletal, profile and functional measurements which are contained in the list of position-describing elements and serve as a basis for graphic representation. (Cf. Figs. 13, 14, 15 and Table 2).

Fig. 13 - Functional measurements for the initial position according to JENIK (1963)

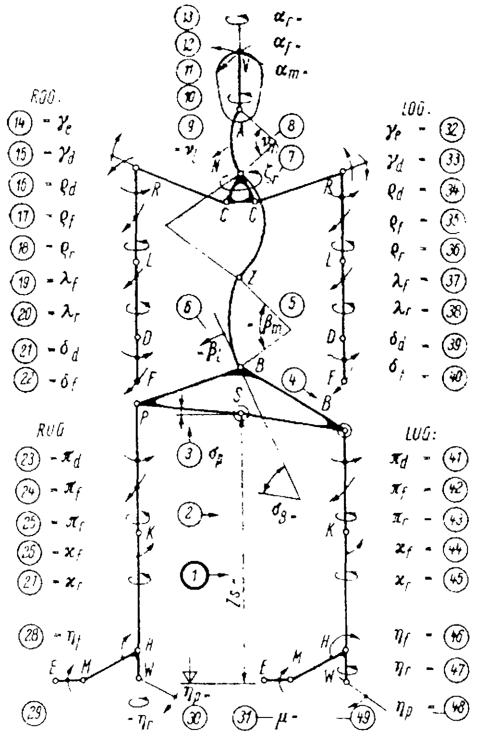


Fig. 14 - Diagram of position-describing elements of the skeletal system according to JENIK (1963)

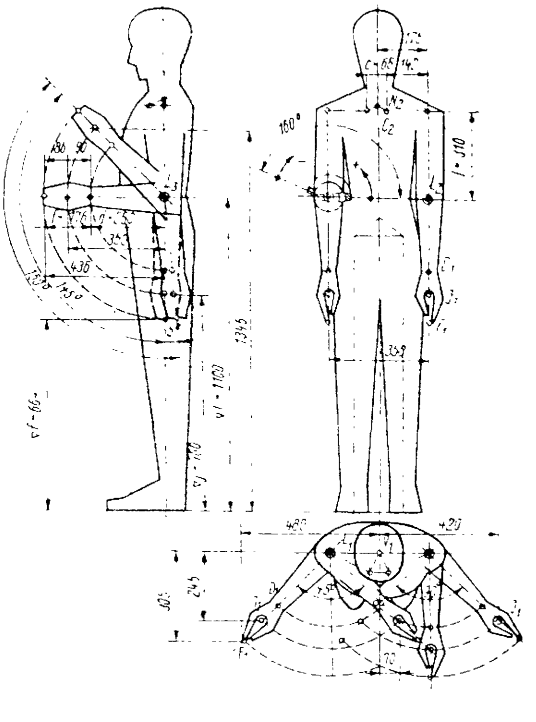


Fig. 15 - Mobility of the elbow-joint, an example of the representation of the mobility of a joint by the somatographic method according to JENIK (1963)

Table 2

description of position						symbol	head, neck and trunk (K, H, R)							
R:							height of middle of body	Z_s		968		0°	—	1
							inclination of body axis	σ_B		65°	90°	0°	90°	2
K + H:							inclination of pelvis	σ_P		0°	90°	0°	90°	3
							right-left orientation	P		+	+	—	±	4
ROG:							med. of lumbar portion of spine	β_m		50°	50°	—25°	75°	5
							Lat of lumbar portion of spine	β_e		0°		0°		6
RUG:							rotation of trunk	ξ_r		0°	60°	60°	120°	7
							med. of cervical portion of spine	V_m		50°	100°	0°	100°	8
LOG:							later of cervical portion of spine	V_f		0°		0°		9
							rotation of neck	V_r		0°	+ 45°	—45°	90°	10
LUG:							nodding of head	α_m		0°	+ 30°	—30°	60°	11
							lat. tilt of head	α_f		0°	+ 15°	—15°	30°	12
No.	Σ	Min.	Max.	Norm.	given	symbol	rotation of head	α_r		0°	+ 15°	—15°	30°	13

left (LOG)							upper members	(ROG) right						
32	55°	— 5°	+ 50°	0°		γ_e	raising of clavicle	γ_e		0°	+ 50°	— 5°	55°	14
33	60°	—30°	+ 30°	0°		γ_d	To-and-fro movement of clavicle	γ_d		0°	+ 30°	—30°	60°	15
34	120°	—30°	+ 90°	0°		ϱ_d	spreading out and bringing down upper arm	ϱ_d		0°	+ 90°	—30°	120°	16
35	90°	20°	+ 70°	0°		ϱ_f	flexing upper arm	ϱ_f		0°	+ 70°	- 20°	90°	17
36	90°	50°	+ 10°	0°		ϱ_r	rotating upper arm	ϱ_r		0°	+ 10°	50°	90°	18
37	150°	5°	+ 145°	0°		λ_f	flexing forearm	λ_f		0°	+ 145°	5°	150°	19
38	160°	70°	+ 90°	0°		λ_r	rotating in- and outwards	λ_r		0°	+ 90°	- 70°	160°	20
39	60°	-15°	+ 45°	0°		λ_d	lat. movement of hand	δ_d		0°	+ 45°	- 15°	60°	21
40	150°	60°	+ 90°	0°		σ_f	flexing the hand	δ_f		0°	+ 90°	—60°	150°	22

Left (LUG)							lower members	(RUG) right						
41	45°	— 15°	+ 30°	0°		π_d	spreading out and bringing down thigh	π_d		0°	+ 30°	—15°	45°	23
42	135°	—15°	+ 120°	0°		π_f	flexing thigh	π_f		0°	+ 120°	—15°	135°	24
43	45°	—12,5°	+ 32,5°	0°		π_r	rotating thigh	τ_r		0°	+ 32,5°	—12,5	45°	25
44	135°	0°	+ 135°	0°		$\varkappa_f$	flexing knee	$\varkappa_f$		0°	+ 135°	0°	135°	26
45	40°	10°	+ 30°	0°		$\varkappa_r$	rotating knee	$\varkappa_r$		0°	+ 30°	10°	40°	27
46	30°	10°	+ 20	0°		η_p	rotating foot in- and outwards	η_p		0°	+ 20°	10°	30°	28
47	50°	30°	+ 20°	0°		η_f	flexing foot	η_f		0°	+ 20°	- 30°	50°	29
48	90°	45°	+ 45°	0°		η_r	rotating foot	η_r		0°	+ 45°	— 45°	90°	30
49	130°	50°	+ 80°	0°		μ	flexing point of foot	μ		0°	+ 80°	— 50°	130°	31

List of position-describing elements according to JENIK (1963). The list links up with the scheme of the position-describing elements and serves in somatography as the basis for the construction of a picture of the human form combining maximum diagrammatic form with maximum anatomical accuracy. In the upper left corner the description of the position is given in words, i.e. R = trunk, K + H = head and neck, ROG = right upper members, and so on. The lowest line of the table shows : No. = number of position-describing elements; the symbol $\sum$ = total range of angular mobility; Max = an extreme value of movement from the neutral position; Min = an extreme value in the opposite direction; Norm = value of the position-describing element in the initial position. In the blank columns under the heading "Given" the actual value of the corresponding quantity is entered. The designation of the quantities corresponds with the scheme in Fig. 14. The designation of the position-describing element is identical for members in one line, and the sequence of columns for the righthand members is the opposite to that of lefthand members. Position-describing elements for head, neck and trunk are given in the upper righthand corner of the table, in the same way as for members.

A scientifically accurate description of the position of the various parts of the body - whether with the help of movement components to the basic planes, somatography or the determination of the range of movement of members on trajectory spheres (BENNINGHOFF-GOERTTLER 1961, p. 214) whose mid-point is fixed in the appropriate joint mid-point, can be carried out in the laboratory but appears impracticable for industrial purposes.

2.3 Sitting position

2.3.1 General

The basic position can be regarded as a mid-position between standing and lying. In this study however the following limitation will be set : sitting - in the European sense - presupposes a chair or in general a seat, which can take the simplest form of a stone or wooden block. Special forms of sitting such as are met with in Asia are not covered in this study.

According to LEHMANN (1961) sitting is an attempt to combine the advantages of standing with lying while avoiding their respective disadvantages. In sitting, the body is more relaxed than in standing; stability is greater, but will depend on the form of sitting and the way it is performed.

This greater stability gives the upper extremities more security of movement combined with a narrower range of movement of the hands. As in performing external work body-weight can be used only to a lesser extent, the deployment of force when sitting is smaller (DEMPSTER 1955). The supporting surface of the body when sitting is provided by the ischial protuberances and the surrounding soft parts and is in general greater than the supporting surface when standing (SCHOBERTH, 1962).

The European style of sitting calls for a facility in the form of a chair or other seat. The body rests on a supporting surface reaching from the dorsal outline of the buttocks to the points of the toes, where the feet rest on the floor (SCHOBERTH, 1962). The surface formed by the protuberances of the buttocks and their surrounding parts serve to support the trunk, head and arms, whose common c.g. lies near the supporting surface.

The hips are at an angle; the pelvis, as compared with the standing position, is tipped back through an angle of 20 - 30° (STIER, 1956). The feet resting on the ground absorb through the knee joints part of the weight of the hips and the weight of the shanks.

2.3.2 Basic sitting positions

The historical development of sitting habits, the individual posture patterns of sitting humans and the various defined basic or rest position in sitting are described in detail in the literature. A concise summary of these results is given by SCHOBERTH (1962), to whose work reference is made.

SCHOBERTH defines three basic sitting positions : the forward, middle and rear sitting position. As a means of distinguishing between these positions he makes use of the weight on the feet, which can be measured easily by means of a weighing machine. According to SCHOBERTH the middle sitting position occurs when the c.g. of the trunk is situated above the ischial protuberances and the feet carry about 1/4 of the total body weight.

In the rear sitting position, too, the projection of the c.g. of the trunk is situated in the surface formed by the ischial protuberances and the surrounding soft parts, but in comparison with the middle sitting position is displaced towards the rear. As a result the load on the feet is reduced to less than 25 % of the total weight.

In the forward sitting position the projection of the c.g. of the trunk is displaced to the front and lies between the surface on which the feet rest and the ischial protuberances. In this position the weight on the feet is greater than 1/4 of the total weight of the body.

2.3.3 The statics of sitting

The forward, middle and rear sitting positions are easily understood as a limiting case of a mechanical consideration :

The main supporting surface in sitting is the area formed by the ischial protuberances and the surrounding soft parts. The weight S supported on this surface can be obtained by subtracting the weight F borne by the feet from the total weight G.

The varying contact pressure or contact forces of the supporting surface can be combined, from the diagram of forces, into a resultant S. The point of application of the resultant can be obtained with the momentum theorem of statics.

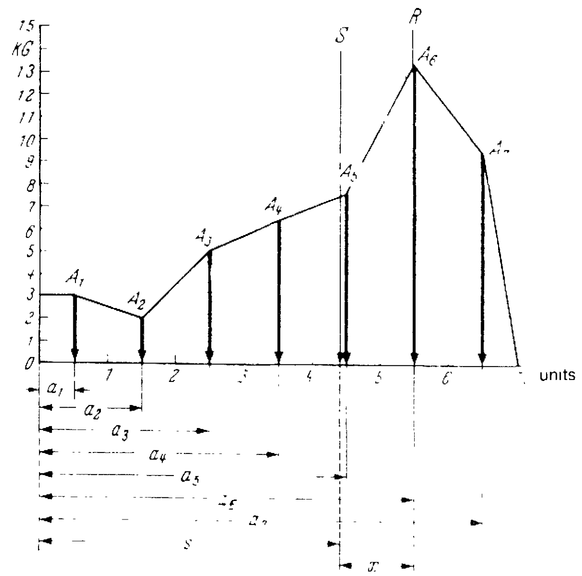


Fig. 16 - Diagram of contact forces according to SCHOBERTH (1962)

The position of the resultant S can be understood in a diagram as the "fulcrum or reference point" for drawing up of the momentum equation.

G = total weight of body
R = trunk weight, weight of head and both arms
U = shank weight
U = 1/9 G (according to H. v. Meyer)
O = hip weight
O = 2/9 G
S = resultant of contact forces of seat
F = foot pressure

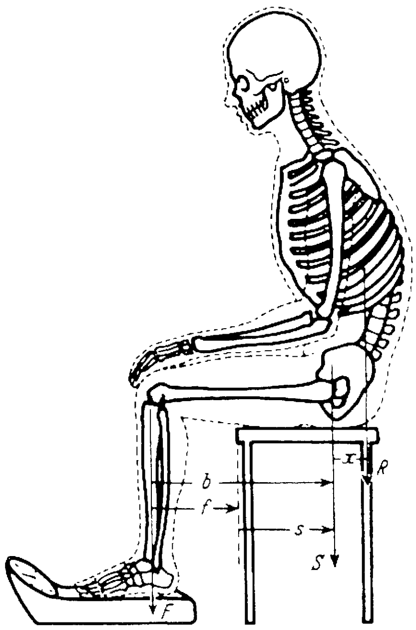


Fig. 17 - Diagram of pressure and contact forces in sitting according to SCHOBERTH (1962)

The point of application of the hip weight is situated at 4/9ths of the hip length calculated from the axis of the hip-joint (according to VON MEYER). For the sake of simplicity in this case the point of application of the resulting contact pressure S can be used in stead of the hip-joint axis as reference point, according to SCHOBERTH.

The momentum equation about S as fulcrum is as follows :

$$F \, . \, b + R \, . \, x = U \, . \, b + 0 \, . \, \frac{4}{9} b$$

with $R = \frac{2}{3} G$ (VON MEYER), $U = \frac{1}{9} G$ and $0 = \frac{2}{9} G$, we have :

$$x = b \, \frac{\frac{1}{9} G + \frac{8}{81} G}{\frac{2}{3} G} - \frac{2 \quad F}{}$$

$$x = b \, \frac{17}{54} - \frac{3}{2} \frac{F}{G}$$

Limiting case 1 : x = 0 - F = 0.21 G (F = 0.23 G, SCHOBERTH)

Limiting case 2 : F = G - x = -1.186b (x = -1.2b SCHOBERTH)

Limiting case 3 : F = 0 - x = 0.314b (x = 0.32b SCHOBERTH)

In the light of these three limiting cases the sitting positions defined by von SCHOBERTH can be explained :

Middle sitting position : the common c.g. of head, trunk and arms coincide with the point of application of the resultant of all contact forces of the sitting area. The load on the feet is about 1/4 G.

Forward sitting position : the projection of the c.g. of the trunk is displaced to the front. The extreme limiting case - the buttocks are detached from the seat and the body is raised - satisfies the condition F = G, i.e. S = 0. In this case the projection of the trunk's c.g. falls in front of the contact area of the feet.

Rear sitting position : the load on the feet is reduced by the displacement of the trunk's c.g. to the rear. The limiting case occurs when the feet have no more weight to bear. The maximum displacement of the trunk's c.g. to the rear is determined by the relation x = 0.32 b (see Fig. 17 on p. 29). It is impossible for the trunk to move back any further without active muscular work.

2.4 Lying position

2.4.1 General

The normal rest position is lying, in which all muscles can be largely relaxed. Because of this muscular relaxation and the favourable hydrostatic circulatory conditions minimum demands are made on the circulation.

Man has become accustomed to regard this position as a mere rest position. Since when the horizontal position is assumed the vegetative nervous system is switched over to thropotropy by a reflex - a circumstance linked with the subjective sensation of fatigue - lying does not provide a suitable position for intellectual work (LEHMANN, 1962).

Lying can be defined in mechanical terms as follows :

Lying is a stable position of equilibrium of a long narrow object which lies horizontally, i.e. in its entire length, on a large supporting surface (surface of the body in contact with the support). In this position, when the posture is relaxed, the joints are slightly flexed.

2.4.2 Lying as a working position

Lying is unsuited to physical work because, for example, the shoulder-blades are leaned upon and consequently the scope of the arms for movement is severely restricted. Moreover it is more difficult for the rest of the body to move in the lying position. To compensate for this disadvantage a man is forced to raise up the upper trunk, especially the shoulder and head. This static strain on the muscles is very fatiguing.

In industry, workplaces that require men to take up a lying position are hardly to be met with anymore. The few exceptions are motor mechanics underneath a car (whose situation could be eased by using a pit or a hoisting platform), jewel polishers and miners working in very low seams. Modern workplace design tries to avoid the lying position as far as possible; nevertheless owing to the remaining exceptions scientific recording and investigation of the lying position must not be ignored.

2.5 Special forms of standing : squatting and kneeling

In the European context, squatting and kneeling are to be regarded as transitional postures which can only be tolerated for a short time because of the unfavourable conditions of the muscles, joint and organs.

Squatting is locally fatiguing because of the heavy demands it makes on the leg muscles. Squatting low down can lead to circulatory disorders in the lower extremities, particularly in the hollows of the knee.

In kneeling the body weight is also carried by the shin-bone and knee-cap. Because of the lack of padding, neither of these additional contact surfaces are suited to bearing long loads. In this posture the joints of the lower extremities are exposed to strain.

The postures of kneeling and squatting are to be regarded as special positions of standing and can be brought under the same classification. The heavy muscular stress involved in maintaining these transitional positions is reflected in the fact that energy transformation exhibits higher values than during normal standing.

