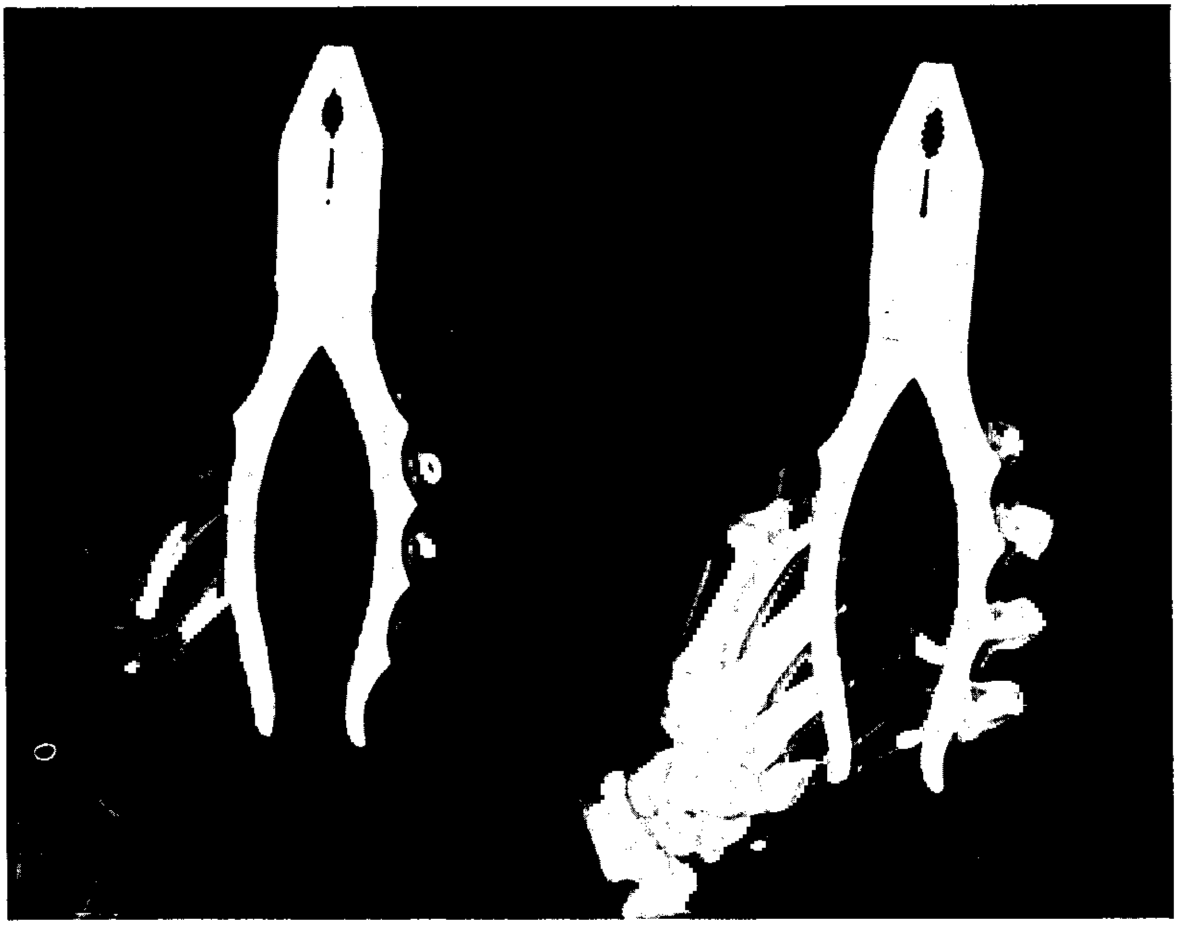


Figure 32-34. Form-fitting hand tools often fit only the hands of the designer. When an oversized or undersized hand grips a finger grooved handle, then undesirable pressure upon the surfaces of the joints may be exerted.[49]

should also be made of nonporous materials so that they will not soak up or retain oils or other liquids.[49]

Power Tools

The operating mechanism of most power tools are either reciprocating (i.e., vibratory) or rotary. They are operated by either compressed air or by electricity.

When selecting reciprocating or vibratory tools, the frequency and amplitude spectrum of the vibrations transmitted onto man should be evaluated.[40] The risk of somatic resonance response is highest when amplitude exceeds 100 microns within a frequency band between 3 to 125 Hertz. This has already been discussed in general terms under the heading of "Man-Equipment Interface." With respect to the operation and selection of hand tools, Raynaud's Syndrome (i.e., White Fingers) provoked at critical frequencies or potential exacerbation of developing bone and joint disease, deserves careful consideration.

When tools are activated by a rotating mechanism, the maximum torque transmitted upon the axis of rotation of the forearm should be below 12 inch-lbs. A 2-handed power tool should be designed with an angle of 120° between the gripping axes of both hands (Figure 32-40) for optimum operation when firmly held.

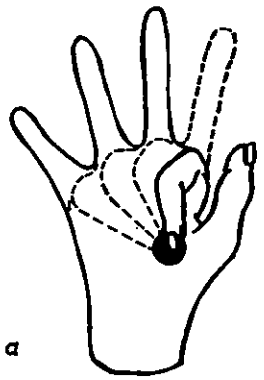
Tools powered by electricity should not be operable without a ground line which uses the third or middle prong of the power plug. Makeshift conversion from 3-prong to 2-prong adaptors should be prevented by appropriate plug and socket design.

MANUAL MATERIALS-HANDLING AND LIFTING

Almost one-third of all temporarily disabling injuries at work are related to the manual handling of objects.[50] Many of these are avoidable and are the consequence of inadequate or simplistic biomechanical task analysis.

The Elements of a Lifting Task

Relative severities of materials-handling operations and differences in lifting methods can only



Basmajian, J. V.: Muscles Alive: Their Function Revealed by Electromyography, 2nd Edition. Baltimore, The Williams & Wilkins Co., 1967.

Figure 32-35. The fingers buttress against each other when flexed.[77]

be evaluated when all elements of a lifting task are considered together as an integral set (Table 32-3).

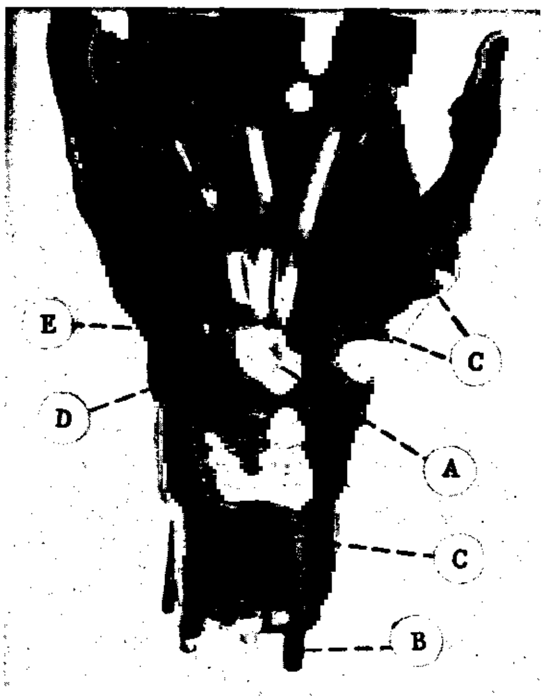
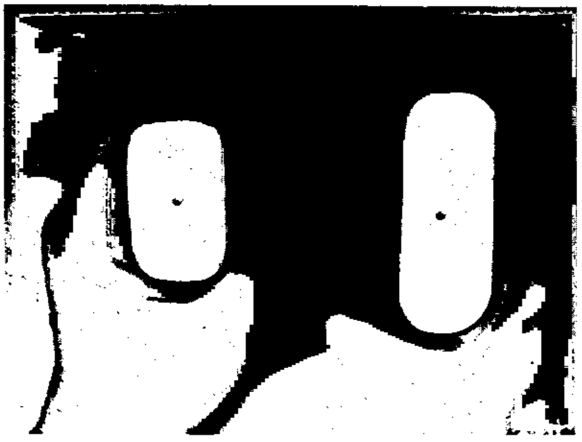


Figure 32-36. Through the carpal tunnel (A) pass many vulnerable anatomical structures: blood vessels (B) and the median nerve (C). Outside of the tunnel, but vulnerable to pressure are: the ulnar nerve (D) and a major artery, the palmar arch (E).