3. Development of a classification and a coding system suitable for electronic data processing

3.1 Classification principles

3.1.1 General and simple applicability

The classification here developed is based on the external description of the body's working positions found in practice. Moreover its sphere of applicability is not in general to be confined to one branch (for example, coalmining) but to be equally valid for all workplaces. Naturally the accuracy and easy application of the process tend to conflict with each other. If we give priority to the practicability of the process this means at the same time certain simplifications and restrictions. A scientifically highly efficient but too complicated system is just as undesirable as one that is over-empirical and unsystematic.

3.1.2 A description suited to electronic data processing

A series of studies of the physiological and technical aspects of work - one of the latest publications in this sector is that of SÄMANN (1970) - has already dealt with the significance and the varying degrees of efficiency of individual bodily positions. The still outstanding statistical work relating to the frequency of bodily positions and postures found in industrial workplaces necessitates a systematic determination which can be most readily and fully achieved by resorting to electronic data processing (EDP). To enable EDP-systems to be used in the evaluation of wide-ranging material, a verbal description must be dispensed with in favour of a classification that can be numerically coded.

For this purpose coding according to the decimal classification is particularly advantageous.

3.1.3 Variability within classes

With the large number of degrees of freedom of bodily positions and postures in the human body, an adequate number of individual data can be quantitatively determined. In doing this it cannot be said a priori with certainty what characteristic of a position is to be regarded as typical and what other characteristic can perhaps be neglected. For this reason, great importance must be attached, at least in the initial stage, to the determination of details whose significance can perhaps be proven or rejected only after searching studies. Although every effort should be made to make the descriptions accurate, the system must be flexible enough to allow of details of minor importance being ignored, without affecting its usefulness.

3.2 Classification of bodily positions and postures

3.2.1 Bodily positions selected

The basic criterion for classification is bodily positions. Corresponding to the comments made in the first chapter, three positions and two special standing positions were chosen for the classification :

1. Standing
2. Sitting
3. Lying
4. Squatting
5. Kneeling

These should be supplemented - in accordance with the definition given on page 3 - with data on the specific features of bodily positions as well as a number of further (ambient) factors such as weight loads, supports, obstacles.

3.2.2 Classification of standing

On the basis of the normal position defined, in which the main centres of gravity of all members, with the exception of the feet, lie in a single frontal plane, an attempt will be made to determine the observed position in the light of the following criteria and to pass on from a qualitative to a quantitative classification :

1. Carriage of head to carriage of head in the normal position

2. Trunk posture to trunk posture in the normal position

3. Upper extremities

   a) classification by types of movement
   b) reach of arms
   c) description of position

4a. Supporting surface

   a) type of foot position
   b) c.g. of body to the supporting surface

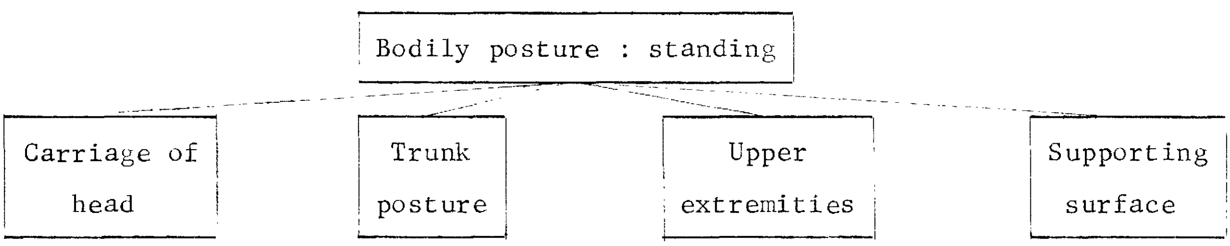
4b. Additional support

A scheme of possible deviations from the reference value will be drawn up for the individual characteristics. As far as possible deviations will be shown first qualitatively and then, for closer accuracy, also quantitatively. If the possibilities of variation cannot be classified in advance, it will still be possible to classify the measured data direct under a sub-point of the scheme.

In schematic terms, the construction of the classification for the standing position can be represented as follows :

a) Definition of the standing position.
   Checking whether the bodily posture met with or to be described meets the requirements of the definition.

b) Characterization and determination of bodily posture by assigning suitable characteristics of the individual sub-systems or of measured data to the sub-points concerned;
   Or : bodily posture can be defined by means of 4 variables. A scheme of possible deviations from the reference value is drawn up for each variable.



3.2.3 <u>Scheme for carriage of head</u>

The range of motion is characterized by the extent of the deviation - in degrees - from the normal position. According to the studies carried out by BATCH, the following angles, which can be read off the diagram, correspond to the maximum range of movement of the head relative to the neck :

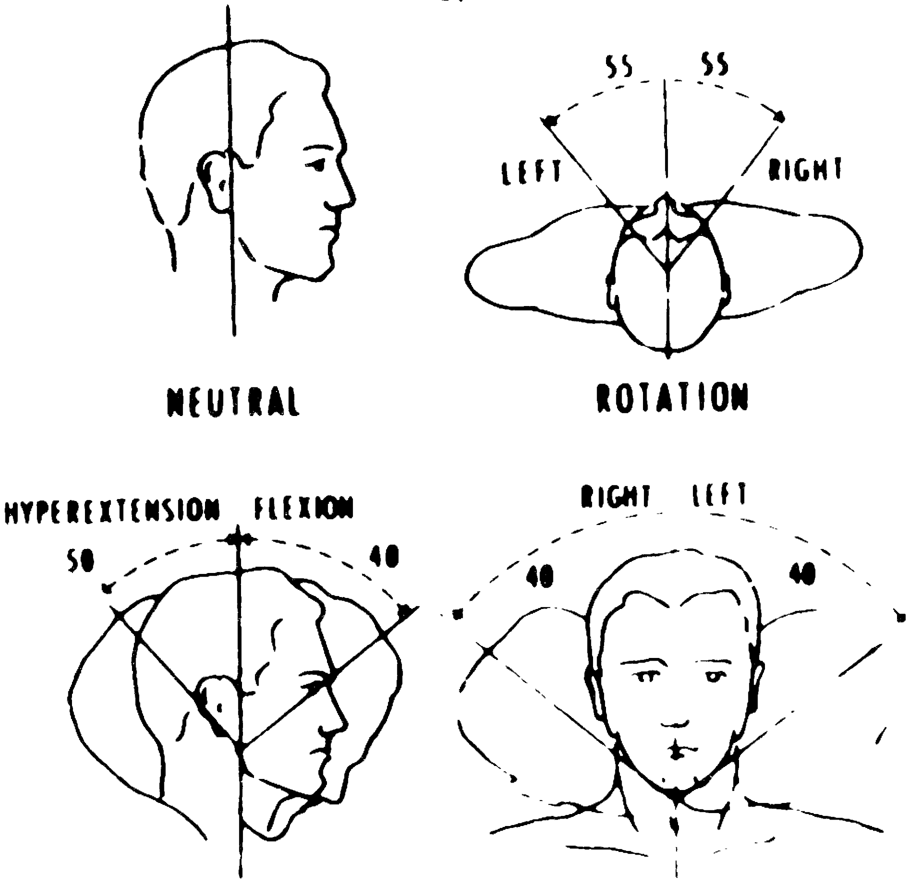


Fig. 18 - Range of motion of the head according to BATCH (1955)

By breaking down the carriage of the head into various angular areas a scheme could be drawn up under which the division into angular areas at first is arbitrary and, where necessary, can be more accurately described or completely dispensed with (Fig. 19).

3.2.4 Scheme for trunk posture

By analogy with the development of the scheme for the carriage of the head, the angles for the maximum range of motion are divided into sub-sectors and the spatial deviation from the normal position considered in the three basic planes (Fig. 21).

Scheme Carriage of head

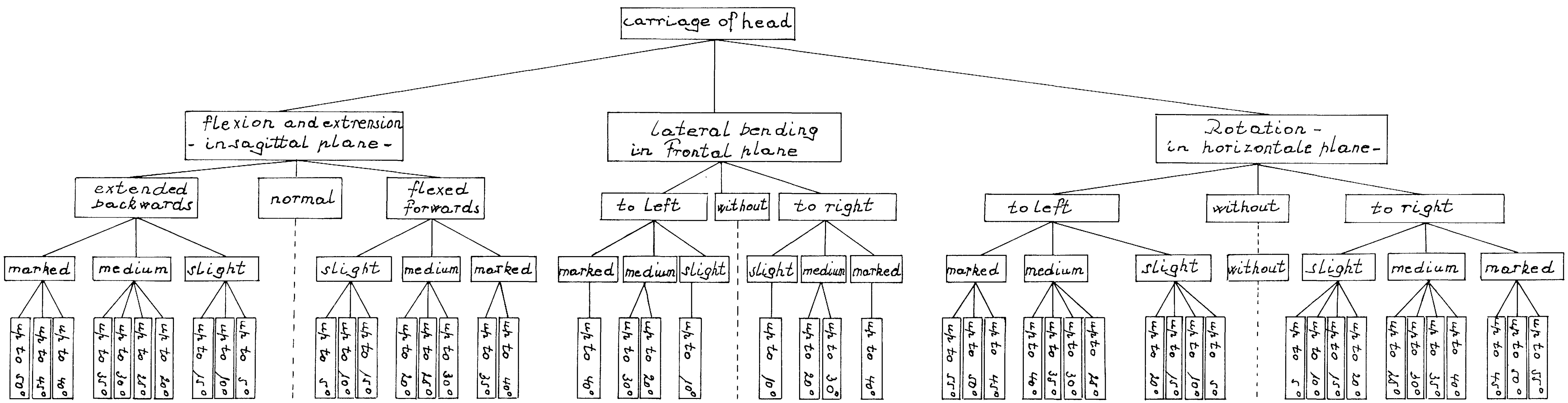


Fig. 19

Scheme: Trunk posture

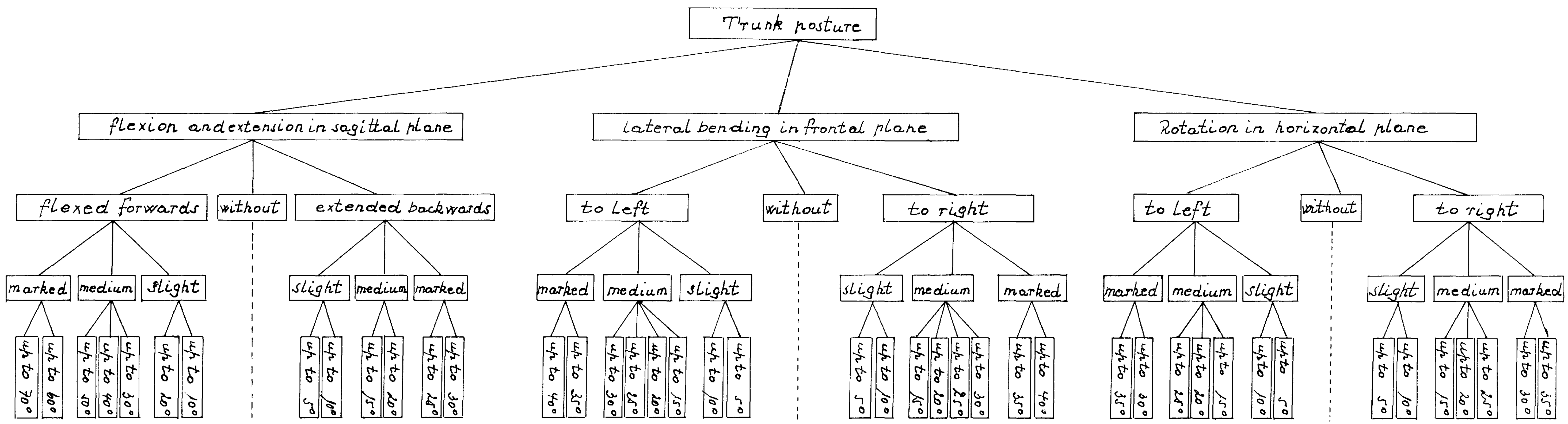


Fig. 21

For the range of motion of the trunk, the results given in Fig. 20 according to BATCH are available.

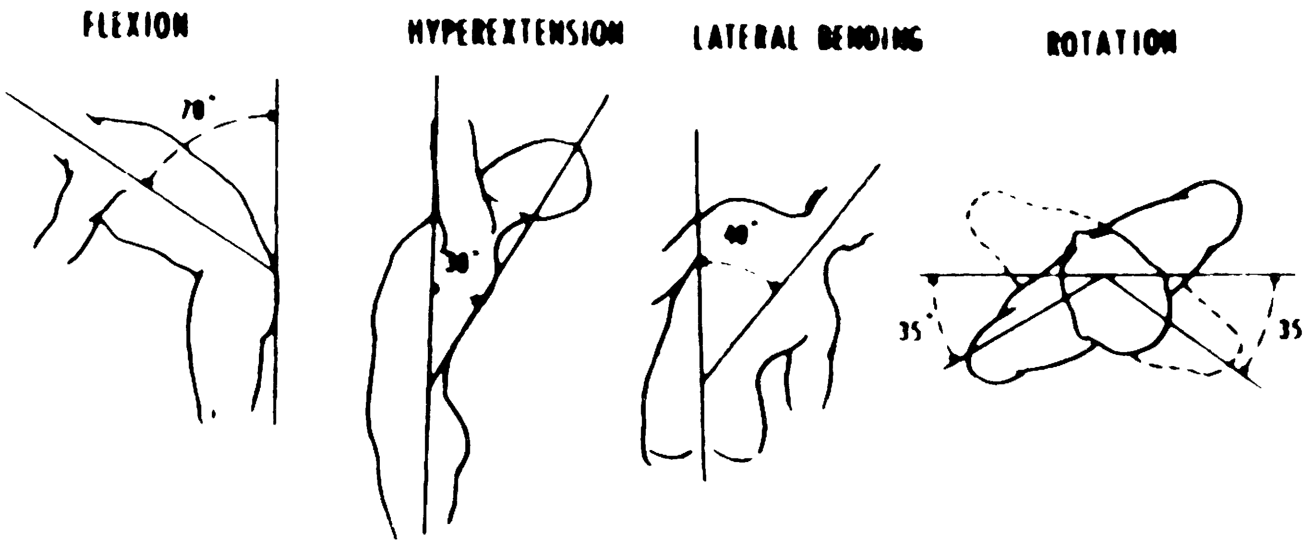


Fig. 20 - Range of motion of the trunk according to BATCH (1955)

3.2.5 Scheme for the upper extremities

For the purpose of describing the upper extremities of the posture observed two things are required : a quantitative determination of motion by type and a description of position (Fig. 26).

Motion can be broken down quantitatively, in so far as the course of motion is apparent, into the types given by STIER (1959) :

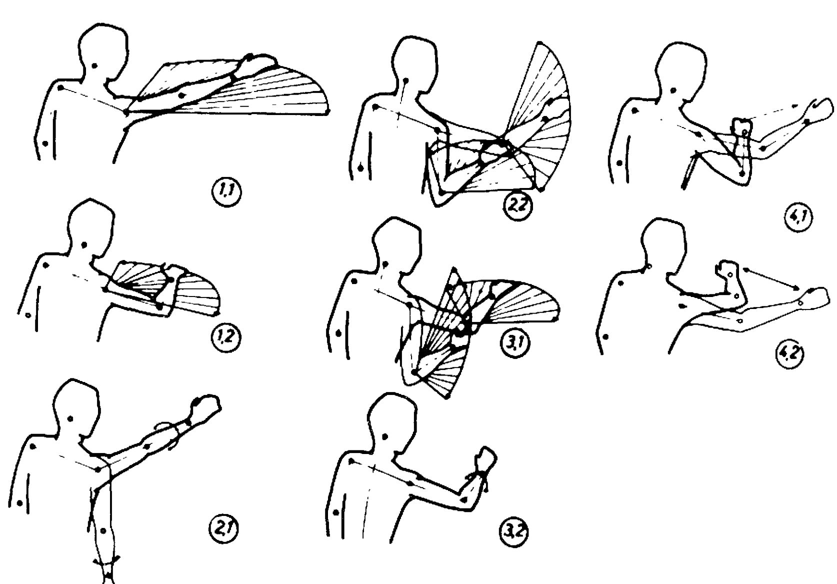


Fig. 22 - Types of motion of the arm according to STIER (1959)

1. Motions of upper arm about shoulder-joint
1.1 with extended forearm
1.2 with forearm angled at 90°

2. Rotations of upper arm about its longitudinal axis
2.1 with extended forearm
2.2 with forearm angled at 90°

3. Motions of forearm
3.1 about elbow-joint
3.2 about its longitudinal axis

4. Combined motions
4.1 heterotropic motion
4.2 homotropic motion

The quantitative determination of the position - here the hand - is carried out by means of polar coordinates, starting out from the appropriate mid-point of the shoulder-joint. Given three data, two angular coordinates and one distance coordinate, the position in space of the hand is clearly determined.

On similar lines to those followed in the studies by ROHMERT (1966), the distance coordinate is expressed as a percentage of the max. reach of the arm, in order to compensate for inter-individual differences in reach. The lateral position and the height - relative to the mid-point of the shoulder-joint - are given by angles α and β (Figs. 23 to 25, p. 43).

The angle α describes the height of the hand. The horizontal plane through the mid-point of the shoulder-joint corresponds to the angle $\alpha = 0$. The angle β is defined as positive in an upward direction and negative in a downward direction. The angle β gives the lateral position of the hand. The parallel plane through the mid-point of the shoulder-joint to the sagittal ground plane separates the positive angle (lying outwards from the reference plane) and the negative angle (lying inwards from the reference plane).

Scheme: Upper extremities

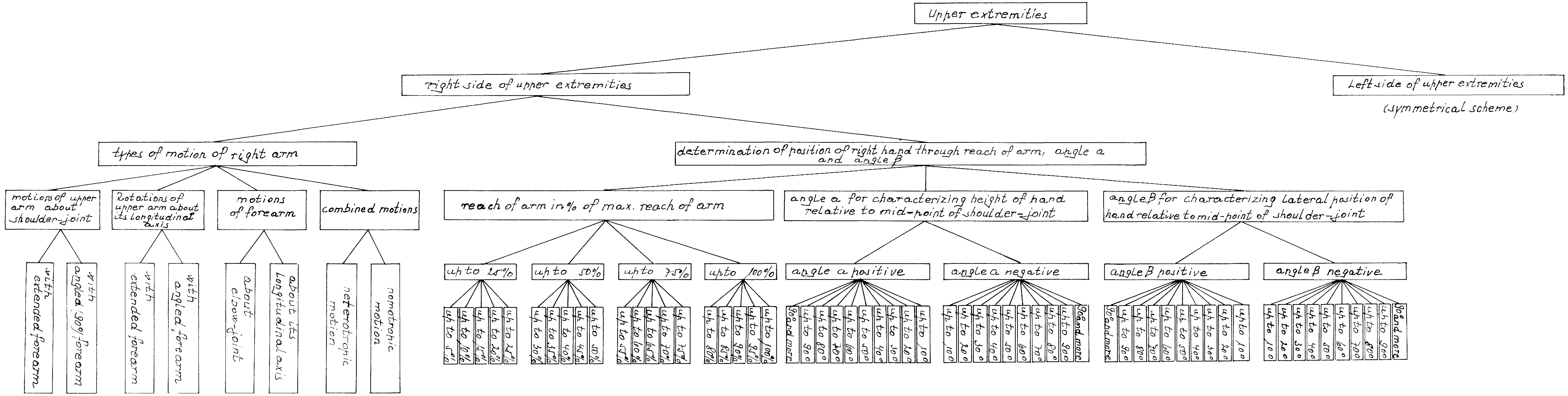


Fig. 26

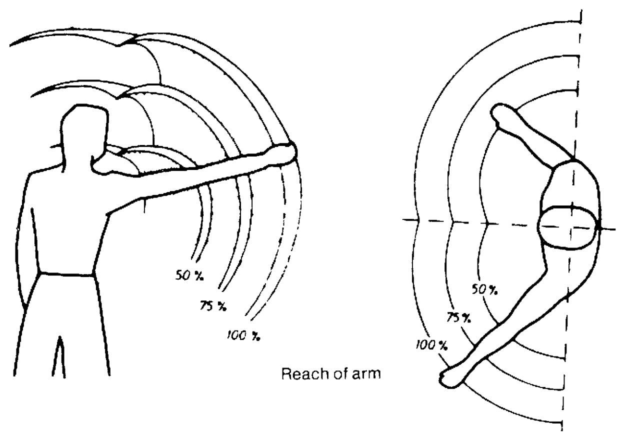


Fig. 23 - Possible position of points of application of force relative to the body according to ROHMERT (1966)

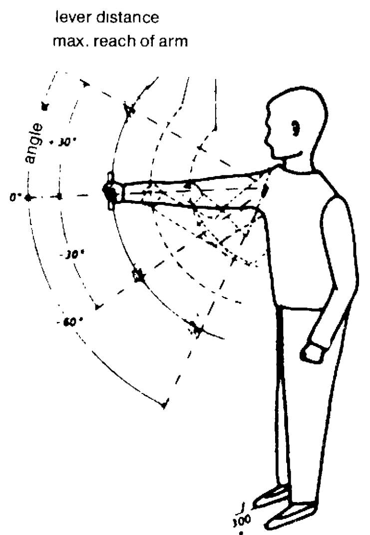
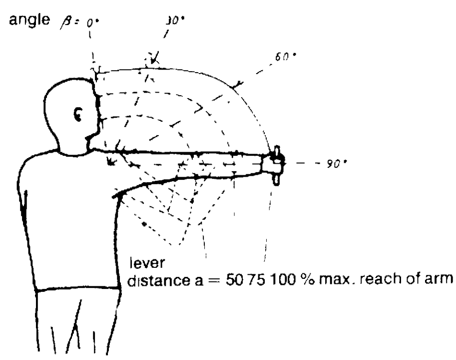


Fig. 24 - Establishment of points of application of force through angles and reach of arm according to ROHMERT (1966)



angle gives position of hand lever relative to the horizontal plane through the shoulder-joint

angle gives position of hand lever relative to the median plane of the body

Fig. 25 - Possible position of points of application of force relative to the body : description of both angular coordinates in polar coordinate system according to ROHMERT (1966)

3.2.6 Scheme for supporting surface

The size and type of supporting surface provided by the floor depends on the posture of the legs and exerts an influence on stability in standing. Here, too, the scheme must provide the possibility of describing the supporting surface quantitatively - e.g. cm^2, angle - and qualitatively.

The simultaneous availability of quantitative and qualitative characteristics has the advantage that, where there is no possibility of quantitative determination - e.g. classification of a bodily posture on the basis of a photograph - recourse may be had to the qualitative description. Moreover, the combination of qualitative and quantitative characteristics are easier to demonstrate (see Fig. 26).

The classification of leg posture by qualitative aspects is carried out through a comparison of the leg posture observed in 5 typical postures (RIEDEL, 1955).

Scheme: Supporting surface

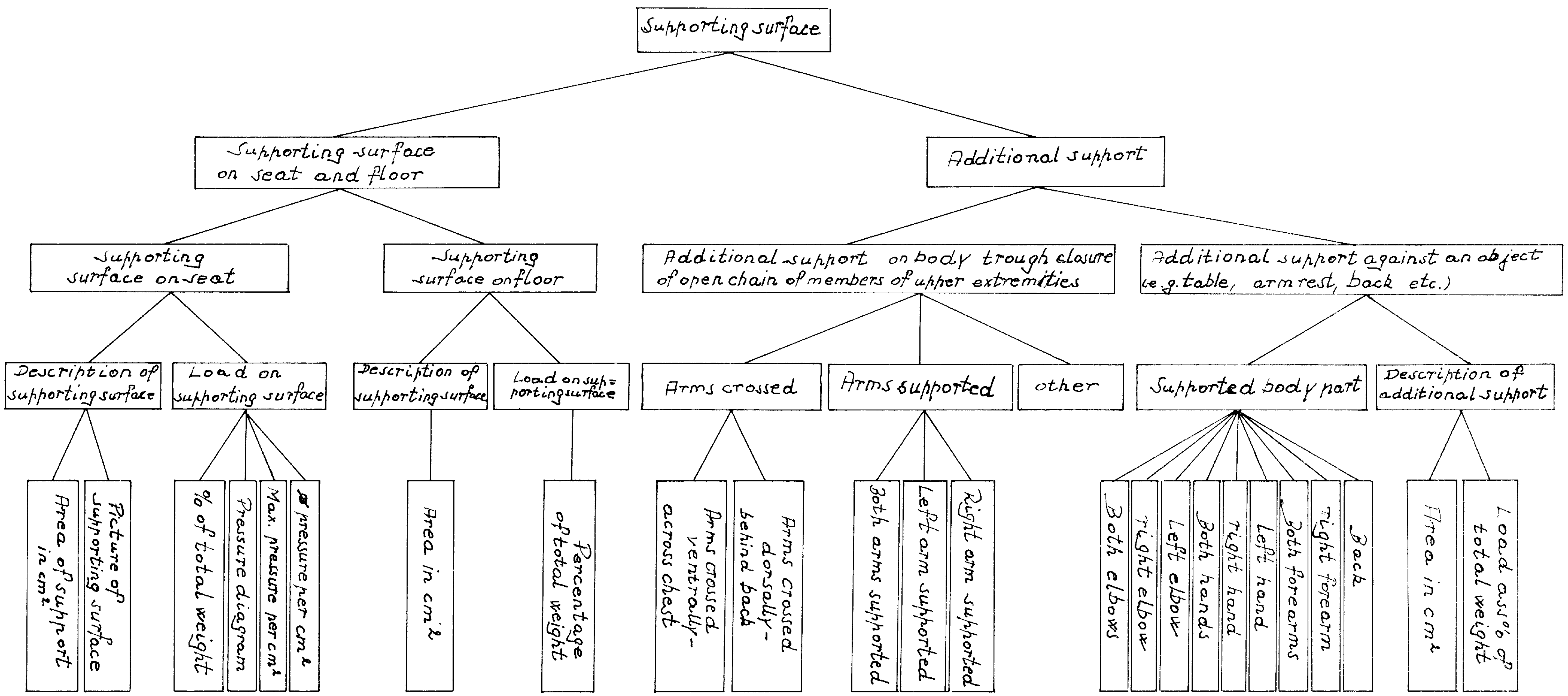


Fig. 28

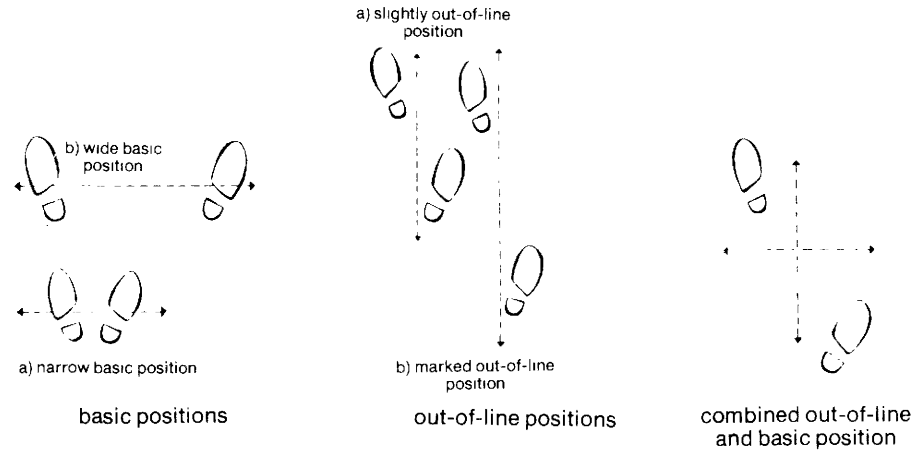


Fig. 27 - Typical leg postures according to RIEDEL (1955)

The values to be measured for the quantitative determination of the supporting surface must be assigned to the sub-points of the scheme. The size of the supporting surface and the "foot distance" - distance of the soles from the mid-point of the hip-joint - are expressed as a percentage of the maximum foot distance and the stability angle. In the latter case it is sufficient to give the directions in which the maximum and minimum stability angle occurs.

In addition to the supporting surface depending on the leg posture adopted, a man can improve his stability by having recourse to an additional support. As the variety of additional supports is immense, only the most frequently occurring cases are shown in the scheme. The closing of the open kinematic chain of members of the upper extremities - e.g. crossing of the arms - is also taken to be a supporting surface as in this way stability in standing is increased (BUYTENDIJK, 1956).

3.2.7 Classification of sitting

For the following classification of the possible sitting posture the "middle sitting position according to SCHOBERTH" is chosen as reference or basic position : this is defined by the position of the c.g. of the trunk and the supporting force of the feet - 1/4 g - and is easily checked (see p. 27).

In order, for the purpose of classifying bodily positions, to enable a comparison to be made between postures when standing, lying and sitting, it would be an advantage if the individual schemes developed for the description of the postures adopted when standing could also be applied meaningfully to sitting postures.

The following objections may be made to the unchanged application of the criteria for the description of standing postures to sitting postures :

1. The sitting posture taken up cannot be regarded in isolation because it largely depends on the working environment, i.e. on components such as sitting facilities, field of work, seeing distance etc.

2. The posture of the trunk does not display any direct relation with the sitting position assumed (SCHOBERTH, 1962).

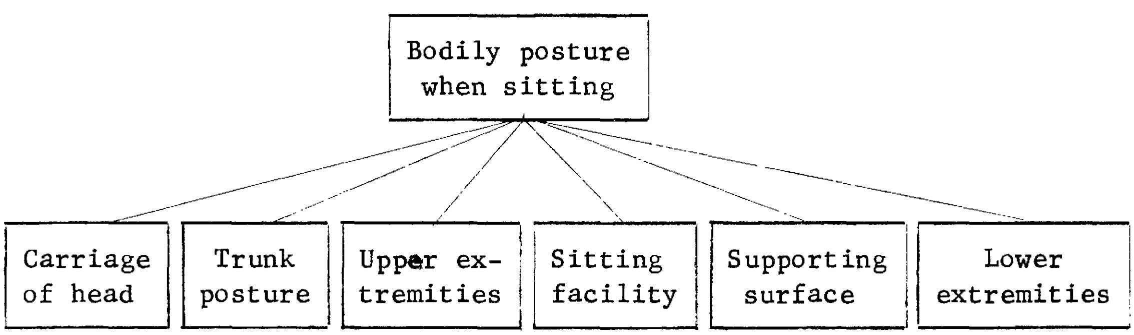
The following changes are found as compared with the classification for standing :

1. Sitting facilities, an important component for the sitting posture, are embodied in the classification.

2. The position of the lower extremities is covered in a separate scheme.

The scheme for the trunk posture remains in the classification - although the trunk posture provides no conclusion regarding the sitting position - since when the trunk posture is known the position of the mid-point of the shoulder-joint, needed to establish the position of the hand, can be described.

In this way the following criteria, together with their variants, can be checked for the purpose of determining the observed posture in the seated position and, if necessary, the measured data assigned to the sub-points of the classification :



The scheme for carriage of head (Fig. 19), trunk posture (Fig. 21) and upper extremities (Fig. 26) in sitting is similar to the representation of standing. Figs. 29, 30 and 31 show the scheme for : sitting facility (Fig. 29), supporting surface (Fig. 30) and lower extremities (Fig. 31).

3.2.8 Classification of lying

The classification of lying will not be gone into in further detail in this paper. There are two reasons for this. Lying as a working position is desirable neither in practice nor often from the physiological point of view (see Chap. 1.4.2)

During evaluation of the relevant photographic material a series of photographs showing pronounced bent or twisted positions was admittedly found but none in a clearly lying position.

Should a description in a scheme be found necessary, it is possible to adopt an approach similar to that adopted for standing under gravitational direction turned through an angle of 90°.

3.2.9 Classification of squatting and kneeling

Squatting and kneeling should be regarded as special cases of standing an can be grasped directly by means of the classification of standing.

Scheme: Sitting facility

Fig. 29

Scheme: Supporting surface

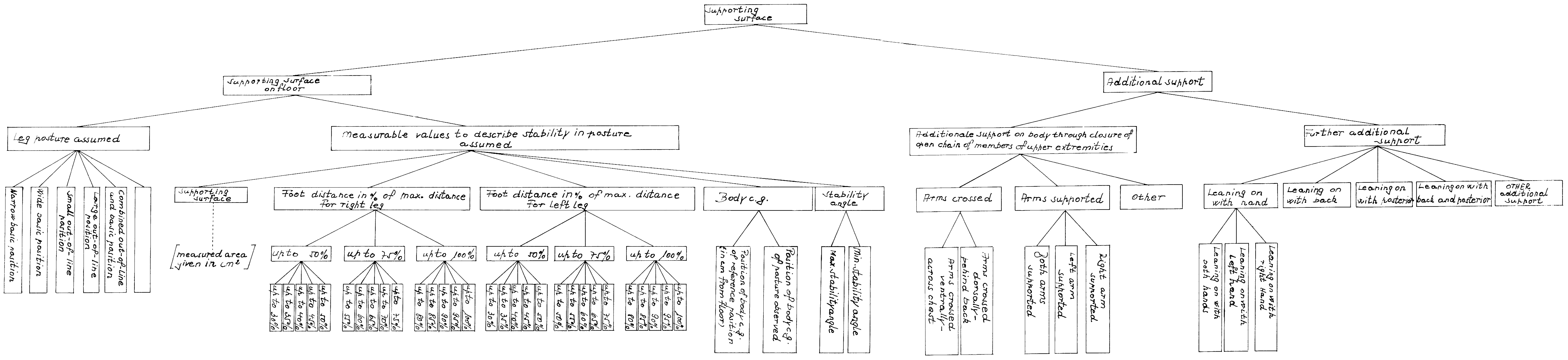


fig. 30

Scheme: Lower extremities

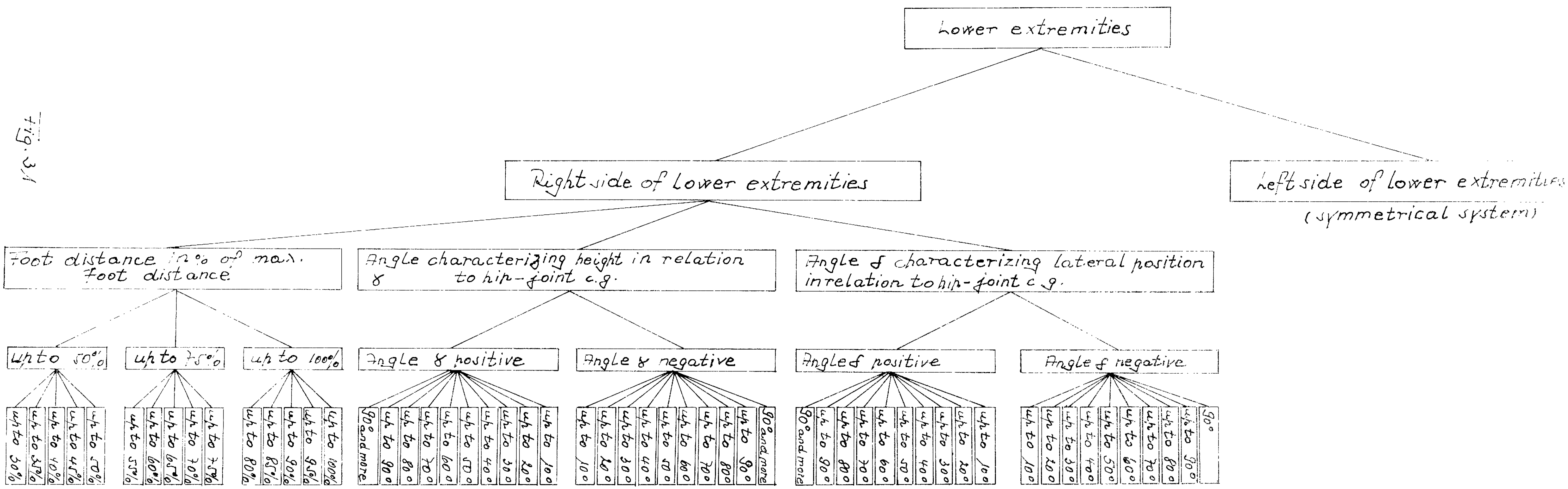


Fig. 3.1

3.3 Coding of bodily position and postures in terms of standing

The classification of the description of an observed bodily posture in standing is made up of the four sub-systems. Representation in the form of a 'family tree' was chosen because it is the easiest to grasp.