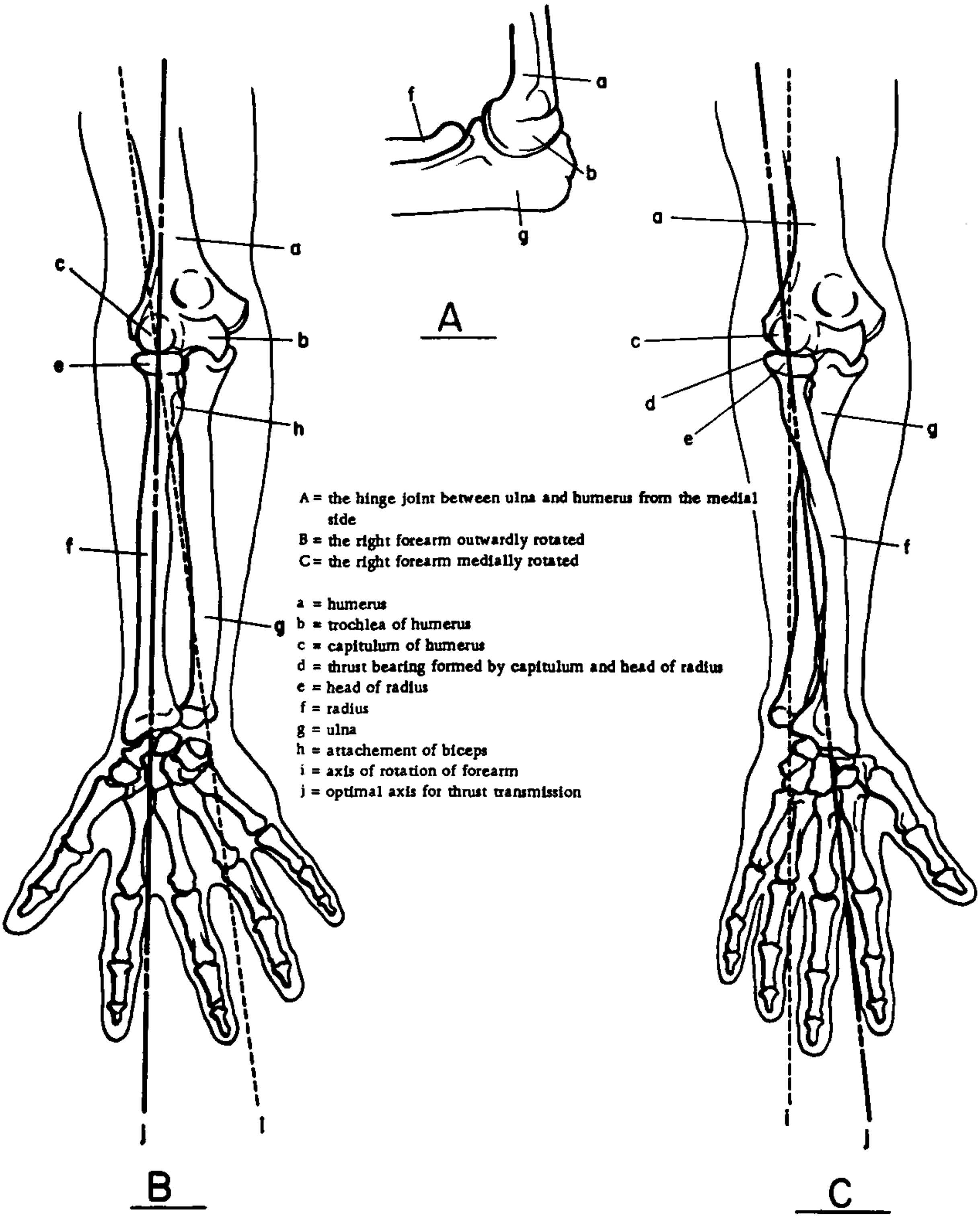


Tichauer, E. R.: Gilbreth Revisited. New York, American Society of Mechanical Engineers, 1966.

Figure 32-37. Too wide a pistol grip on an electric hand drill prevents a firm grasp because distal phalanx of a finger cannot be flexed strongly unless middle phalanx has been prepositioned by bending. A grasp around a handle which is too wide will produce large compressive forces on joints and may lead to joint disease or trigger finger if tool is used often enough and long enough.[73]

All these elements are of different mechanical dimensions (Table 32-4) but, nevertheless, have one basic property in common. Any change in magnitude of any element of a lifting task produces a change in magnitude of metabolic activity. Thus, no matter what the dimensions of mechanical stress imposed upon the human body during materials-handling are, the physiological response will result in increased energy demand and release, conveniently measured in "calories." Therefore, physiological response to biomechanical lifting stress has always the dimensions of work. Hence, the measurement of metabolic activity through computation of oxygen uptake per unit of time provides a convenient experimental method for the objective measurement of the relative severity of materials-handling and other chores. The current consensus[51] assumes on the basis of an 8-hour working day, that the limit for heavy continuous work has been reached when oxygen uptake over and above resting level approaches 8 kilo-calories per minute. 6 kilo-calories per minute seems to be the upper limit for medium heavy continuous work while an increment of 2 kilo-calories per minute appears to be the dividing line between light and medium-heavy work (Table 32-5).

However, application of metabolic measurement is often not possible. The procedure requires expensive equipment, great expertise and is often difficult to perform on the shop floor. Furthermore, the objective assessment of work stress through the analysis of respiratory gases is an ex post facto procedure. The job exists already and its energy demands are computed so that possible corrective action may be considered. It is, of course, much better to analyze a task objectively while both job as well as workplace layout are



A = the hinge joint between ulna and humerus from the medial side
B = the right forearm outwardly rotated
C = the right forearm medially rotated

a = humerus
b = trochlea of humerus
c = capitulum of humerus
d = thrust bearing formed by capitulum and head of radius
e = head of radius
f = radius
g = ulna
h = attachement of biceps
i = axis of rotation of forearm
j = optimal axis for thrust transmission

Figure 32-38. THE CONSTRUCTION OF THE SKELETON OF THE FOREARM.

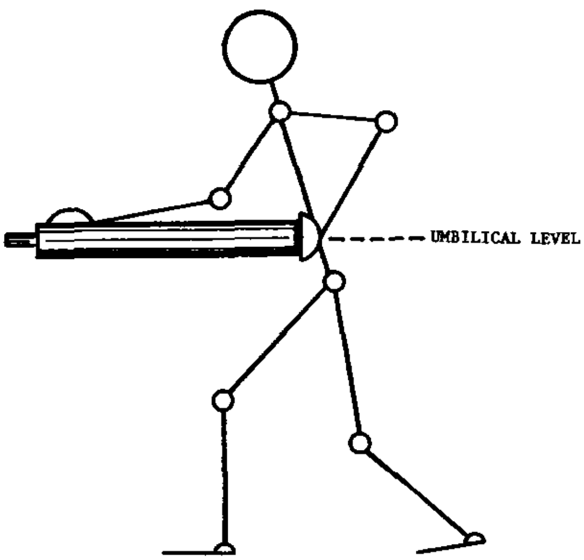


Figure 32-39. The axis of action as well as the center of mass of a heavy two-handed powertool should be located in that transverse plane which passes through the umbilicus.

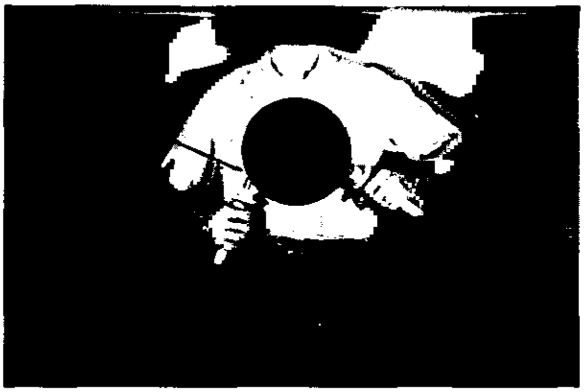


Figure 32-40. The included angle between the axes of the handles of a two-handed power tool should approximate 120 degrees to achieve optimal biomechanical posture.

still in the design stage. Recourse must then be taken to elemental analysis.

By definition, a state of lifting exists whenever a moment — no matter in which direction — acts upon the vertebral column. A "moment" is defined as magnitude of the force times distance of application. The three "static moments" (Table 32-3/a) are easy to compute, either from drawings, from photographs, or by speculative analysis. Moments are conveniently expressed in foot-pounds, multiplying the force acting upon an anatomical structure with its distance from the point of maximal stress concentration. The heaviest article normally handled by man at work is his own body. Only rarely do workers handle objects weighing 150 lbs., and, in most instances, the mass of an object moved is quite insignificant when compared to the weight of the body segment involved in the operation. For example, the majority of handtools or mechanical components in industry weigh considerably less than ½ lb., but an arm, taken as an isolated body segment, weighs 11 lbs.[52, 53]

The sagittal lifting moment is the one easiest to compute and is of greatest severity when lifting loads and putting loads down right in front of the body. It is most conveniently derived by graphical methods. First, the weights of the body segments involved in a specific task are obtained from reliable tables.[54] Then a "stick figure" of proper anthropometric dimensions (Figure 32-41) is drawn and the location of the center of mass for each body segment as well as for the load handled is marked. Finally, the sum of all moments acting upon a selected anatomical reference structure (in this case the lumbo-sacral joint) is computed and becomes the sagittal biomechanical lifting equivalent of the specific task under consideration.

The estimation of sagittal lifting equivalents is of great practical usefulness in the comparison of work methods. It is often necessary to decide if a task is better performed sitting as opposed to standing (Figure 32-42). A schematic sketch or a photograph is then a convenient aid to decision making. The masses involved, i.e., the torso above the lumbo-sacral joint plus neck, head, upper limb and the object manipulated are identical for each individual, in both the seated and standing postures. According to data by Abt,[55] the body mass in the case of a 110-lb. female would be 45 lbs. To this, the weight of the object handled, in this case, 20 lbs., is added. Then computing moments,[56, 57] the distance from the lumbo-sacral joint to the center of mass of body segments and load combined equals approximately 1½ ft. (Figure 32-42/L). However, in the case of a seated individual, value "L" becomes approximately 2½ feet. This is due to the forward leaning posture of trunk and the outstretched arm. Therefore the torque exerted on the lumbar spine now is increased to 146 ft.-lbs. or nearly 50% more than when standing. This explains why, in so many instances, when unnecessary chairs are introduced in the work situation, workers, instead of being overjoyed, complain rightly about much increased work stress.

Analyzing lifting tasks routinely in terms of moments tends to develop in supervisors a healthy and critical attitude toward cut and dried "cookbook rules of lifting." The principle of "knees bent-back straight-head up" is well enough known. However, a simple diagram (Figure 32-43) shows that in many work situations sensible concessions must be made to the influence of body measurements on work stress. In Figure 32-43 "Mr. X," long legs, short torso shows the anthropometric configuration of a typical male; while "Ms. Y," relatively long torso and fairly short legs, has female body characteristics. It can be

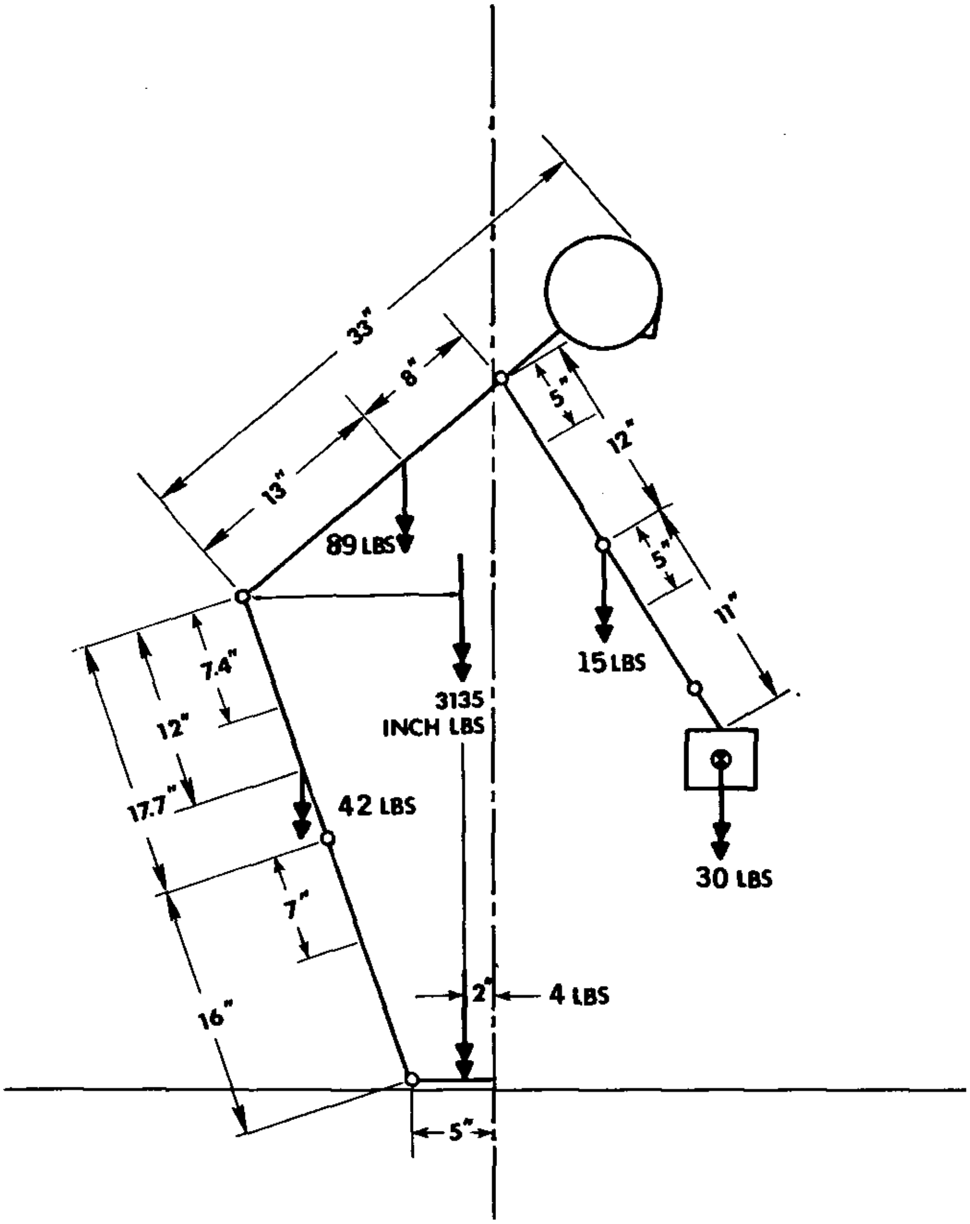
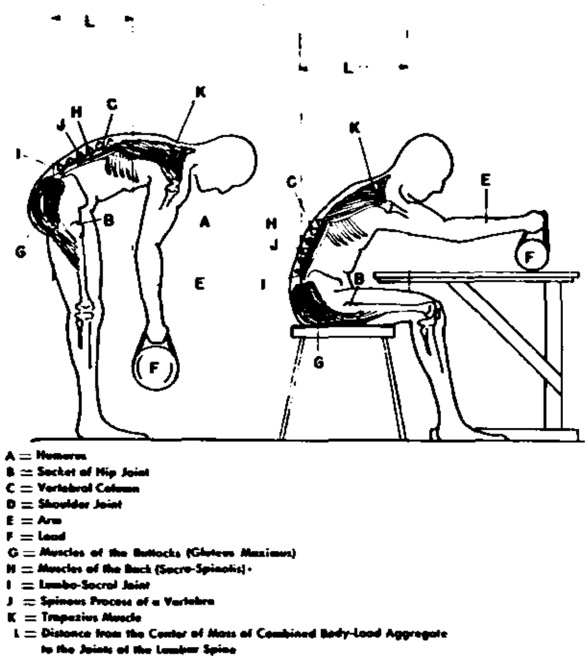


Figure 32-41. Graphic computation of the location of center of mass of whole body and body segments as well as of the sagittal moment acting upon the lumbo-sacral joint can be conveniently accomplished through the use of stick figures. This example shows that an improper working posture, a load weighing only 30 lbs., combined with the mass of the various body segments involved in a lifting task, may produce a torque exceeding 3000 inch-lbs., which is the lifting equivalent of a very severe task.

readily seen that "Mr. X" does not benefit at all from application of the standard lifting rule simply because his body build prevents him from getting under and close to the load. Therefore, distance "L" in Figure 32-43/b is no shorter than distance "L" in Figure 32-43/a; therefore, the moments acting on the lumbar spine are the same in both cases. Ms. "Y," however, due to a differently proportioned body, can get under the load and close to it. Thus, distance "L" now becomes much shorter and the moments on the lumbo-sacral joint and therefore, also work stress, are approximately halved. Under such circumstances, provided that the height of the workbench cannot be changed, the standard lifting rule may be applied to the female, while in the case of the male, no benefit is derived. To the contrary, working in the "approved lifting posture" may lull a male worker into a sense of false security.

It has already been described earlier (Figure 32-33) how a light but bulky object will often impose a lifting stress much greater than the one



Tichauer, E. R.: Ergonomics of Lifting Tasks Applied to the Vocational Assessment of Rehabilitees. Rehabilitation in Australia, Oct. 1967, pp. 16-21.

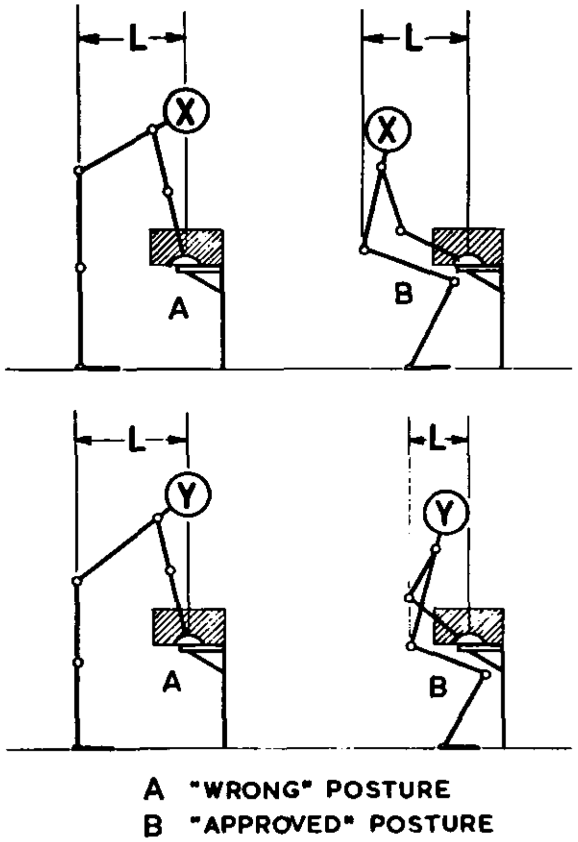
Figure 32-42. A change from standing to seated working posture may move the centre of mass of the combined body load aggregate away from the lumbar spine and thus increase stress there. When changing from standing to seated work, reach length should be kept as short as possible.[52]

exerted by a heavier article of greater density. Indeed, the ergonomic problems resulting from recent trends in miniaturization and containerization have added a serious and perhaps sinister overtone to the age-old jocular question: "Which is heavier — one pound of lead or one pound of feathers?" The feathers, of course; they are so much bulkier!

In many instances, however, other moments in addition to the sagittal one must be considered. Lateral bending moments assume importance whenever a job calls for "side-stepping" (Figure 32-44) or the handling of materials on trays. Likewise, consideration of torsional moments becomes necessary when materials are transferred from one surface or workbench to another (Figure 32-45).

All moments like the other elements of a lifting task add up, not algebraically but vectorially. The magnitude of lateral and torsional moments is computed by procedures similar to the one described for the sagittal moment. Often a mathematical computation becomes unnecessary because trained ergonomists soon develop the knack to "guesstimate" rather correctly the magnitude of all three moments by looking at the worker, motion pictures or a drawing of the workplace layout.

It may be assumed that, when the vector sum of all three moments is 350 inch-lbs. or less, the work is light and can be performed with ease by untrained individuals, male as well as female, irrespective of body build. Moments above this level but below 750 inch-lbs. put a task into the classification of "medium-heavy" requiring good body structure as well as some training. Tasks above this but below 1200 inch-lbs. are considered to be heavy requiring selectivity in the recruitment of labor, careful training and attention to rest pauses. Whenever the vector sum of moments exceeds those stated before, then the work is very heavy in nature, cannot always be performed on a continuing basis for the entire working day and requires great care in recruitment and training.



Tichauer, E. R.: Ergonomics of Lifting Tasks Applied to the Vocational Assessment of Rehabilitees. Rehabilitation in Australia, Oct. 1967, pp. 16-21.