On the basis of this classification it will be shown that coding is possible. This would necessitate 43 columns on a punched card. The slightly modified system will hereafter be used in the following Chapter 4 in the evaluation of photographs. With these photographs deviations from the normal posture can only be assigned a place in qualitative terms.

Classification of standing

Column	Line	Defined content of column and line
1		Bodily posture
	1	Bodily posture standing
	2	Bodily posture sitting
	3	Bodily posture lying
	4	Special position kneeling
	5	Special position squatting
2		Carriage of head - description of deviation from reference position in the sagittal plane (flexion and extension)
	1	Extended backwards
	2	Normal (i.e. reference position = deviation 0)
	3	Flexed forwards

Column	Line	Defined content of column and line
3		Quantification - column 2 :
	0	No deviation
	1	Deviation up to 5°
	2	Deviation up to 10°
	3	Deviation up to 15°
	4	Deviation up to 20°
	5	Deviation up to 25°
	6	Deviation up to 30°
	7	Deviation up to 35°
	8	Deviation up to 40°
	9	Deviation up to 40° and more
4		Carriage of head - description of deviation from reference position in the frontal plane (lateral bending)
	1	Deviation to left (in field of vision of subject)
	2	Without deviation (i.e. reference position)
	3	Deviation to right
5		Quantification - column 4 :
	0	No deviation
	1	Deviation up to 10°
	2	Deviation up to 20°
	3	Deviation up to 30°
	4	Deviation up to 40°
6		Carriage of head - description of head rotation in horizontal plane
	1	Rotation to left
	2	Without rotation (i.e. reference position)
	3	Rotation to right

Column	Line	Defined content of column and line
7		Quantification - column 6 :
	0	Without rotation
	1	Rotation up to 5°
	2	Rotation up to 10°
	3	Rotation up to 15°
	4	Rotation up to 20°
	5	Rotation up to 25°
	6	Rotation up to 30°
	7	Rotation up to 35°
	8	Rotation up to 40°
	9	Rotation up to 40° and more
8		Trunk posture - description of deviation from reference position in sagittal plane (bending and extension)
	1	Extended backwards
	2	Normal (i.e. reference position = deviation 0)
	3	Bent forwards
9		Quantification - column 8 :
	0	No deviation
	1	Deviation up to 5°
	2	Deviation up to 10°
	3	Deviation up to 15°
	4	Deviation up to 20°
	5	Deviation up to 30°
	6	Deviation up to 40°
	7	Deviation up to 50°
	8	Deviation up to 60°
	9	Deviation up to 70° and more

Column	Line	Defined content of column or line
10		Trunk position - description of deviation from reference position in frontal plane (lateral bending)
	1	Deviation to left
	2	Without deviation (i.e. reference position)
	3	Deviation to right
11		Quantification - column 9 :
	0	Without deviation
	1	Deviation up to 5°
	2	Deviation up to 10°
	3	Deviation up to 15°
	4	Deviation up to 20°
	5	Deviation up to 25°
	6	Deviation up to 30°
	7	Deviation up to 35°
	8	Deviation up to 40°
	9	Deviation up to 45° and more
12		Trunk posture - description of trunk rotation in horizontal plane
	1	Rotation to left
	2	Without rotation (i.e. reference position)
	3	Rotation to right
13		Quantification - column 12 :
	0	Without rotation
	1	Rotation up to 5°
	2	Rotation up to 10°
	3	Rotation up to 15°
	4	Rotation up to 20°
	5	Rotation up to 25°
	6	Rotation up to 30°
	7	Rotation up to 35°
	8	Rotation up to 40°
	9	Rotation up to 45° and more

Column	Line	Defined content of column and line
14		Upper extremities - determination of right side of upper extremities in columns 14 - 19
		Description of type of motion
	0	Description not possible or unnecessary
	1	Motions of upper arm about shoulder-joint with outstretched upper arm
	2	Motions of upper arm about shoulder-joint with angled fore-arm
	3	Rotation of upper arm about longitudinal axis with out-stretched forearm
	4	Rotation of upper arm about longitudinal axis with angled forearm
	5	Motions of forearm about its longitudinal axis
	6	Motions of forearm about elbow-joint
	7	Combined motions of a homotropic type
	8	Combined motions of a heterotropic type
15		Determination of position of right hand - 1st component : reach of arm in % of max. reach
	0	Reach of arm up to 10% of max. reach
	1	Reach of arm up to 20% of max. reach
	2	Reach of arm up to 30% of max. reach
	3	Reach of arm up to 40% of max. reach
	4	Reach of arm up to 50% of max. reach
	5	Reach of arm up to 60% of max. reach
	6	Reach of arm up to 70% of max. reach
	7	Reach of arm up to 80% of max. reach
	8	Reach of arm up to 90% of max. reach
	9	Reach of arm up to 100% of max. reach

Column	Line	Defined content of column and line
16		Determination of position of hand - 2nd component : angle α characterizing height of hand relative to mid-point of shoulder-joint
	1	Angle α positive (hand above mid-point of shoulder-joint)
	2	Angle α negative (hand below mid-point of shoulder-joint)
17		Quantification - column 16
	0	Deviation up to 10°
	1	Deviation up to 20°
	2	Deviation up to 30°
	3	Deviation up to 40°
	4	Deviation up to 50°
	5	Deviation up to 60°
	6	Deviation up to 70°
	7	Deviation up to 80°
	8	Deviation up to 90°
	9	Deviation up to 100° and more
18		Determination of position of hand - 3rd component : angle β characterizing lateral position of hand
	1	Angle β positive (hand turned outwards)
	2	Angle β negative (hand turned inwards)
19		Quantification - column 18 :
	0	Deviation up to 10°
	1	Deviation up to 20°
	2	Deviation up to 30°
	3	Deviation up to 40°
	4	Deviation up to 50°
	5	Deviation up to 60°
	6	Deviation up to 70°
	7	Deviation up to 80°
	8	Deviation up to 90°
	9	Deviation up to 90° and more

Column	Line	Defined content of column and line
20-25		Upper extremities - Determination of left side analogous to columns 14-19
26		Supporting surface - qualitative description by type of leg posture adopted
	0	Qualitative determination not possible or unnecessary
	1	Narrow basic position
	2	Wide basic position
	3	Slight out-of-line position
	4	Large out-of-line position
	5	Combined out-of-line and basic position
	6	Other leg posture
27 28 29		Measurable values of supporting surface - supporting surface given in cm^2 (rounded up or down)
30		Foot distance in % of max. distance for right leg
	0	Foot distance up to 10 % of max. distance
	1	Foot distance up to 20 % of max. distance
	2	Foot distance up to 30 % of max. distance
	3	Foot distance up to 40 % of max. distance
	4	Foot distance up to 50 % of max. distance
	5	Foot distance up to 60 % of max. distance
	6	Foot distance up to 70 % of max. distance
	7	Foot distance up to 80 % of max. distance
	8	Foot distance up to 90 % of max. distance
	9	Foot distance up to 100 % of max. distance
31		Foot distance in % of max. distance for left leg Content of lines 0 - 9 analogous to content of lines of column 30

Column	Line	Defined content of column and line
32		Position of body's c.g. in the reference position -
33		given in cm
34		(calculated from floor)
35		Position of body's c.g. in the body position to
36		be determined - given in cm
37		(calculated from floor)
38		Max. stability angle -
39		given in degrees
40		Min. stability angle -
41		given in degrees
42		Additional support on body through closure of open chain of members of upper extremities
	0	No additional support
	1	Arms crossed corsally (behind back)
	2	Arms crossed ventrally (across chest)
	3	Both arms supported
	4	Right arm supported
	5	Left arm supported
	6	Other supporting surface on body
43		Further supporting surfaces
	0	No supporting surface
	1	Leaning on with right hand
	2	Leaning on with left hand
	3	Leaning on with both hands
	4	Leaning on with back
	5	Leaning on with posterior
	6	Leaning on with back and posterior
	7	Other supporting surface

4. Evaluation of a collection of photographs of workplaces and bodily positions from underground workings in the coalmining industry with a computer program in FORTRAN IV

4.1 Description of material investigated

4.1.1 General review

The photographs were taken in the course of investigations by the Institut für Arbeitswissenschaft of the Darmstadt Technische Hochschule in a number of coalmines in the Ruhr area and in the Saar in the years 1968 to 1969. A searching industrial physiology investigation of the bodily stress to which coalminers are exposed was carried out with the financial support of the Directorate-General for Social Affairs of the Commission of the European Communities by TEMMING (1969).

The collection comprises a total of 601 pictures of which 254 have been left out of account. These included casual photographs, photographs of instruments, material and machines, and others taken during breaks. Some cannot be evaluated for technical reasons. The remaining 347 photographs show men engaged in various activities in different workplaces (in all 477 persons, see p. 53).

An attempt will be made to investigate information on the type and frequency of bodily postures, stored in these photographs, with the classification developed. As, however, it is impossible, in determining working postures, to make quantitative statements on the basis of photographs, a slightly modified classification is developed which enables a sub-division to be carried out by qualitative characteristics. This departure from a quantitative to a purely qualitative description of the working postures observed weakens the informative nature of the results since the qualitative ranking of characteristics is carried out subjectively.

4.1.2 Classification by workplaces

The photographs should be assigned to the underground workplaces investigated. This has the advantage that in addition to an overall determination of all bodily positions, the posture observed in each workplace is also shown. Should typical and distinct postures be found in each workplace, then the additional outlay will be justified. The workplaces studied can be sub-divided according to the type of working task into three groups.

1) Handling : The performance of work is intended essentially to bring about a change in the form or a change in the function of the objects to be handled (examples : straightening of bent road timbering sections in a bending press; withdrawing a hydraulic coal-face support). The simple removal of the material to be handled from place to place is of minor importance.

2) Loading and unloading of haulage equipment : The workplaces falling under this group are situated at the initial or end-points of a usually long chain of transport operations.

3) Reloading operations : For technical and organizational reasons, it is often necessary in pit operations to convey material on different carrier systems. As a working task and the technical equipment at reloading points can often differ widely from those of the loading and unloading points, a distinction will be made in the representation of the individual results between these groups.

At some points, activity characteristics are encountered which justify the inclusion in more than merely one of the groups mentioned. These points were grouped in the light of the most important working operations. Within the three main groups of workplaces a further sub-division can be made on the basis of a second criterion,the absence of presence of mechanical auxiliaries :

1) Workplaces where no such mechanical facilities are installed so that workers assigned to them have to rely exclusively on their own muscular energy.

2) Workplaces at which use is made both of muscular energy and of powered equipment.

A disadvantage of this classificatory criterion is that as against a large number of different workplaces at which outside energy is used to a greater or lesser extent, there is only a limited number of workplaces at which only manual labour is carried out. As is to be expected, the differences between the few highly mechanized workplaces is larger than those between partly or non-mechanized workplaces.

Overall the selection of persons photographed at the individual workplace categories was distributed with the following frequencies :

1) Handling, non-mechanized	35 persons
2) Handling, mechanized	24 "
3) Loading and unloading, non-mechanized	185 "
4) Reloading, non-mechanized	47 "
5) Reloading, mechanized	186 "
	477 persons

In the following paragraphs a few examples will be given of the individual workplaces.

4.1.3 Workplace : handling, non-mechanized

At this workplace supports withdrawn from various working places are delivered to be straightened on a bending press (Figs. 32 to 34).

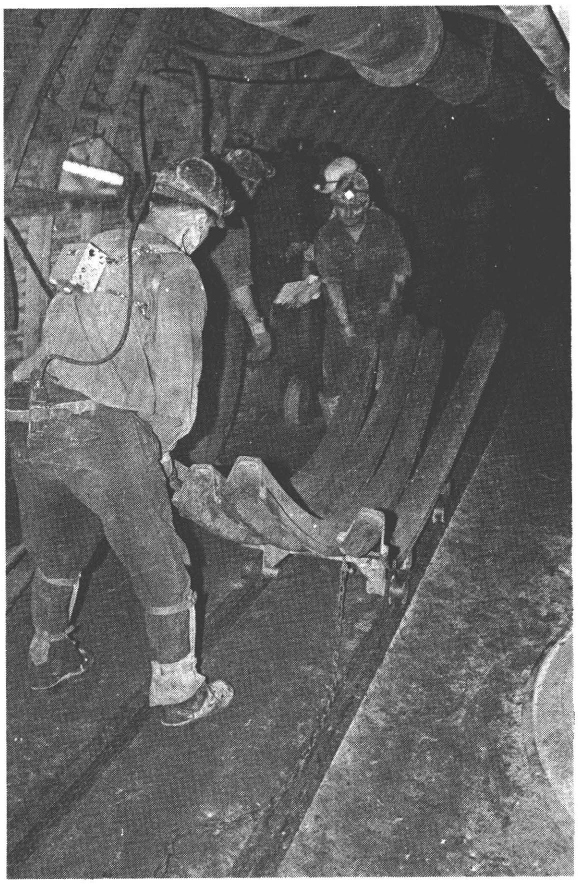


Fig. 32 - Bent support sections delivered from timber-withdrawing workings are unloaded by hand

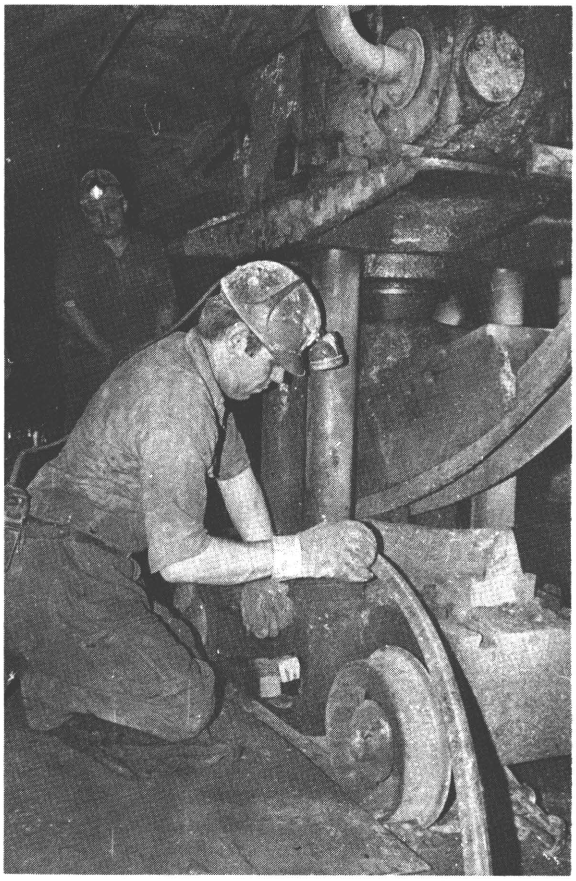


Fig. 33 - Bending press for straightening support sections

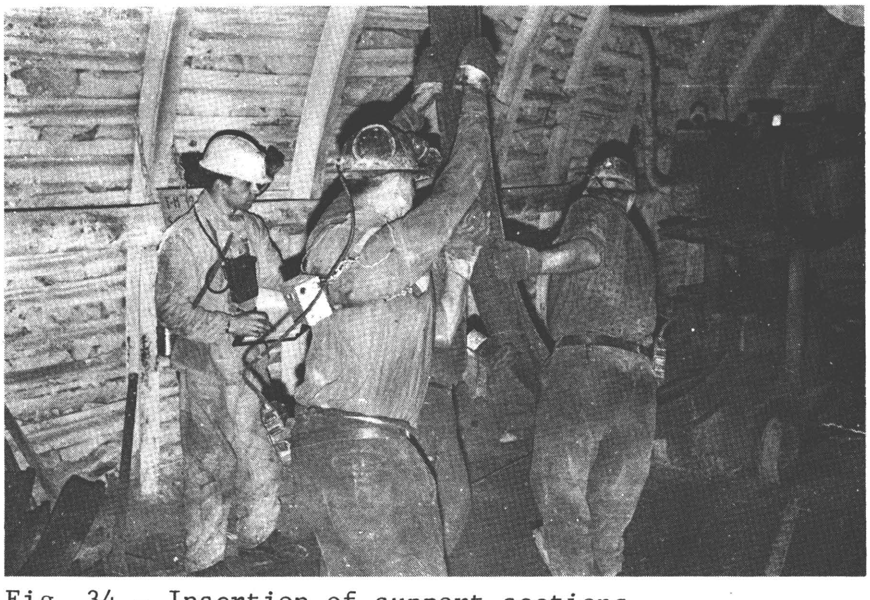


Fig. 34 - Insertion of support sections in the bending press

4.1.4 Workplace : Handling, mechanized

The photographs taken at this working place show the subject in the process of drawing props at the face. The props and caps are loosened (Fig. 35) and drawn out with the aid of a small winch (Fig. 36).