Figure 32-43. Postural corrections in training for lifting should be aimed at reducing torques acting on the spine. "X," an anthropometric male, does not benefit materially from the "approved" lifting posture because "L," the distance from the center of mass of load to the fourth lumbar vertebra, does not shorten materially. "Y," an anthropometric female, does benefit from the "bent knees, straight back" rule because she can get under the load. When matching worker and task, the measurements of the individual worker as well as the dimensions of the workplace should be considered.[52]

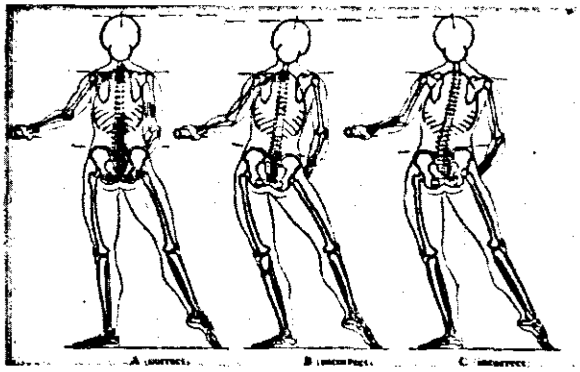


Figure 32-44. Side stepping induces heavy lateral bending moments acting on the spine. (from: SPARGER, C.—Anatomy and Ballet-by A. and C, Black Ltd., London, 1960).

The gravitational components are elements of a lifting task which are always present.

In physics work is defined as a product of force and the distance through which this force acts. Thus, lifting 10 lbs. against gravity to a height of 5 feet will constitute 50 foot-lbs. of work. Likewise, pushing an object horizontally for a distance of 5 feet when 10 lbs. of pushing force are required to perform this task throughout this distance will also result in 50 foot-lbs. of work.

This definition, however, is not always applicable from the standpoint of work physiology. For example, if an individual pushes with all his force against the wall and moves neither his body nor the wall, he has not accomplished any work in the sense of physics. Nevertheless, during the entire time while his muscles are under tension, his metabolic activities have increased, and the added energy demands of the living organism manifest themselves in the expenditure of additional calories which, in physics, are assigned the dimensions of work. The event which causes such physiological work to be performed is called "isometric activity." Isometric "work" is performed whenever a muscle is under tension, but produces no visible motion. Another kind of "physiological work" is "tension time."[58] This also results in an increased expenditure of calories and is performed whenever muscle is under tension for an interval of time. Tension time is always present and must always be taken into consideration whenever a materials-handling task is performed. It can be estimated simply by taking the weight of the object handled plus the weight of the body segment involved in the task, and multiplying this by the time the musculature is under tension.

Both "isometric work" and "tension time" are assigned the dimensions of "impulse" which equal force multiplied by time. For the practical purposes of work stress estimation, "isometric work" and "tension time" are added algebraically together, and their sum, named the "isometric component" (as distinct from "isometric work") is in turn added vectorially to the other gravitational components (Table 32-3).

A vector defined by the dimensions of impulse is obviously not additive with other vectors carrying the dimensions of work. To overcome this difficulty, a simple mathematical transformation is useful.[58]

Dynamic work is defined as the product of the weight of an object handled multiplied by the vertical distance through which it is lifted upwards against gravity. It has the dimensions of work as defined by physics.

Negative work is performed whenever an object is lowered at velocities and accelerations of less than gravity so that work against the gravity vector is performed. To avoid complex computations, it is practical under industrial working conditions to accept the recommendation by Karpovich[59] to assume that one-third of that work which would have been expended when lifting the same object over the same distance in an upward direction is approximately equal to the dynamic work equivalent of the task.

TABLE 32-3

The Elements of a Lifting Task

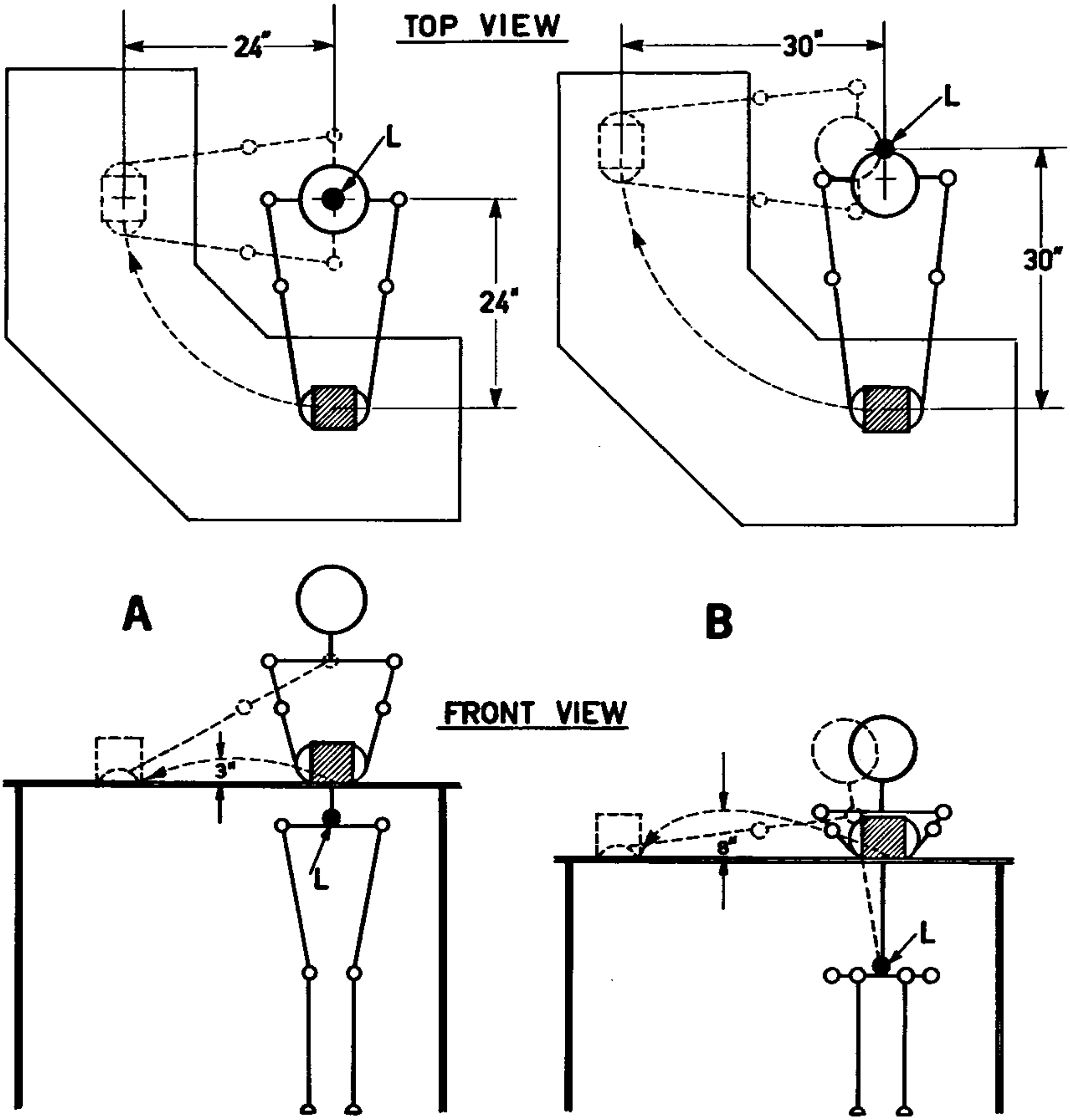
(a) Static Moments	(b) Gravitational Components	(c) Inertial Forces
sagittal	isometric	acceleration
lateral	dynamic	aggregation
torsional	negative	segregation

(d) Frequency of Task

Finally, the inertial forces have to be considered. Often acceleration over several inches of distance is too insignificant to demand numerical evaluation of this vector, provided that isometric activity is given due consideration. However, the forces involved in the aggregation and segregation of man and load do affect work stress to a high degree.

In order to maintain equilibrium in upright posture, it is necessary that the center of mass of the body be located above a line passing through the sesamoid bones of the big toes. Whenever a load is lifted, then object and human body become one single aggregate and during the act of aggregation, the combination of load and body and the formation of a single center of mass exert forces upon vulnerable anatomical reference points. Likewise, during segregation the displacement of the center of mass of the body exerts forces on diverse anatomical structures.

Inertial forces have the dimensions of mass multiplied by acceleration (i.e., force). Objects such as are commonly handled in industry are lifted (i.e., aggregated) over approximately three seconds, while release (i.e., segregation) is much faster requiring only a time interval of somewhat less than 1/25th of a second. Therefore the severity of a lifting task is greatest at the instant of



L = lumbo-sacral joint

Figure 32-45 & 46 (A & B). Schematic Drawing of the Lifting Task Evaluated Quantitatively in the Text of Standing (A) and Seated (B) Position. Solid lines describe posture at beginning, broken lines posture at end of task.

load release.

It was already mentioned that the severity of a lifting task can be reliably evaluated by theoretical analysis. Under such circumstances, all the elements of a lifting task as listed in Table 32-3 are described quantitatively and the values then added as vectors. The addition of vectors, however, demands that the quantities involved in the computation are of identical dimensions. Therefore it is necessary, prior to final computation, to reduce the elements of a lifting task to values with compatible dimensions. It was already established by the pioneers of work physiology[60, 61] that the basic activity of the musculo-skeletal system leading to increased energy demands, expressed in terms of calories (dimensions of work) would be isometric effort (dimensions of impulse).