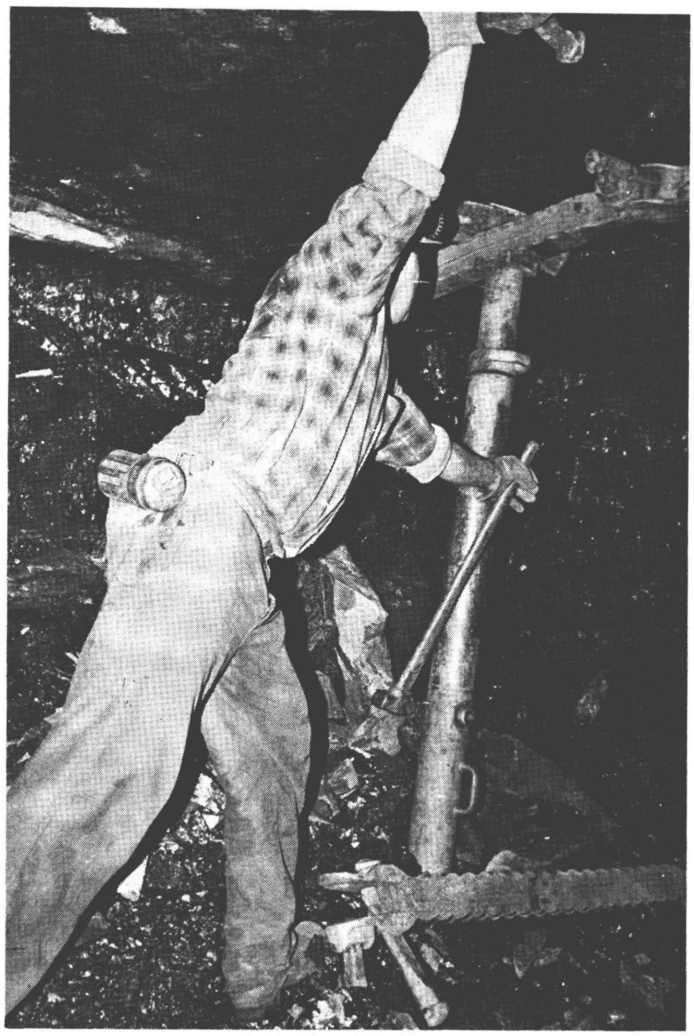


Fig. 35 - Releasing the prop

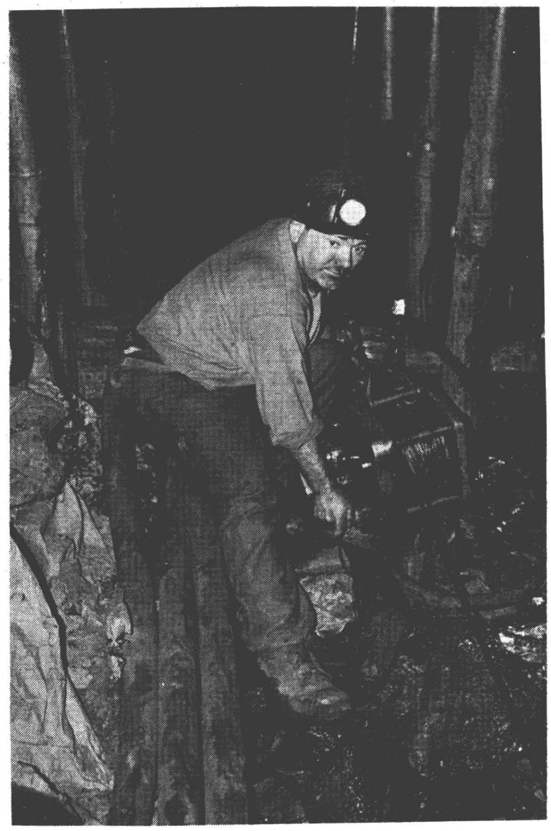


Fig. 36 - Winch for drawing props and caps

Finally the haulage rope is detached from the props and caps which are loaded into the haulage rope trough (Fig. 37).

Fig. 37 - Loading of props and caps into the haulage rope trough

4.1.5 Workplace : Loading and unloading, non-mechanized

Here the operator is engaged in bringing up material for the advance heading, unloading it (Fig. 39) and stacking it in the rising heading. The work is carried out entirely by hand. During waiting times occurring in the work cycle other work, e.g. clearing up, coal steeping, and putting the intermediate pick into position (Fig. 38) is carried out. The working conditions are very fatiguing because the seam is only about 1 m high.

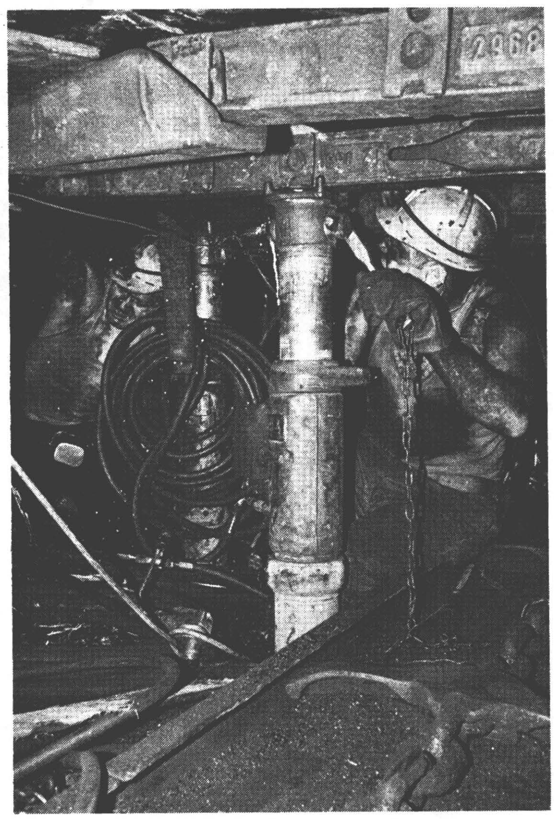


Fig. 38 - Putting intermediate pick into position

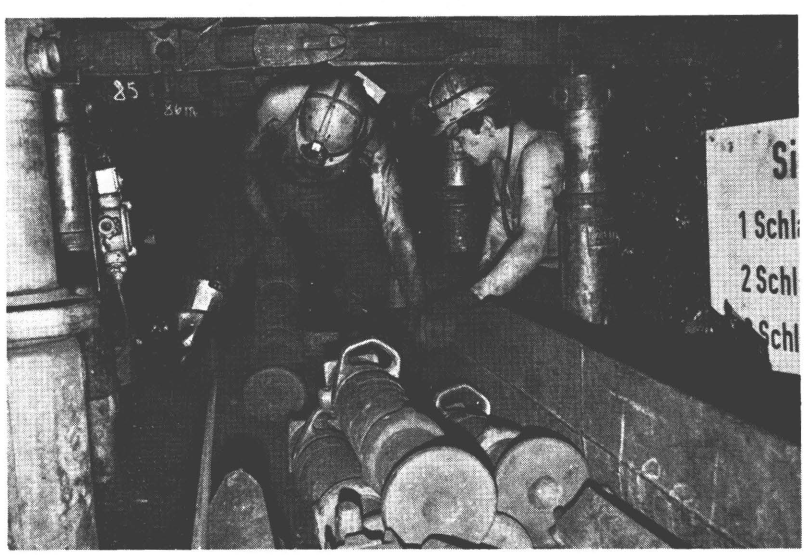


Fig. 39 - Unloading props

4.1.6 Workplace : Reloading, non-mechanized

The material delivered is here reloaded onto another transport system (Fig. 40). The loaded car is pushed very close to the roadway haulage unit. The material (ties, bars and support sections) can be directly reloaded (Fig. 41).

Fig. 40 - Reloading of ties

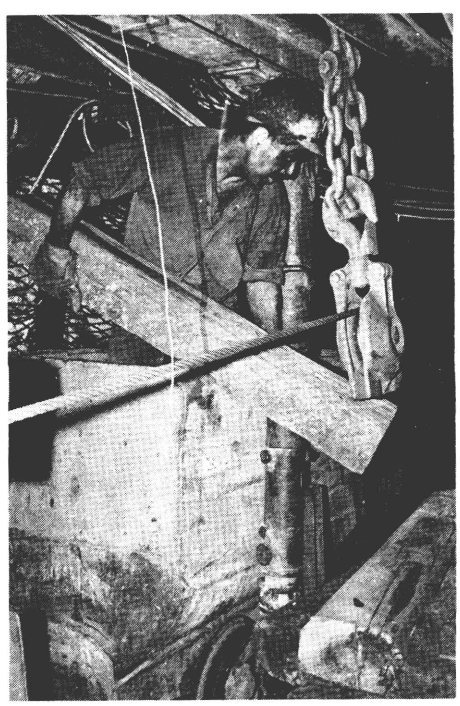


Fig. 41 - Reloading from transport car into roadway haulage unit

4.1.7 Workplace : Reloading, mechanized

In this workplace, too, the material is reloaded onto various transport units. Containers are moved with the aid of a travelling winch fitted with a hoisting device driven by compressed air (Fig. 42).

Fig. 42 - Transport of containers by means of travelling winch

In a few cases the material is loaded from the containers onto the roadway haulage unit (Fig. 43). This occurs when insufficient space is available for a container at the destination.

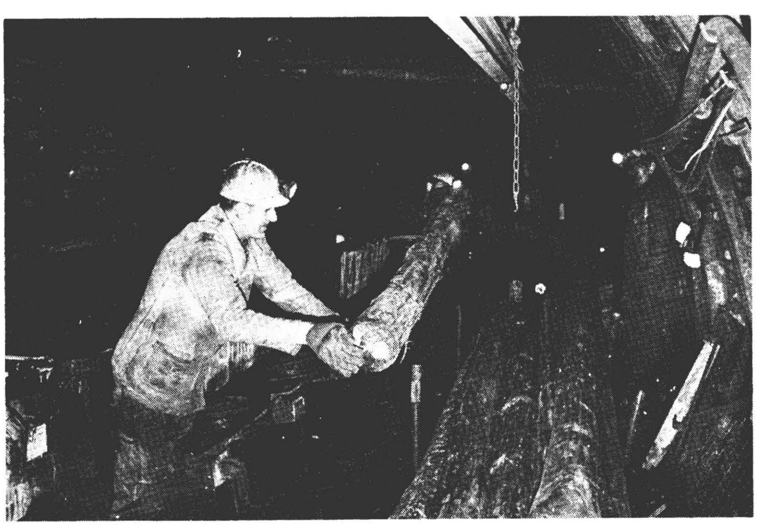


Fig. 43 - Reloading onto roadway haulage unit

4.2 Coding

4.2.1 Preliminary remark

The determination of bodily positions and postures when standing, sitting, kneeling and squatting is carried out with a modified classification (as compared with that developed in Chapter 3) because deviations from the reference positions can only be described qualitatively.

The highly simplified classification for the sitting position, in the case of the criteria sitting facility and supporting surface, is directly tailored to the available collection of photographs and cannot be applied in this form to other workplaces.

Moreover it is to be noted that postures are determined fully from the activity of the operator in isolation.

4.2.2 Coded classification for the evaluation of the collection of photographs

Column	Code	Content of column and line
1		Bodily position :
	1	Standing position (columns 1-28)
	2	Sitting position (columns 1-24, 27-33)
	3	Lying position (this position is not available)
	4	Special position : squatting (columns 1-28)
	5	Special position : kneeling (columns 1-28)

Column	Code	Content of column and line
2		Carriage of head : flexion and extension in sagittal plane
	1	Bent forwards
	4	Normal position
	7	Bent backwards
	9	No conclusion can be drawn from the photograph
3		Qualitative determination of column 2 :
	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
	9	No conclusion to be drawn from photograph
4		Carriage of head : lateral bending in frontal plane
	1	Bending to left
	4	Normal position (no bending)
	7	Bending to right
5		Qualitative determination of column 4 :
	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

Column	Code	Content of column and line
6		Carriage of head : rotation in horizontal plane
	1	Rotation to left
	4	No rotation (normal position)
	7	Rotation to right
7		Qualitative determination of column 6 :
	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
8		Trunk position : bending and stretching in sigittal 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

Column	Code	Content of column and line
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 in horizontal plane
	1	Rotation to left
	4	No rotation (normal position)
	7	Rotation to right
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

Column	Code	Content of column and line
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 right hand 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
17		Qualitative determination of column 16 :
	1	Hand very high above mid-point of shoulder-joint
	2	Hand far above mid-point of shoulder-joint
	3	Hand slightly above mid-point of shoulder-joint
	5	Hand slightly below mid-point of shoulder-joint
	6	Hand far below mid-point of shoulder-joint
	7	Hand very far below mid-point of shoulder-joint
	9	No conclusion can be drawn from the photograph
18		Height of left hand relative to mid-point of shoulder-joint
	1	Above mid-point of shoulder-joint
	4	Level with shoulder-joint
	7	Below mid-point of shoulder-joint
	9	No conclusion can be drawn from the photograph

Column	Code	Content of columns and line
19		Qualitative determination of column 18 :
	1	Hand very high above mid-point of shoulder-joint
	2	Hand far above mid-point of shoulder-joint
	3	Hand slightly above mid-point of shoulder-joint
	5	Hand very slightly below mid-point of shoulder-joint
	6	Hand far below mid-point of shoulder-joint
	7	Hand very far below mid-point of shoulder-joint
	9	No conclusion can be drawn from the photograph
20		Lateral position of right hand relative to mid-point of right shoulder-joint
	1	To the front (outside)
	2	To the rear (outside)
	4	Not laterally displaced
	5	To the rear, inside
	7	To the front, inside
	9	No conclusion can be drawn from the photograph
21		Qualitative determination of column 20 :
	1	Hand very far outwards
	2	Hand far outwards
	3	Hand slightly outwards
	4	Hand not laterally displaced
	5	Hand slightly inwards
	6	Hand far inwards
	7	Hand very far inwards
	9	No conclusion can be drawn from the photograph

Column	Code	Content of columns and lines
22		Lateral position of left hand relative to mid-point of left shoulder-joint
	1	To the front, outwards
	2	To the rear, outwards
	4	Not laterally displaced
	5	To the rear, inwards
	7	To the front, inwards
	9	No conclusion can be drawn from the photograph
23		Qualitative determination of column 22 :
	1	Hand very far outwards
	2	Hand far outwards
	3	Hand slightly outwards
	4	Not laterally displaced
	5	Hand slightly inwards
	6	Hand far inwards
	7	Hand very far inwards
	9	No conclusion can be drawn from the photograph
24		Supporting surface on floor :
	1	Narrow basic position
	2	Broad basic position
	3	Slight out-of-line position
	5	Wide out-of-line position
	6	Combined out-of-line and basic position
	7	Other leg posture
	8	Feet not on floor
	9	No conclusion can be drawn from the photograph
25		Description of leg posture (right leg) :
	1	Right leg strongly flexed
	2	Right leg medium flexed
	3	Right leg slightly flexed
	5	Right leg extended
	9	No conclusion can be drawn for the right leg

Column	Code	Content of column and line
26		Description of leg posture (left leg) :
	1	Left leg strongly flexed
	2	Left leg medium flexed
	3	Left leg slightly flexed
	5	Left leg extended
	9	No conclusion can be drawn for the left leg
27		Additional support on body through closure or propping of upper extremities
	1	Upper extremities not closed, no bodily support
	2	Arms folded behind back
	3	Arms folded across chest
	5	Right arm laid down or supported
	6	Left arm laid down or supported
	7	Both arms laid down or supported or hanging
	9	No conclusion can be drawn from the photograph
28		Further additional support
	1	Leaning on with right hand
	2	Leaning on with left hand
	3	Leaning on with both hands
	4	Leaning on with back
	5	Leaning on with posterior
	6	Leaning on with back and posterior
	7	Other type of additional support
	8	Without other additional support
	9	No conclusion can be drawn from the photograph
29		Description of sitting facility (confined to the sitting facilities occurring in the collection of photographs)
	1	Stool
	2	Temporary or makeshift seat on appliance or material
	3	Seat on floor

Column	Code	Content of column and line
30		Foot distance in % of max. foot distance (right foot)
	1	Right foot up to 25 %
	2	Right foot up to 50 %
	3	Right foot up to 75 %
	4	Right foot up to 100 %
	9	No conclusion can be drawn from the photograph for the right foot
31		Foot distance in % of max. foot distance (left foot)
	1	Left foot up to 25 %
	2	Left foot up to 50 %
	3	Left foot up to 75 %
	9	Non conclusion can be drawn from the photograph for the left foot
32		Height of foot relative to the appropriate mid-point of hip-joint (right foot)
	3	Right foot above mid-point of hip-joint
	5	Right foot slightly below mid-point of hip-joint
	6	Right foot far below mid-point of hip-joint
	7	Right foot very far below mid-point of hip-joint
	9	No conclusion can be drawn from the photograph for the right foot

Column	Code	Content of column and line
33		Height of foot relative to the appropriate mid-point of hip-joint (left foot)
	3	Left foot above mid-point of hip-joint
	5	Left foot slightly below mid-point of hip-joint
	6	Left foot far below mid-point of hip-joint
	7	Left foot very far below mid-point of hip-joint
	8	No conclusion can be drawn from the photograph for the left foot
35		Load on right hand through weights or masses
	1	No weights in right hand
	2	Light weights in right hand
	3	Medium-heavy weights in right hand
	4	Heavy weights in right hand
	5	Light weights in both hands
	6	Medium-heavy weights in both hands
	7	Heavy weights in both hands
	8	Balancing with right hand when carrying load on shoulder
	9	Details cannot be given from the photograph
36		Load on left hand through weights or masses
	1	No weights in left hand
	2	Light weights in left hand
	3	Medium-heavy weights in left hand
	4	Heavy weights in left hand
	5	Light weights in both hands
	6	Medium-heavy weights in both hands
	7	Heavy weights in both hands
	8	Balancing with left hand when carrying load on shoulder
	9	Details cannot be given from the photograph

Column	Code	Content of column and line
37		Other loads carried
	1	No loads
	2	Loads carried on shoulder (light)
	3	Loads carried on shoulder (medium)
	4	Loads carried on shoulder (heavy)
	5	Details cannot be given from the photograph
		Additional designation
51-52		Film No.
53-54		Picture No.
56		Person No.
58		Job
		1) handling
		2) loading and unloading
		3) reloading
60		Degree of mechanization
		1) mechanized
		2) non-mechanized

4.3 Setting up computer program in FORTRAN IV

4.3.1 Utilization

The processing of the following 'photo evaluation' computer program was carried on an IBM 7040 computer of the Computer Centre of the Darmstadt Technische Hochschule. Operations are carried out under the control of the IBSYS operating system with available FORTRAN IV translator and about 27,000 free storage locations. FORTRAN IV was chosen as programming language.