Work with rehabilitees caused researchers in the immediate period following World War II to assume that for computational purposes it would be desirable to reduce all elements of physical work to quantities having the dimensions of impulse (i.e., force × time). The soundness of this approach was validated by Starr.[58] To make all elements of a lifting task dimensionally compatible with isometric effort, the following operations are performed:

1. The vector sum of the three moments is divided by distance (moment arm) and multiplied by performance time.
2. The total physiological effort equivalent of isometric dynamic and negative work is obtained from the formula:
   physiological effort equivalent =
   $$\int_0^t m\,|a+g|\,dt;$$
   where t is performance time and a is acceleration other than gravity, while g is the acceleration due to gravity and m equals mass.
3. The inertial forces of acceleration, aggregation and segregation are multiplied by their time components. This converts all elements into equivalents of physiological effort with the isometric dimensions of lbF sec or Force lbs. multiplied by time.

The following practical example will illustrate in step by step fashion the mode of application of this approach to lifting problems.

Solved Problems

The lifting and transfer of a box weighing 30 lbs. from a table to a sideboard without side-stepping can be performed either seated or standing (Figure 32-46).

When standing the object is picked up from a point in the midsagittal plane two feet in front of the midcoronal plane. It is put down in the midcoronal plane two feet to the right from the midsagittal plane. Operation time amounts to two seconds per box and maximum height of lift is 3 inches. Frame by frame film analysis shows aggregation and segregation times to be 0.5 seconds and 0.04 seconds respectively, while segmental analysis (Figure 32-41) permits the assumption that the displacement of the center of gravity of the body in aggregation and segregation equals 2 inches.

When the worker is in a seated position, and the workbench interferes with knees and other anatomical features, the worker must move further away from the task, and now the distances from the coronal and sagittal plane respectively will equal 30 inches. Performance, aggregation and segregation times are now 4 seconds, 0.6 seconds and 0.05 seconds respectively. The changed postural configuration increases the displacement of the center of mass during aggregation and segregation from 2 inches to 3 inches and the maximum height of lift from 3 inches to 8 inches.

For the purposes of comparative work stress evaluation, the following assumptions are made:

1. Accelerations and decelerations are constant and equal in magnitude for all displacements.
2. The path of the center of mass of the box approximates a straight line from pick-up point to the maximum height of lift.
3. Peak velocity of displacement is attained midway between aggregation and segregation points, and is assumed to be twice the average velocity.
4. The load accelerates from 0 to peak velocity and decelerates back to 0.

Sagittal and lateral moments are obtained in lbF ft, by multiplying the weight of the box by its distance from the midcoronal and midsagittal plane respectively. To compute the torsional moments, the mass of the box is multiplied by its acceleration and the resulting force multiplied by the distance. The weight of trunk and arms was neglected in these calculations because they are constant for both postures, and their inclusion would have increased the complexity of computation considerably without materially increasing the accuracy for the purposes of estimation.

The following symbols will be used throughout calculations:

w = weight of the load
m = mass of the load
W = weight of the man
M = mass of the man
lbF = pounds force
l = reach of arm in ft.
t = operating time in seconds.
a = acceleration and deceleration during the operation
b = acceleration and deceleration during aggregation
c = acceleration and deceleration during segregation
S = total path travelled during the operation in ft.
h = height to which the load is lifted in ft.
t' = aggregation time in seconds.
t'' = segregation time in seconds.
x = distance through which the center of gravity moves in aggregation and segregation.

Subscript 1 denotes standing position.

Subscript 2 denotes sitting position.

The numerical values of those parameters which describe adequately both lifting tasks, the standing and the seated one, for the purposes of quantitative analysis, are stated in Table 32-4. On the basis of these values, the elements of both lifting tasks are now computed as represented in Table 32-5. Now the values obtained are made isodimensional with physiological isometric effort for the purposes of computation as derived in Table 32-6. Finally, the total level of physiological effort for standing and seated work while performing the lifting task is computed by the methods shown in Table 32-7. The results of this analytical exercise, provided that the frequency of lift is the same in both cases, shows clearly that in this case a standing working posture requires far less effort and that the provision of seating accommodations far from making the task easier, would require almost twice the effort expanded by a standing worker.

As this chapter addresses itself specifically to biomechanics proper, a comprehensive treatment of lifting and materials-handling would exceed the boundaries of the section and lead to overlap with other chapters. Nevertheless, occupational safety and health problems stemming from manual materials-handling are numerous and complex. Therefore, wide cross-reading on all aspects of manual materials-handling is recommended. By way of illustrative examples, culled from a larger number of equally excellent publications, Astrand[62] and others[63] are cited as a good source of reference on work physiology. McCormick[64] deals in a comprehensive fashion with the human factors aspects of lifting and back problems while Snook[65] and Snook and Irvine[66] treat the psycho-physiological aspects of the problem extensively. Finally, the publications of the National Safety Council,[67] Himbury[68] and Grimaldi[69] are recommended as general references which place the problem of manual materials-handling into proper perspective with respect to the overall problem of occupational safety and health.

MEASUREMENT AND EVALUATION IN BIOMECHANICS

Americans have always been a nation of problem solvers. The history of this country in fields economical and social, as well as technological, bears ample witness to this. Thus it is but logical that all industrial, as well as technological development in this country stems from the need to overcome and solve problems of design, production, distribution and use of manufactured articles. However, the very concept of "problem solving" implies that an existing situation is unsatisfactory and must be improved. Therefore American industry traditionally has subscribed to the "improvement approach" as the principal avenue towards economic efficiency and viability of private enterprise. This, in many instances, has led to

TABLE 32-4
Numerical Values of Parameters
Describing Lifting Example

Symbol	Values	
	Standing	Sitting
t	$t_1 = 2.00$ secs	$t_2 = 4.00$ secs
t'	$t' = 0.50$ secs	$t'_2 = 0.60$ secs
t''	$t''_1 = 0.04$ secs	$t''_2 = 0.05$ secs
l	$l_1 = 2$ ft.	$l_2 = 2.5$ ft.
h	$h_1 = 1/4$ ft.	$h_2 = 2/3$ ft
x	$x_1 = 1/6$ ft.	$x_2 = 1/4$ ft.
$S = 2\sqrt{\frac{l^2}{2} + h^2}$	$S_1 = 2\sqrt{\frac{2^2}{2} + \left(\frac{1}{4}\right)^2}$ $= 2.8722$ ft.	$S_2 = 2\sqrt{\frac{(2.5)^2}{2} + \left(\frac{2}{3}\right)^2}$ $= 3.7784$ ft.
$a = \frac{4S}{t^2}$	$a_1 = \frac{4(2.8722)}{2^2}$ $= 2.8722$ ft/sec^2	$a_2 = \frac{4(3.7784)}{4^2}$ $= .9446$ ft/sec^2
$b = \frac{4x}{(t')^2}$	$b_1 = \frac{4(1/6)}{0.5^2}$ $= 2.6664$ ft/sec^2	$b_2 = \frac{4(1/4)}{0.6^2}$ $= 2.7777$ ft/sec^2
$c = \frac{4x}{(t'')^2}$	$c_1 = \frac{4(1/6)}{0.04^2}$ $= 416.6250$ ft/sec^2	$c_2 = \frac{4(1/4)}{0.05^2}$ $= 400.0000$ ft/sec^2

TABLE 32-5
Values of Elements of Lifting State in Their Proper Dimensional Units

Elements	Values	
	Standing	Sitting
Sagittal Moment $= wl$	$wl_1 = 30(2) = 60$ lbF ft	$wl_2 = 30(2.5) = 75$ lbF ft
Lateral Moment $= wl$	$wl_1 = 30(2) = 60$ lbF ft	$wl_2 = 30(2.5) = 75$ lbF ft
Torsional Moment $= mal$	$ma_1l^1 = .9316(2.8722)2$ $= 5.3514$ lbF ft	$ma_2l_2 = .9316(.9446)\ (2.5)$ $= 2.1997$ lbF ft
Isometric + Dynamic + Negative Work $= \int_0^t m \mid a+g \mid dt$	$\int_0^2 .9316(2.8722+32.2)dt$ $= (.9316)\ (35.0722)\ (2)$ $= 65.3464$ lbF sec	$\int_0^4 .9316(.9446+32.2)dt$ $= (.9316)\ (33.1446)4$ $= 123.5100$ lbF sec
Acceleration Force $= ma$	$.9316(2.8722) = 2.6757$ lbF	$.9316\ (.9446) = 0.8799$ lbF
Aggregation Force $= (m+M)b$	$= (.9316+6583)\ (2.6664)$ $= 14.9049$ lbF	$(.9316+4.6583)\ (2.7777)$ $= 15.5270$ lbF
Segregation Force $= (m+M)c$	$= (.9316+4.6583)$ (416.6250) $= 2328.8920$ lbF	$= (.9316+4.6583)\ (400)$ $= 2235.96$ lbF
Vector Sum of Moments $= \{(\text{sagittal moment})^2$ $+ (\text{lateral moment})^2$ $+ (\text{torsional moment})^2\}^{1/2}$	$= \sqrt{60^2+60^2+(5.3514)^2}$ $= 85.3514$ lbF ft	$= \sqrt{(75)^2+(75)^2+(2.1997)^2}$ $= 106.0888$ lbF ft

TABLE 32-6
Values of Elements of Lifting in Physiological *"Work"* Units with Their Calculations

Element	Standing	Sitting
Work due to Moments $= \frac{\text{vector sum in lbF ft} \cdot t}{l}$	$= \frac{85.3514\ (2)}{2}$ $= 85.3514$ 1bF sec	$= \frac{106.0888\ (4)}{2.5}$ $= 169.7420$ 1bF sec
Isometric + Dynamic + Negative *Work*	$= 65.3464$ 1bF sec	$= 123.5100$ 1bF sec
Acceleration *Work* $= ma \cdot t$	$= 2.6757\ (2)$ $= 5.3514$ 1bF sec	$= (0.8799)\ (4)$ $= 3.5196$ 1bF sec
Aggregation *Work* $= (m+M)\ b \cdot t'$	$= (14.9049)\ (.5)$ $= 7.4524$ 1bF sec	$= (15.5270)\ (.6)$ $= 9.3162$ 1bF sec
Segregation *Work* $= (m+M)\ c\,t''$	$= (2328.8920)\ (0.04)$ $= 93.1556$ lbF sec	$= (2235.96)\ (0.05)$ $= 111.7980$ lbF sec

uneconomic product design and manufacturing methods. Particularly prior to the development of rational methods of workplace design as are available today, it was accepted procedure to conceive products hastily, establish manufacturing processes intuitively, and then, on the shop floor, during actual production runs to review gradually deficiencies in product design or manufacturing methods. Such improvement normally takes place over several months or years. This approach was not only feasible, but also highly desirable during past decades when, for example, the "T" model of the Ford remained in full production for approximately 30 years. In the past, this very same classical process of gradual improvement of products as well as method was also applied successfully to the reduction of health hazards and the redesign of stressful work situations.

First evidence of work-induced trauma and occupational disease was obtained then the causes were identified and eventually removed.

The effectiveness of "improvements" in both fields economical as well as occupational health are customarily measured in terms of "cost reduction." In many industries "cost reduction" is expected as a matter of course from supervisory

TABLE 32-7
Physiological "Work" in LbF sec

Description	Physiological "Work" in 1bF sec	
	Standing	Sitting
Moments (Vector Sum)	85.4	169.7
Work (Isometric + Dynamic + Negative)	65.3	123.5
Acceleration	5.4	3.5
Aggregation	7.4	9.3
Segregation	93.2	111.8
Total	256.7	417.8

and engineering personnel during the first months or years of production of a new article. This helps produce a strong temptation among those who are responsible for "efficiency" to design products and work methods initially imperfect to provide opportunities for later cost reduction. This, of course, is false economy which may well lull management into a sense of false security while a competitive position is being lost. The trait of viewing "cost reduction" as the only index of managerial effectiveness is especially strong in enterprises which maintain effective cost accountancy systems. There cost avoidance is occasionally actively discouraged because it is not easy to measure in terms of dollars and cents, while cost reduction shows up clearly in the ledger.

Often the practitioner in ergonomics is challenged to justify his activities in terms of savings accrued by the improvement of existing operations.

There are three main areas of evaluation of activity which are of prime interest to the practitioner in industry:

(1) historical evaluation:
(2) analytical evaluation: and
(3) projective evaluation.

Historical Evaluation

The improvement and cost reduction approaches outlined above are so firmly ingrained in industrial practice that quite often interest of manufacturing enterprises in biomechanics is initially triggered by a patently obvious breakdown in occupational safety and health resulting in increased manufacturing expense, poor personnel relationships, and a distorted image of corporate objectives, projected to consumers. The result is normally a request for historical evaluation of past activities and events. Such study is normally conducted within the framework of reference of the "four big C's" of any investigation of a breakdown in occupational safety and health:

1. Cause.
2. Consequence.
3. Cost.
4. Cure.

In most instances, the consequence and the cost are known; what remains to be discovered is the true cause and the cure.

In any such study, theoretical analysis is the most powerful tool available to the investigator. Experimental methods are often not only expensive and lengthy, but also quite superfluous when applied to a critique of events of the past. In addition, the procedures of theoretical analysis offer a depth of scope and a degree of privacy and confidentiality not available whenever experimentation with man as a subject is conducted.

The investigation is normally initiated by identifying the environmental stress vectors (Figures 32-19 & 32-20) which may be implicated. Whenever mechanotaxis could be one of the possible vectors involved, then the next step would be to ascertain if the principles of motion economy (Table 32-1) or the prerequisites of biomechanical work tolerance (Table 32-2) were to some extent disregarded in the design of products or work methods. Step by step, to check out procedures with the aforementioned tables in hand is the best approach. At this juncture, it is often possible to suggest possible causes for the observed anatomical, physiological or behavioral failure and frequently, an inexpensive and easily applied corrective action may be suggested.

It should however be constantly borne in mind that too simplistic an approach may prevent the detection of the actual anatomical failure points. The locus of observation of evidence of work strain is frequently quite remote in terms anatomical as well as in time from the point of application of work stress mechanism. This is, in fact, very often the case when less than due attention has been paid to the biomechanical prerequisites of work tolerance. Then the following questions should be asked:

1. Are the muscular constituents of the kinetic element involved large enough to perform the task without undue fatigue?
2. Do hand tools, machine controls, or other mechanotactic vectors evident at the workplace interfere with adequate blood supply to the muscle masses performing the actual work?
3. Are all kinetic chains working at adequate levels of mechanical advantage?
4. Are the sensory feedback mechanisms in the kinetic chain adequate to elicit some protective response by the worker to excessive stress?

Whenever the frequency of incidence of occupational ill health or accidents increase, after a manufacturing process has been in safe operation for some time, then the following questions should be asked: WHAT CHANGES IN EQUIPMENT DESIGN, TOOLS USED, WORKING POPULATION EMPLOYED OR WORK METHOD APPLIED HAS TAKEN PLACE IMMEDIATELY PRIOR TO THE BREAKDOWN OF HAZARD CONTROL?

A case study will illustrate the power of theoretical analysis.

A case study in historical evaluation of the biomechanical causes of a series of accidents. In a factory producing basic chemical materials, a sudden and dramatic increase of "pedestrian accidents" was observed. Workers crossing aisles were hit by fork-lift trucks transporting materials on pallets. Common human-factors engineering approaches were explored, the trucks made more visible and zebra-striped, the aisles better lit and automatic warning horns were installed on some of the vehicles. However, none of these measures was of any avail. Then the question was asked: Why were so many workers crossing the aisles and walking around instead of being seated in comfort and safety at the workplace? Work sampling studies[70] revealed two things: firstly, that the accident frequency was proportional to the density of pedestrian traffic in the aisles and, secondly, that from a certain date onwards brief periods of absenteeism from the workplace had increased dramatically in number and, consequently, more people were walking in the aisles at any instant. The time of this change of workmen's behavior coincided with the introduction of a new tool. A rather expensive electrical brush used to clean trays was replaced by a much cheaper and apparently far more effective paint scraper (Figure 32-26). As stated under the "Prerequisites of Biomechanical Work Tolerance" (Table 32-2) I-1, the new and cheaper tool interfered with the blood supply to the ring and little finger. The resulting numbness and tingling caused the individuals afflicted to lay down their tools at frequent intervals and to seek relief by exercising their hands. First, line supervisors tried to counteract the decrease in productivity by frequent admonitions. Now, in order to avoid arguments with their supervisors, workers simply made use of every conceivable opportunity for brief absences from the job. Trips to the washroom, the tool room, the store, etc., became rather frequent, and this was the true cause of the rapid increase in accidents unjustly ascribed to the fork-lift trucks. The first of the four big C's, the true cause of the accidents, had been identified as absence from the workplace produced by an ergonomically incorrect designed tool. It only remained to develop a cure. The handle of the paint scraper was redesigned (Figure 32-47). As a result, workers spent more time per day in productive activity and thus output and economy of operation increased, while at the same time, due to diminished exposure to vehicles in the aisles, accident rates returned to normal.

Analytical Evaluation

The procedures of analytical evaluation are most often called for when an already existing manufacturing operation is generally satisfactory but has to be improved, either in order to make it more competitive or to reduce training time, to eliminate operator discomfort and to enhance the health and well-being of the working population.

Theoretical analysis applied as described in the aforegoing paragraph is the initial step in all analytical evaluation. However, very often this will not suffice and certain experimental measures must be employed. The simplest and perhaps most effective aid in this kind of study is cinematography and subsequent frame-by-frame analysis. This will permit a detailed evaluation of the worker's reaction to each event at the workplace, and to each contact with tool, machine, or manufactured article. Very often slow-motion viewing of the manufacturing operation will reveal biomechanical or ergonomic defects as well as reflex reactions which cannot be detected with the naked eye because of the brief duration of many such events. The fact that the "hand is quicker than the eye" is well known to stage magicians who wish to deceive the spectators in the audience. The movie camera prevents self-deception by the work analyst. There is currently a strong trend towards the use of videotape for such purposes. This should be discouraged because the evolution of videotape is not adequate for the detection of fine details of expression, blanching of the skin, or frame-by-frame analysis. Furthermore, color videotaping is exorbitantly expensive while color film, especially in the Super-8 size, is economical and tells much more than a black-and-white picture.

Figure 32-47. Redesigned Paint Scraper, Eliminating Interference with Blood Supply in the Fingers as Described in Figure 26.

Finally, manufacture of a videotape from movie film is very inexpensive while the converse, i.e., the manufacture of a movie film from a videotape, is a very expensive operation. Furthermore videotape, being magnetic in nature, requires more careful storage and is sensitive to magnetic fields, and often gets accidentally erased.