Input was effected as program and data card deck with the aid of punched cards, output of results on data lists.

The program consists of four parts which were used for the following possibilities of the results-output and could be fed in separately.

4.3.2 Program part 1 serves for the control output of all read-in data. The input data cards are reproduced according to their punched contents.

4.3.3 Program part 2

In program part 2 the frequency of code numbers 1-9 (cf. classification in Chapter 3.2.2) is decoded for the position characteristics of columns 1-37.

```
$JOB    WATFOR    943   TEMMING   PHOTO = EVAL  T E T E T E T E T E T E T
$TIME             4
$LINE             1000
$IBJOB
$IBFTC PHOTO01
       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)
  510 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.MEND) GOTO 780
```

```
    GOTO 770
780 CONTINUE
    END
```

4.3.4 Program part 3

Program part 3 brings together the code numbers (posture characteristics) by workplace groups. These groups are designated by the following numbers :

Group 1 : Handling non-mechanized
Group 2 : Handling mechanized
Group 3 : Loading and unloading non-mechanized
Group 4 : Reloading non-mechanized
Group 5 : Reloading mechanized
Group 6 : Loading (mechanized and non-mechanized)
Group 7 : Reloading (mechanized and non-mechanized)
Group 8 : Non-mechanized workplaces
Group 9 : Mechanized workplaces
Group 10 : Combination of all workplaces

```
$JOB    WATFOR    943   TEMMING   PHOTO EVALUATION  T E T E T E T E T E T E
$TIME             3
$LINE             500
$IBJOB
$IBFTC PHOTO03
       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) + NNUMBER(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
```

4.3.5 Program part 4

Program part 4 provides the possibility of breaking down the frequencies of the coincidence of all position characteristics.

The code numbers of individual position characteristics (1-37) are in each case classified and combined according to the code number of a specific characteristic designated as 'classification criterion'. This is done successively for all characteristics (1-37), each characteristic being treated as 'classification criterion'.

The breakdown is given in absolute frequencies; the percentage figure of the corresponding overall occurrence is given in brackets.

```
$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(5,1603) (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)
 2008 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(6,2009 NS, (CHARACT(NS,MN), MN = 2,12)
 2009 FORMAT(2X,12HCHARACT NO. ,13,2H..,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) NINSGE
 3003 FORMAT(10X,38HNUMBER OF CODINGS EVALUATED = ,115)
  850 CONTINUE
  873 CONTINUE
      END
```

4.4 Representation of results

4.4.1 General

Below the distributions and conditions of the bodily positions and most important posture characteristics observed will be briefly described as the result of the evaluation of the collection of bodily positions. In evaluating the results, a number of limitations must be considered :

1) The collection of photographs covered only underground workings in coalmines, and there only the special sector of materials haulage.

2) The small number of 477 photographs does not permit statistic certainty for a typical representation of the actual position.

3) The photographs were taken arbitrarily so that the danger exists that interesting scenes, i.e. those showing extreme bodily positions (e.g. bending in order to raise material from the ground or throw it away) will predominate.

4) Qualitative characteristics were ranked by a person according to his subjective notions and are also subject to inaccuracy of interpretation.

Nevertheless there were two reasons why these photographs were used as a practical example of the classification of bodily positions : the original character of the information which was to be acquired as the basis for more far-reaching data and comparisons, and the wide range of extreme positions and postures which data were expected to deliver for the bulk of the classification points.

4.4.2 Bodily positions and workplaces

In defining the working positions observed, in addition to the given workplaces :

handling - non-mechanized (1)
handling - mechanized (2)
loading and unloading - non-mechanized (3)
reloading - non-mechanized (4)
reloading - mechanized (5)
handling - mechanized and non-mechanized (6)
reloading - mechanized and non-mechanized (7)

workplaces (1) and (2) as well as (4) and (5) are grouped under the aspect of the particular common job :

handling - mechanized and non-mechanized (6)
reloading - mechanized and non-mechanized (7).

With the second criterion, too, the lack or availability of mechanical facilities, a further subdivision can be made into

the sum of all non-mechanized working places (8)
and the sum of all mechanized working places (9).

Consideration of all workplaces (10) enables a conclusion to be arrived as to the bodily positions to be expected in the entire working sector.

As must be expected, standing is the most frequently encountered working position, as can be seen from Fig. 44.

In the case of non-mechanized handling, non-mechanized loading and unloading and non-mechanized reloading, it must be borne in mind that the totality of the material to be evaluated is very small (less than 50 photographs). The relatively high proportion of kneeling positions found in the handling workplace is to be attributed to the test subject operating the press in a supervising or service capacity which under the given conditions calls for a kneeling position. The operator working in the loading and unloading workplace is forced to assume a kneeling or pronounced bending position because of the low seam height. In this case kneeling is encountered in 24 % of the cases observed.

The sitting position accounts in all workplaces for about 5.5 % of the cases.

4.4.3 Carriage of head

Fig. 45 shows deviations of the carriage of the head from the normal position in the sagittal plane. In all workplaces (workplace No. 10 of Fig. 45) in which a standing position is assumed, a normal position (relative to the motion in the sagittal plane) can be observed in only 38.6 % of the positions observed. 41.7 % of operators lean the head forwards. Further classification into slight (28.5 %), medium (10.3 %) and marked (2.6 %) bending of the head shows that a slight bending of the head predominates. In 19.7 % of the cases the head assumes a backward extended position. Deviations from the normal position of the carriage of the head in the frontal plane (Fig. 46) amount to 9.8 % to the left and 11.6 % to the right. In nearly 80 % of the persons studied, a normal carriage of the head is found.

Rotation of the head in the horizontal plane (Fig. 47) to the left (15 %) and to the right (18.8 %) is nearly the same. Figures 44-47, from which information can be obtained about the carriage of the head, show that extreme positions, giving rise to high static demands on the muscles, occur only to a very limited extent (less than 5 % of possible cases).

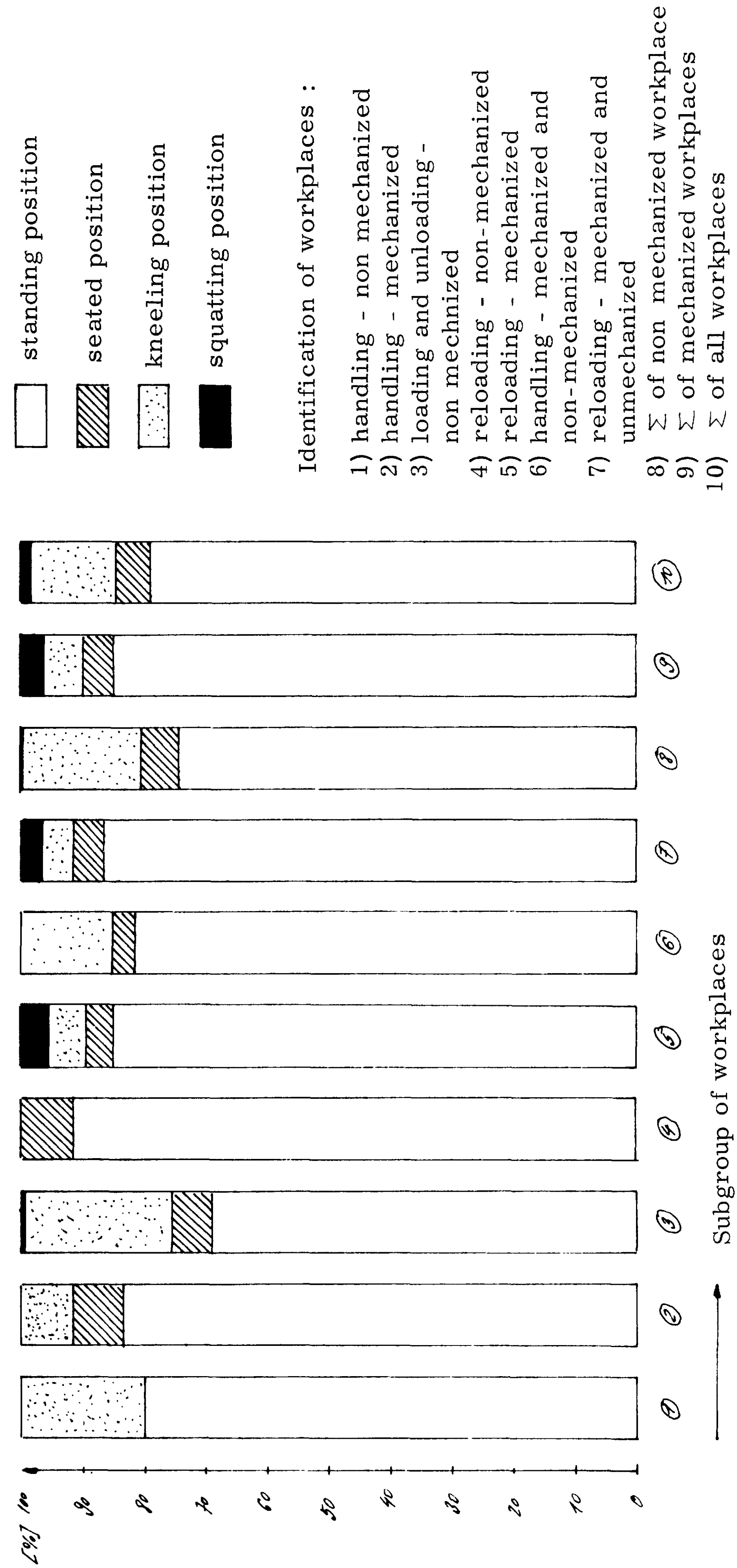
4.4.4 Trunk posture

Fig. 48 shows the bending of the trunk, a very important component for bodily load. The following conclusions can be drawn from the figure : The work is mainly carried out in a position which leads to a heavy load on the human body. In the standing position, flexing of the trunk forwards is very marked at 14.3 %, medium at 13.5 % and slight at 25.9 % of all positions studied.

At the loading and unloading (non-mechanized) workplace, the high proportion (21.6 %) of very marked bending of the trunk resulting from the narrow space at the workplace is understandable.

The normal position of the trunk - calculated on the deviation in the sagittal plane - can be recorded in just 42 % of the positions considered. An extended position of the trunk occurs in only 4.8 % of the cases and this takes a moderate form.

The other motion components of the trunk in the frontal and horizontal plane (Figs. 42 and 50) are determined in a similar way. The diagram shows, however, that in the work sector investigated, the proportion of deviations from the normal position in each plane of motion is limited to 10 % (4.5 % trunk bending to left and 5.3 % to right) and 17.5 % (8.5 % rotation of the trunk to the left and 9 % to the right). Extremely unnatural positions characterized by marked rotational bending of the trunk do not occur in the cases investigated.



<u>Fig. 44</u> - Frequency of bodily positions observed broken down by individual workplaces