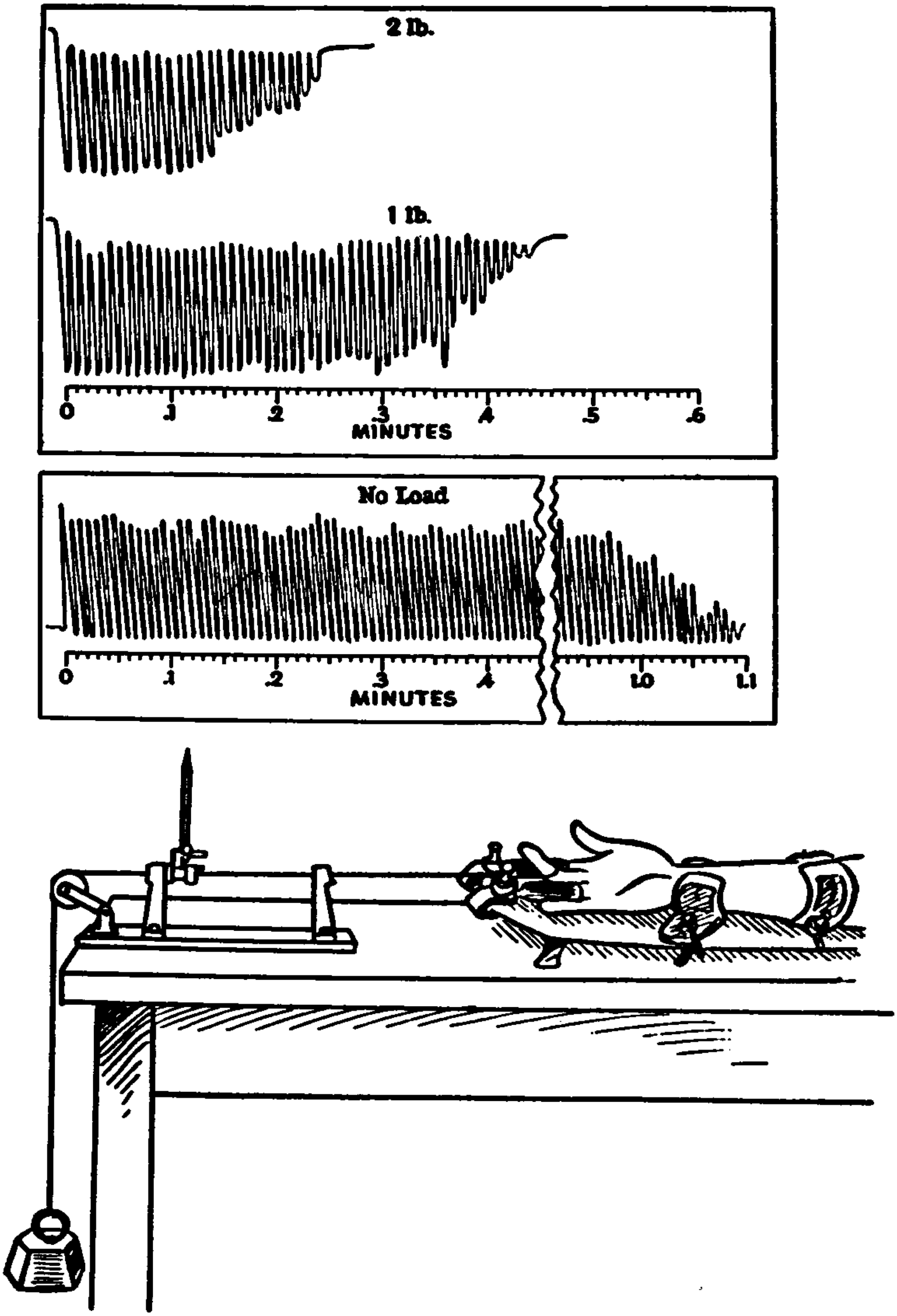
Motion picture analysis of the work situation should allow the viewing of the workplace at least in two different planes, if a realistic appreciation of all the parameters of the layout is to be obtained (Figure 32-48).[71] When movie analysis alone is not adequate as a basis for process evaluation, then recourse to other experimental technologies must be taken.

a. *Dynamometry*. This is a technique concerned with the measurement of the force-time relationship of strength of joint movement. It is employed with advantage in fatigue measurement when a lever system intrinsic to a specific kinetic element, made, by means of a mechanical device, to act against a measured force for a fixed number of cycles or a fixed interval of time. Magnitude of excursion of joint movement as well as magnitude of force developed during the activity are both plotted against time. The ergograph commonly employed for the measurement of finger fatigue in industry (Figure 32-49)[73] is one of the many useful types of dynamometers. The squeeze dynamometer (Figure 32-50)[73] is applicable for the objective measurement of fatigue and work tolerance in squeezing operations of the whole hand, such as are demanded by wraparound grasps of power grips, must be evaluated. The mechanical form of dynamometer used in rehabilitation medicine or physiotherapy is not commonly applicable to industrial circumstances as it is only an indicator of maximal force developed under conditions of a single squeeze.

b. *Myography*. Techniques of ergonometry and dynamometry permit the objective diagnosis of whether an individual is fatigued or incapacitated with respect to the specific job under analysis. Often, however, it is necessary to make a projective prediction about the likelihood of fatigue developing sometime in the future, the possibility of overexertion of a single kinetic

Tichauer, E. R.: Industrial Engineering in the Rehabilitation of the Handicapped. J. Ind. Eng. XIX:96-104, 1968.

Figure 32-48. A realistic impression of the three-dimensional nature of a task can best be obtained by "mirror-box" photography. This chronocyclegraph shows changes in the angle of abduction which influence effort levels in three coordinates.[43]



Munn, N. L.: Psychology — The Fundamentals of Human Adjustment, 3rd Edition. Boston, Houghton Mifflin Co., 1955.

Figure 32-49. FINGER ERGOGRAPH AS DESIGNED BY MOSSO. The pointer at upper left traced a record of movements upon a smoked drum. The first and third fingers are held stationary by being inserted into metal cylinders. Lifting is done by the second finger.

Figure 32-50. An Instrumented Hand Dynamometer Permitting to Explain Subject's Performance Decay as a Function of Fatigue Due to Shape of Tool Handles. (a) 1½-in. handle starting performance, normal pattern. (b) Fatigue pattern after 12 min. of activity. (c) Starting performance in subject with inflamed tendon sheaths resulting in pronounced decay after 2 min. of performance. (d) After 8 min. a complete performance drop in subject c. (e) Subject with damage to nervous system. Original performance pattern showing early decay. (f) Same subject as in e, improved performance pattern after work tolerance training.[73]

element, reduced work tolerance or other hazards to occupational safety and health. Then it is necessary to establish muscular input — biomechanical output relationships. Muscular effort involved in the performance of a specific task can conveniently be demonstrated by electromyography. A myogram is an electrical signal obtained from a contracting muscle. Under laboratory conditions, it may be advantageous to insert needle electrodes directly into the muscle investigated and record the potentials developed during exertion. This is the type of myogram preferred by physicians for the purpose of clinical investigation of neuromuscular disease. In occupational biomechanics, however, bioelectricity is "assumed to be" merely the byproduct of a muscular event which makes it possible to measure strength and sequencing of muscle utilization through techniques non-invasive with respect to the human body. This limits industrial biomechanical procedures to surface electrodes which are adhesive conductive discs similar to those employed in electrocardiography. Before application, the skin is cleansed with alcohol or a similar solvent and good electrical conductive contact between the human body and the electrode is insured by the application of a conductive jelly between electrode and skin. The electrodes are placed so that they "triangulate" the individual muscle or muscle group under study (Figure 32-51).[74] A differential amplifier is then employed to magnify the action potentials so that they can be read on oscilloscopes or paper recorders. A differential amplifier uses three electrodes, one ground and two active electrodes. It augments only the difference between the two active electrodes. As any interference is common to all three electrodes, it is not amplified. This "common mode" rejection makes imperative the use of differential amplifiers in an industrial setting where electrical interference from fluorescent tubes and all kinds of other apparatus is abundant.

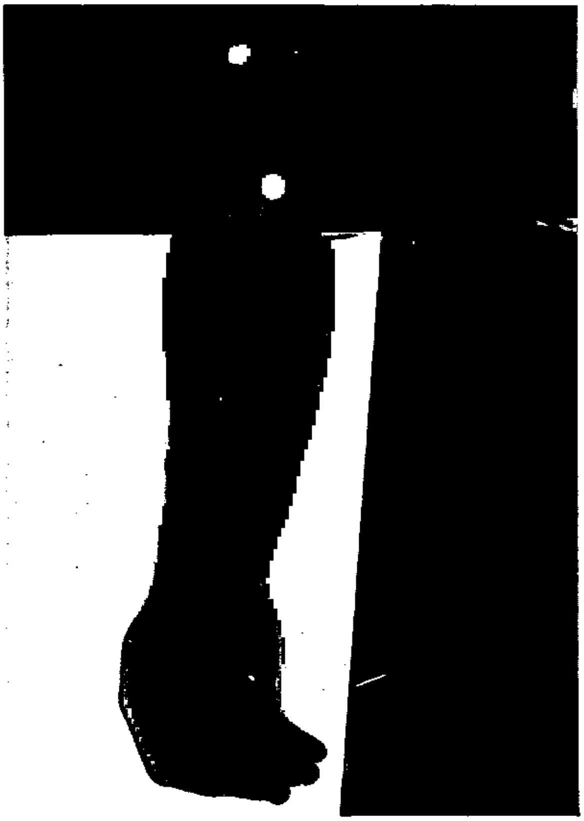
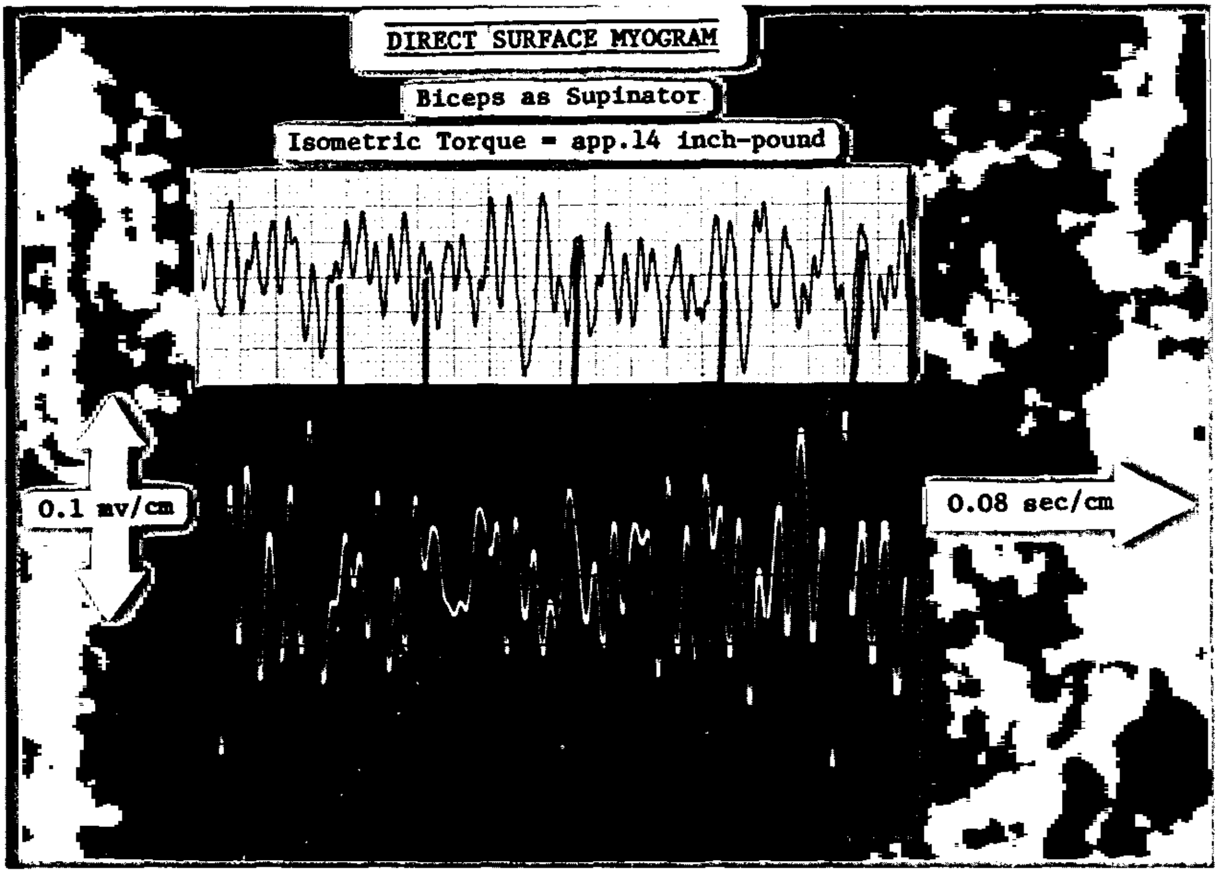