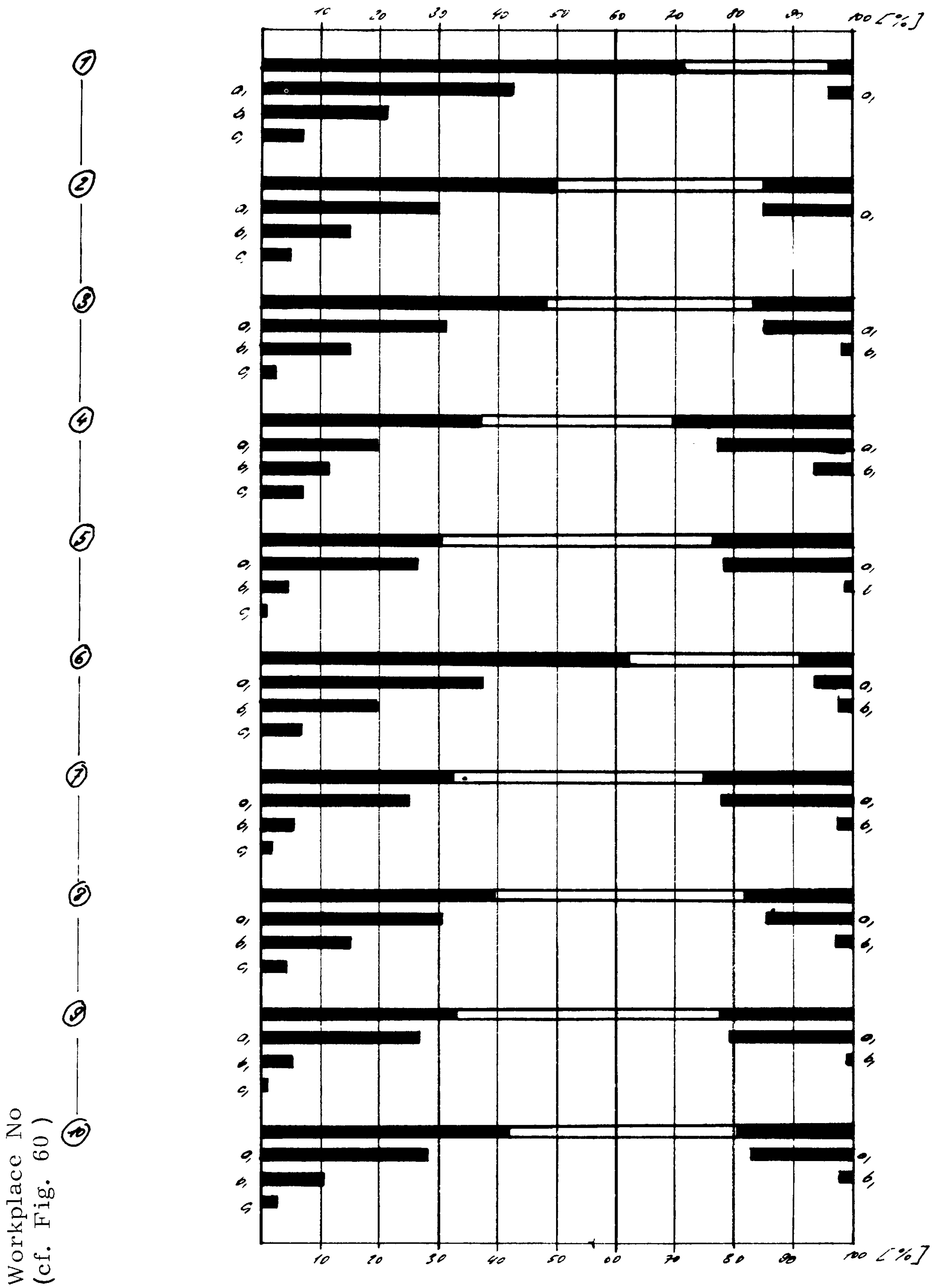


Fig. 45 - Head posture : Flexion and extension in sagittal plane

forwards
a) slight
b) medium
c) marked

normal position

backwards
a) slight
b) medium
c) marked

105/71 e - RCE

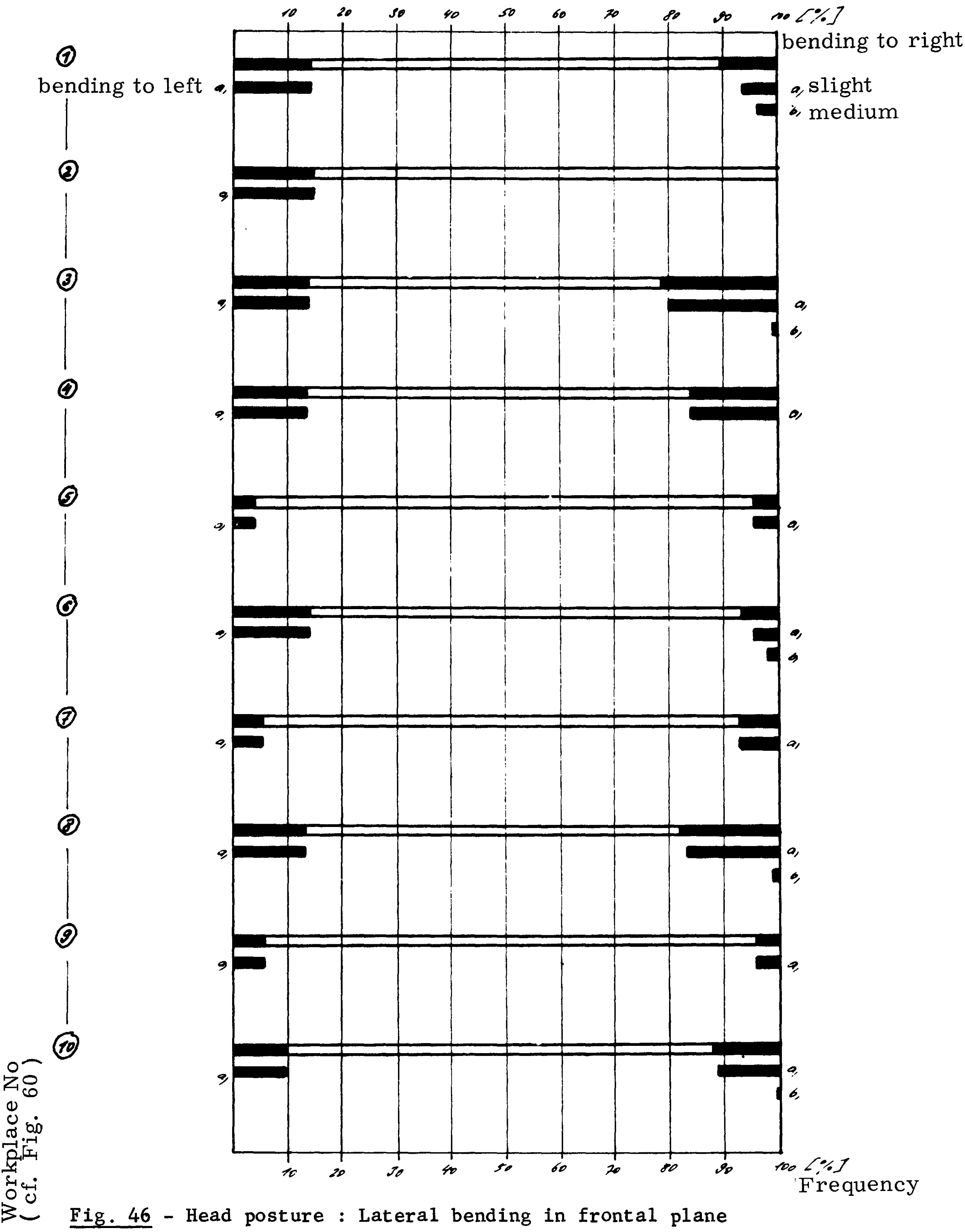


Fig. 46 - Head posture : Lateral bending in frontal plane

leaning to left	normal position	leaning to right
a) slight		a) slight
b) medium		b) medium
c) marked		c) marked

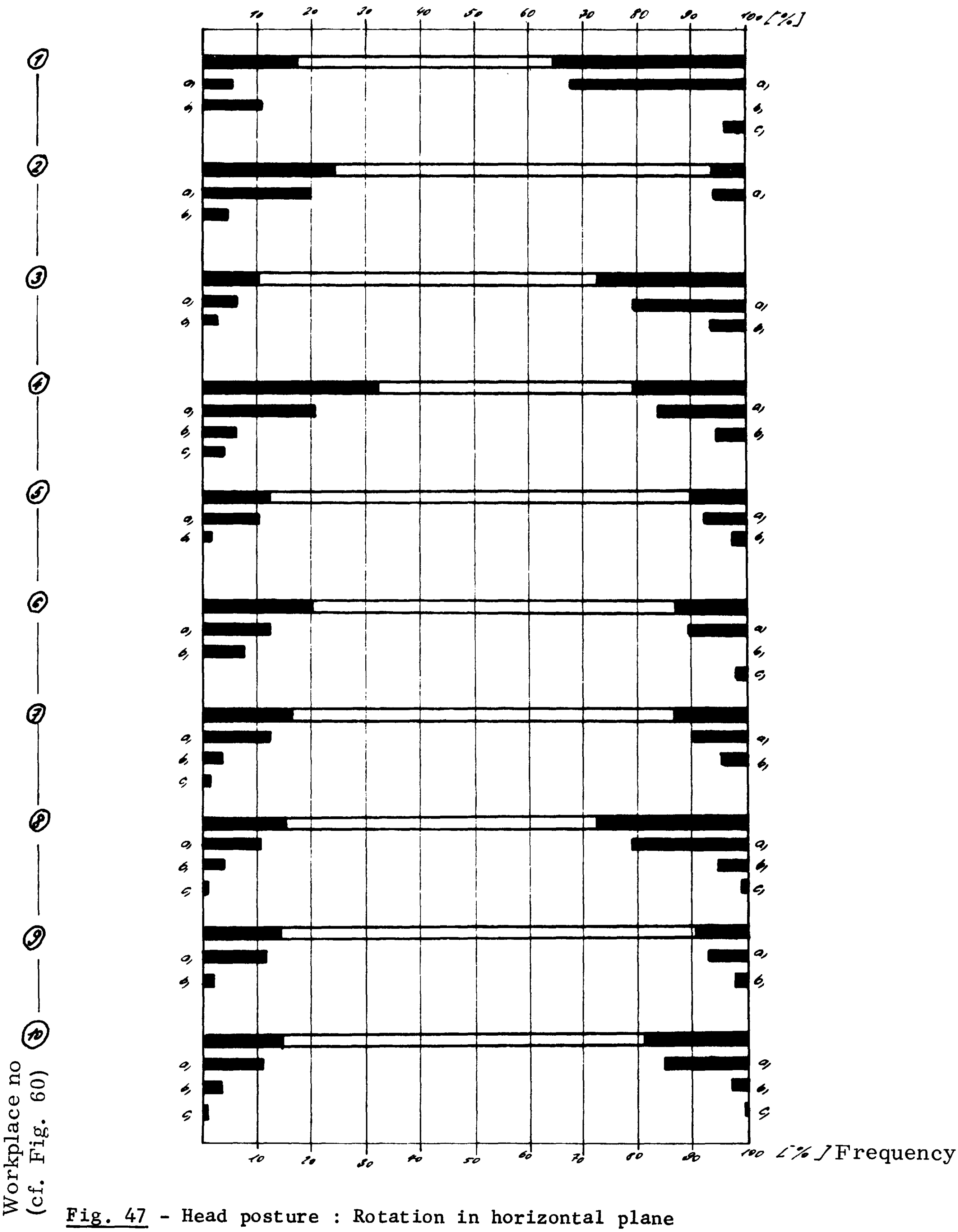


Fig. 47 - Head posture : Rotation in horizontal plane

rotation to left
a) slight
b) medium
c) marked

rotation to right
a) slight
b) medium
c) marked

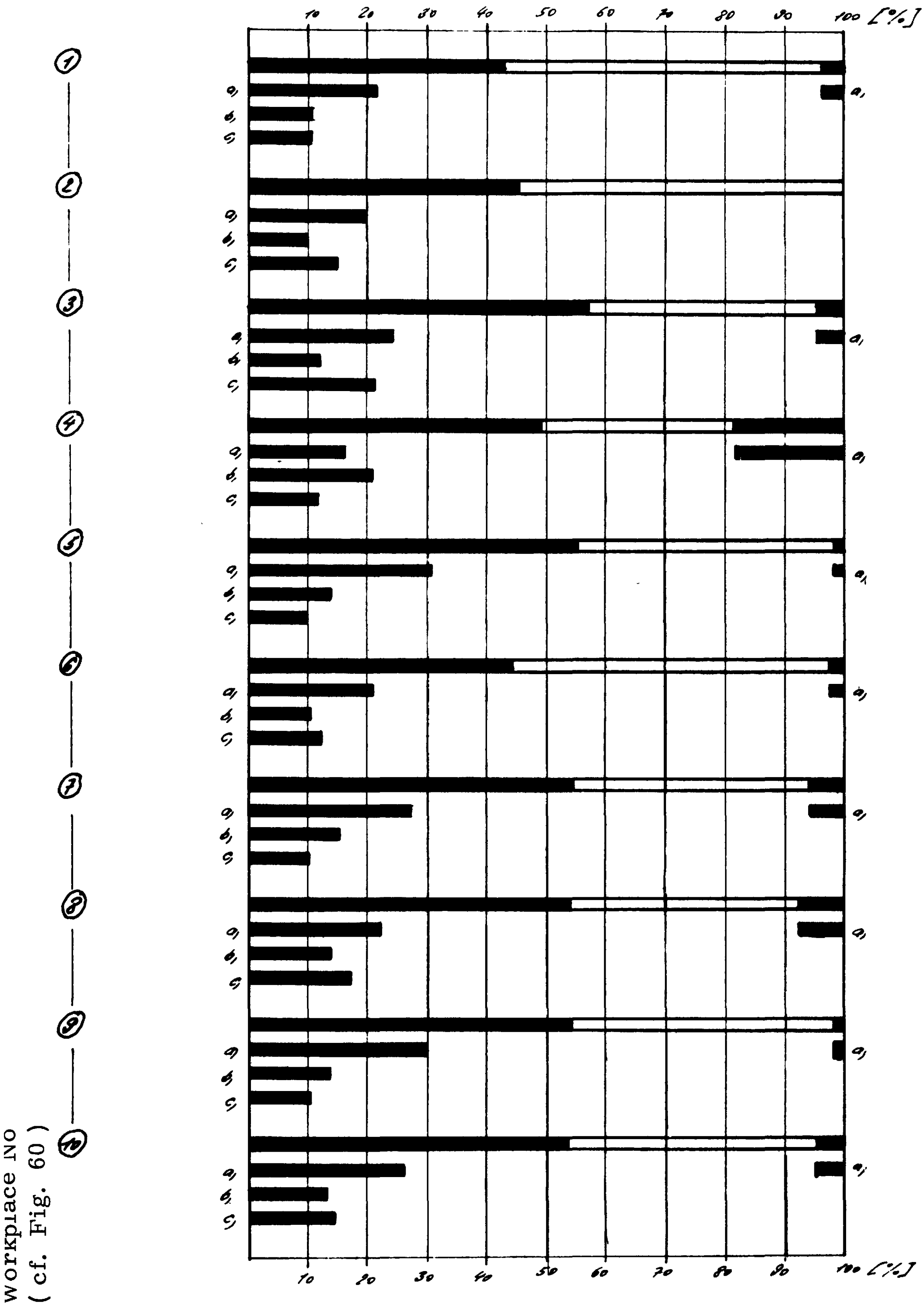


Fig. 48 - Trunk position : Flexion and extension in sagittal plane

forwards
a) slight
b) medium
c) marked

normal posture

backwards
a) slight
b) medium
c) marked

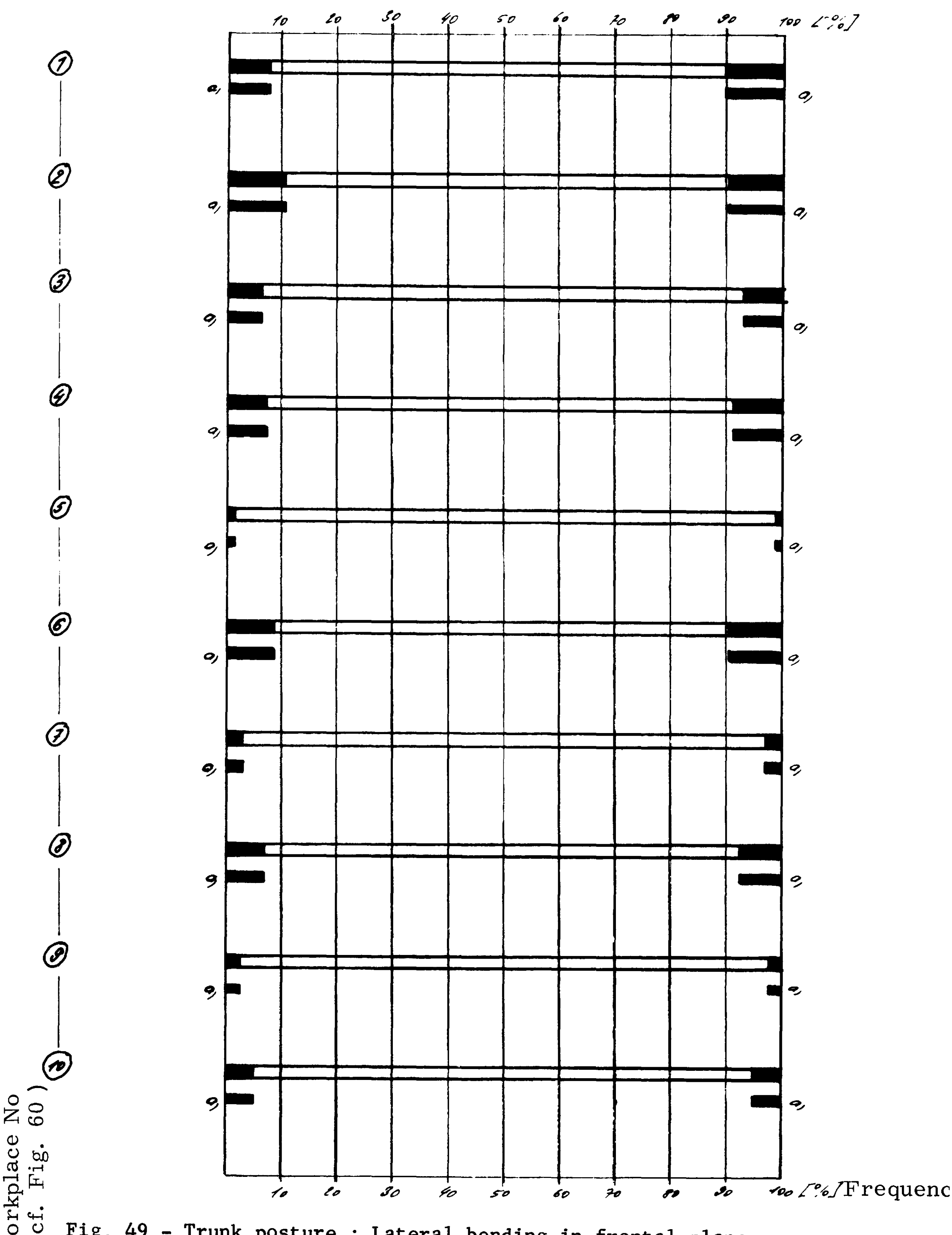


Fig. 49 - Trunk posture : Lateral bending in frontal plane

to left
a) slight
b) medium
c) marked

normal posture

to right
a) slight
b) medium
c) marked

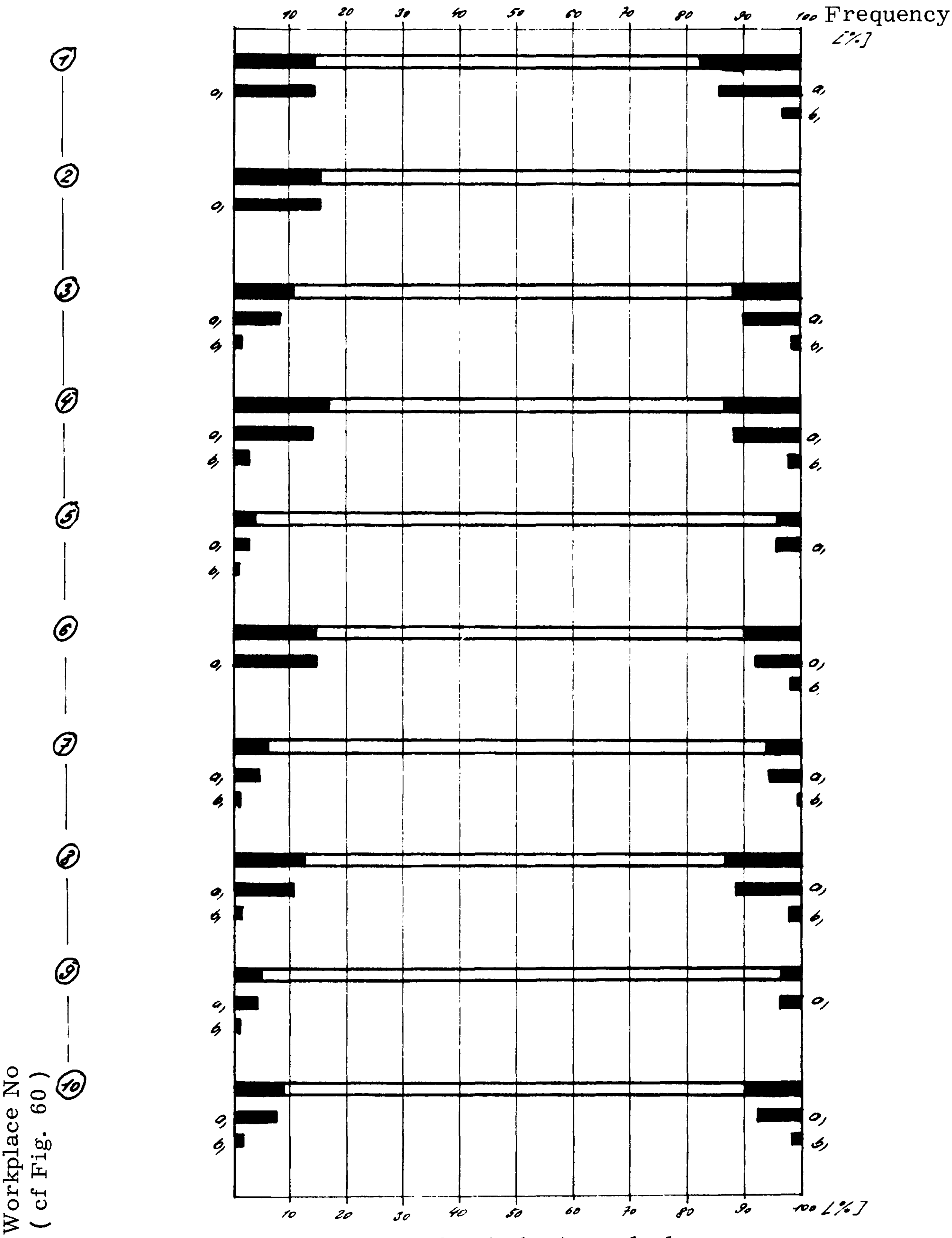
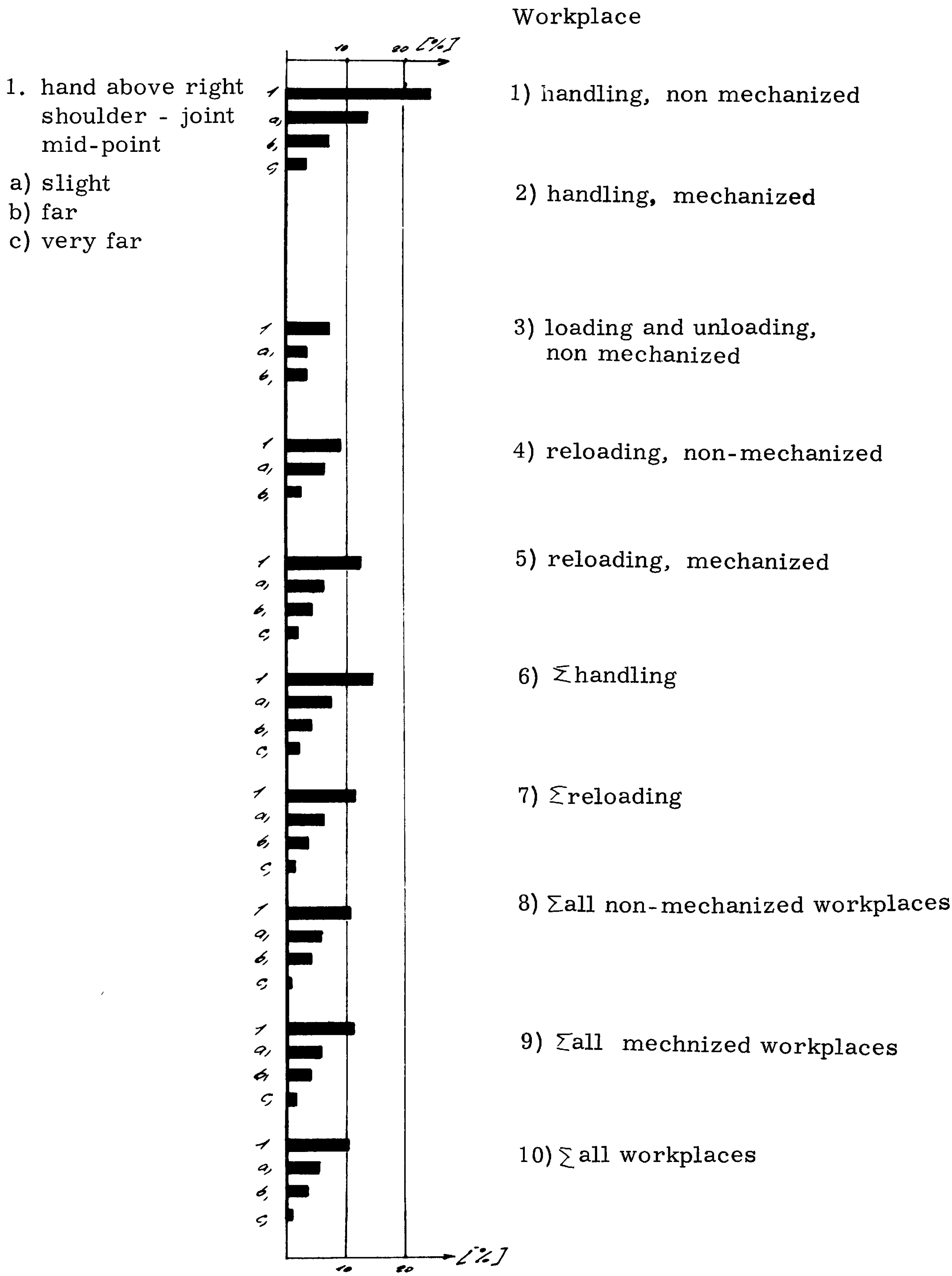


Fig. 50 - Trunk posture : Rotation in horizontal plane

to left
a) slight
b) medium
c) marked

to right
a) slight
b) medium
c) marked



<u>Fig. 51</u> - Height of right hand relative to mid-point of right shoulder-joint (in % of frequency)

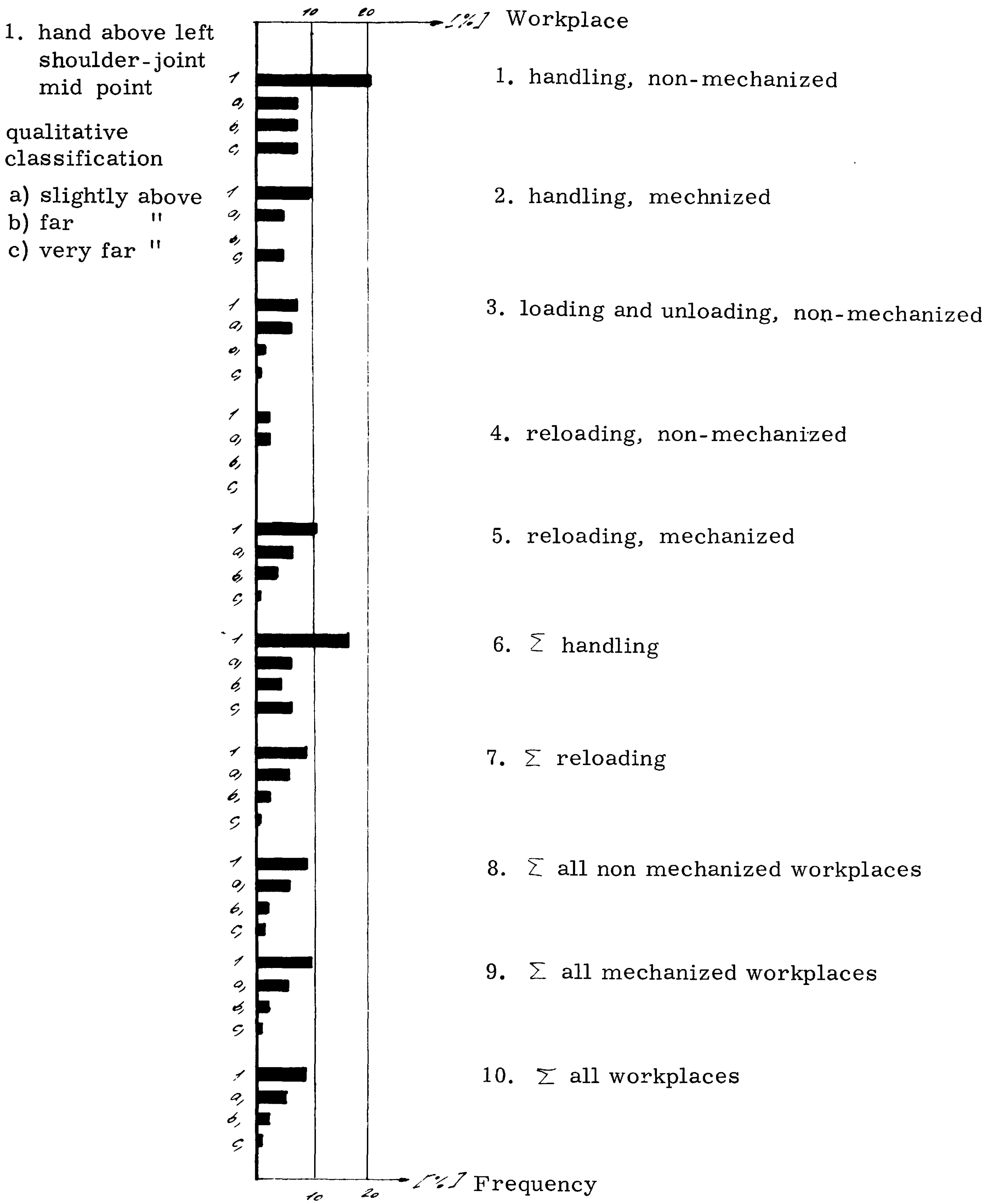


Fig. 52 - Height of left hand relative to mid-point of left shoulder-joint

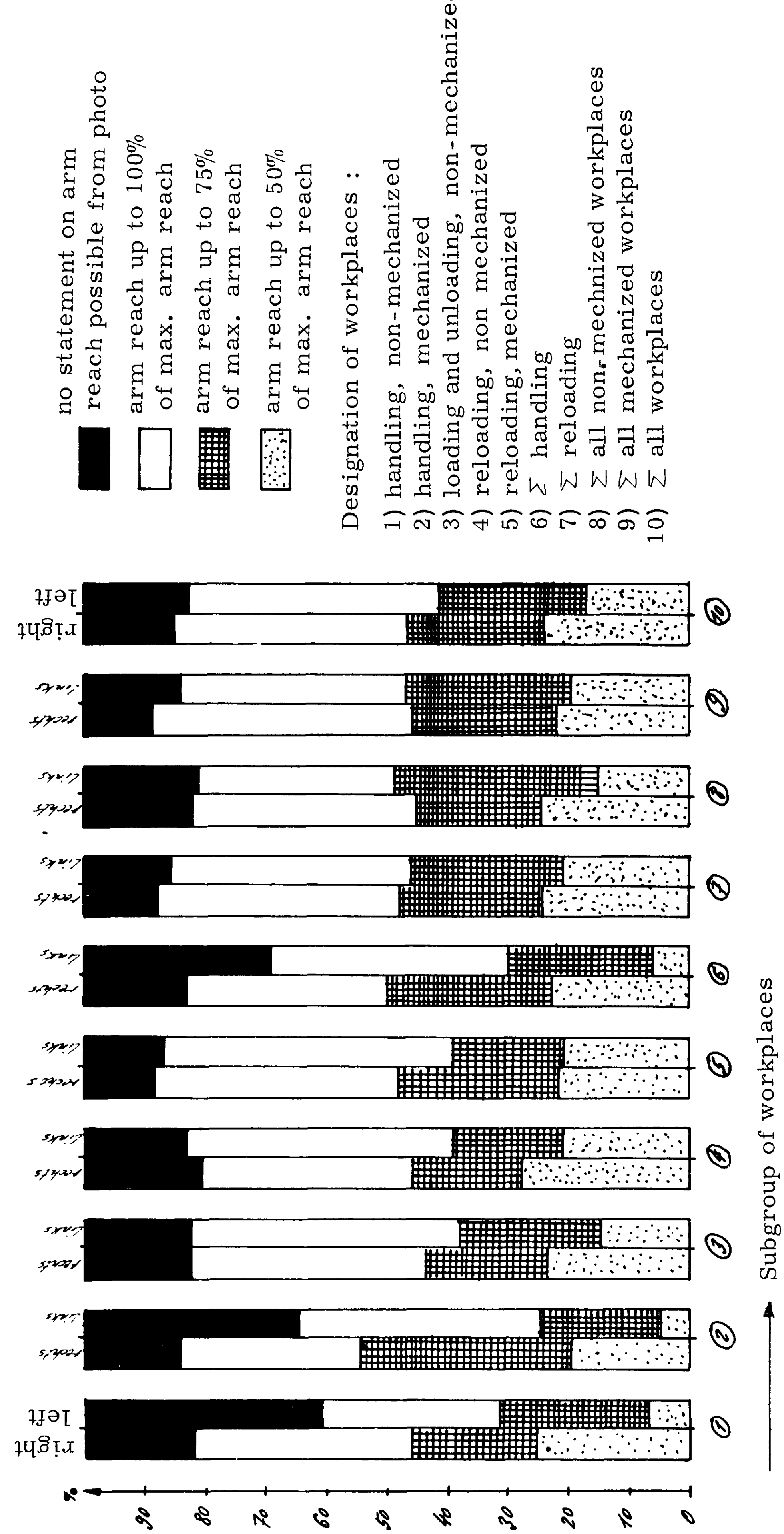


Fig. 53 - Reach of arm in % of max. reach of arm

105/71 e - RCE

4.4.5 Arm posture

A further indication of an additional static load can be given by considering the height of the right (Fig. 51) and the left (Fig. 52) hand. Here - with the exception of non-mechanized and mechanized handling (only in the case of the right hand) - the values of the sub-groups found correspond to the averages in all workplaces. Operations such as 'inserting support sections in the bending press' and 'operating the press' account for the deviations which occur.

In the case of mechanized handling, the right hand carries out most of the assembly work, the sphere of activity of which lies below the mid-point of the shoulder-joint.

No direct conclusions as to the type of static load can be drawn from the diagram of the reach of the arms in % of the max. reach of the arms (Fig. 53) because the height of the points of application of the hand (Figs. 51, 52) must be taken into account for this purpose.

4.4.6 Leg posture

Characteristics, from which conclusions as to stability in standing and the changed position of the body's c.g. can be drawn indirectly, are assigned to columns 23 and 24 of the coded classification (Chapter 4.2.2). The leg positions observed are classified into the basic types shown in Chapter 3.2.6. On average, no conclusion can be drawn as to the leg posture assumed in the case of 38 % of the miners studied because the supporting surface on the floor is generally covered with material, tools etc. Definable leg postures are distributed more or less evenly among all basic types of the supporting surface.

4.4.7 External load

In addition to data regarding position and posture, other loads and weights are determined as characteristics of columns 35, 36 and 37 of the classification used. The right hand (35), the left hand (36) and the shoulders (37) are regarded as the bearing bodily parts. The following picture emerged for the places studied: the right hand was not subjected to any load in 53 % of the cases (left hand in 56 %) and in 11 % of the cases (left hand 9.5 %) was only subjected to a light load.

If the loads to be borne are classified subjectively into three categories : light, medium-heavy and heavy - the right hand accounts for about 33 % of the cases of medium-heavy to heavy loads, and the left hand for 31 % (of which 29 % were handled simultaneously with both hands). In connection with the static work of holding, this high figure is an appreciable one because of unfavourable bodily positions.

As regards the load on the shoulders, in about 99 % of the cases no weight effects were recorded; in 0.5 % of the cases there was a light load (3 cases) and a heavy load (4 cases).

Medium-heavy to heavy loads are distributed as follows : 83 % in the standing position, 3 % in the sitting position and 14 % in the kneeling position. As regards workplaces, it was found that medium-heavy and heavy loads were distributed as to 75 % to non-mechanized and

25 % to mechanized places. For handling, these percentages were about 7 %, for loading and unloading 54 % and for reloading 39 %. This inventory clearly points to the unfavourable conditions prevailing in non-mechanized workplaces, especially where loading and unloading is carried out.

5. Summary

The theory of bodily positions and postures is described in the light of the results of the literature. The notion of bodily position is used for the basic positions of standing, sitting and lying and for the special positions of standing, i.e. squatting and kneeling. Further characteristics are taken into account through postures as variants of positions (e.g. position of head, trunk and arms).

For all the positions shown, a classification is developed which enables shifts of parts of the body from defined reference positions to be described both qualitatively and quantitatively. Coding is defined in such a way as to permit it to be recorded on punched cards and processed in data-processing units.

A collection of 477 photographs showing the bodily positions of miners taken from the material transport sector of underground workings is evaluated with the help of a computer program on a data processing machine.

The example shows that the classification, with a very slight modification - here for the case of a qualitative description - can be satisfactorily used.

A study of the photographs, which were not chosen by any strict criteria, enables conclusions to be drawn about a number of workplaces associated with very high bodily loads

a) because of unfavourable positions and postures and

b) because of additional weights.

This alone would offer an initial basis for scientific work layout. With the help of systematic methods of determination (e.g. multi-moment method) and simultaneous submission to expert opinion, a viable method would be found which would yield the information necessary for a better design for any load situations arising from bodily positions and other adverse factors in industrial workplaces.

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