Figure 32-51. Electrodes for Surface Myography "Triangulating" the Biceps Muscle to Obtain a Maximal Integrated Myographic Signal.

Due to the nature of the procedure, surface electrode myography records the summed signal from a number of action potentials simultaneously, depending upon the placement and size of the electrodes. Because of the brief intervals of time elapsing between individual action potentials, which is sometimes on the order of a few microseconds only, readout devices and recorders may be "overdriven" with respect to speed and time. The signal is then not representative of the nature of the action potential but is conditioned and distorted as a function of the quality of the recording device (Figure 32-52). Even a change in the viscosity of the ink may produce a drastic change in the pattern of the tracing from the same amplifier reproduced on the same recorder. Therefore, in biomechanics, a conditioned type of myogram is employed. It records the sum total of the peaks of the action potentials counted over a sampling interval of time. If the rate at which individual muscle fibers contract is twice as fast, the deflection of the recorder pen will be twice as large. This type of myogram, which is representative of the total number of muscle fibers contracting at any instant, is erroneously but nevertheless commonly referred to as an "integrated myogram."

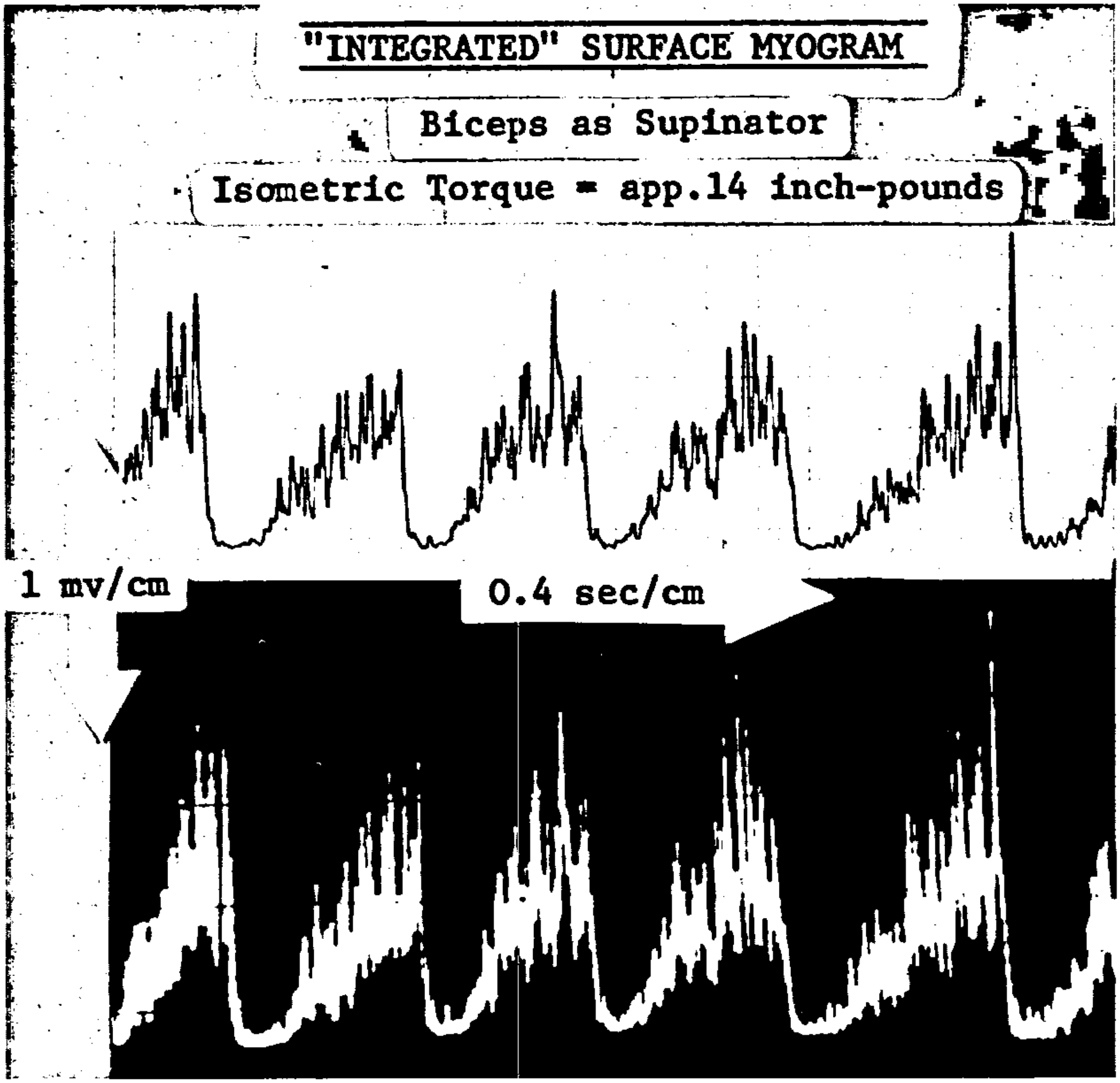
Due to the physiological "all or none law," it is also representative of the effort expended at any instant. As the signal produced requires only a rather slow response capacity of the recorder, it is repeatable and easily obtained with relatively inexpensive equipment (Figure 32-53). It is thus possible to ascertain under field conditions if an undue amount of effort is expended in the performance of a specific maneuver. Likewise, the integrated myogram shows if there is proper sequencing between muscles involved in an operation. There should always be a "peak and valley" relationship between protagonist and antagonist muscles (Figure 32-54).

It cannot be too strongly emphasized that the industrial myogram is employed not to detect pathology, but to detect fatigue indicated by changes in the pattern of the myogram; to establish whether muscles function in the most desirable sequence and whether a specific muscle is actually involved in a specific productive operation. When the areas of application which define also the limits of usefulness of an integrated sur-



Tichauer, E. R., Gage, H., Harrison, L. B.: The Use of Biomechanical Profiles in Objective Work Measurement. J. Ind. Eng. IV: 20-27, 1972.

Figure 32-52. A Simultaneous Recording of the Biceps Muscle Firing Pattern Displayed on a Chart Recorder (Upper Half) and an Oscilloscope (Lower Half) at Exactly the Same Sensitivity and Speed. Only five points of similarity are evident, because the signal speed of the myogram exceeds the rise time and slew rate of commercial chart recorders.[16]



Tichauer, E. R., Gage, H., Harrison, L. B.: The Use of Biomechanical Profiles in Objective Work Measurement. J. Ind. Eng. IV: 20-27, 1972.

Figure 32-53. The Same Biceps Contraction Pattern as Shown in Fig. 52 Chart Recorder (Upper Half), Oscilloscope (Lower Half). However the signals here have been conditioned by summing all action potentials over time so that the trace now represents the analog of the firing rate, which is indicative of the total activity of the muscle mass at any instant during the sampling period. The signals are fully compatible with the frequency response of the chart recorder. The integrated myogram produces repeatable and very reliable measurements of muscular activity levels.[16]

face myogram are kept clearly in mind, then this electrophysiological signal will be found to be an eminently useful tool in the objective analysis of work situations.

There are, of course, other and perhaps even more precise approaches to electromyography in fatigue study,[75, 76, 77] but many of these require the true laboratory setting of a clinical or research institution. Preferred fields of application of electromyography are the comparative evaluation of handtool designs, of lifting stress when objects of different weight or shape are to be handled, etc. It is often a more convenient and reliable means of work and effort measurement than metabolic investigations.

c. *The Biomechanical Profile.* It is often de-

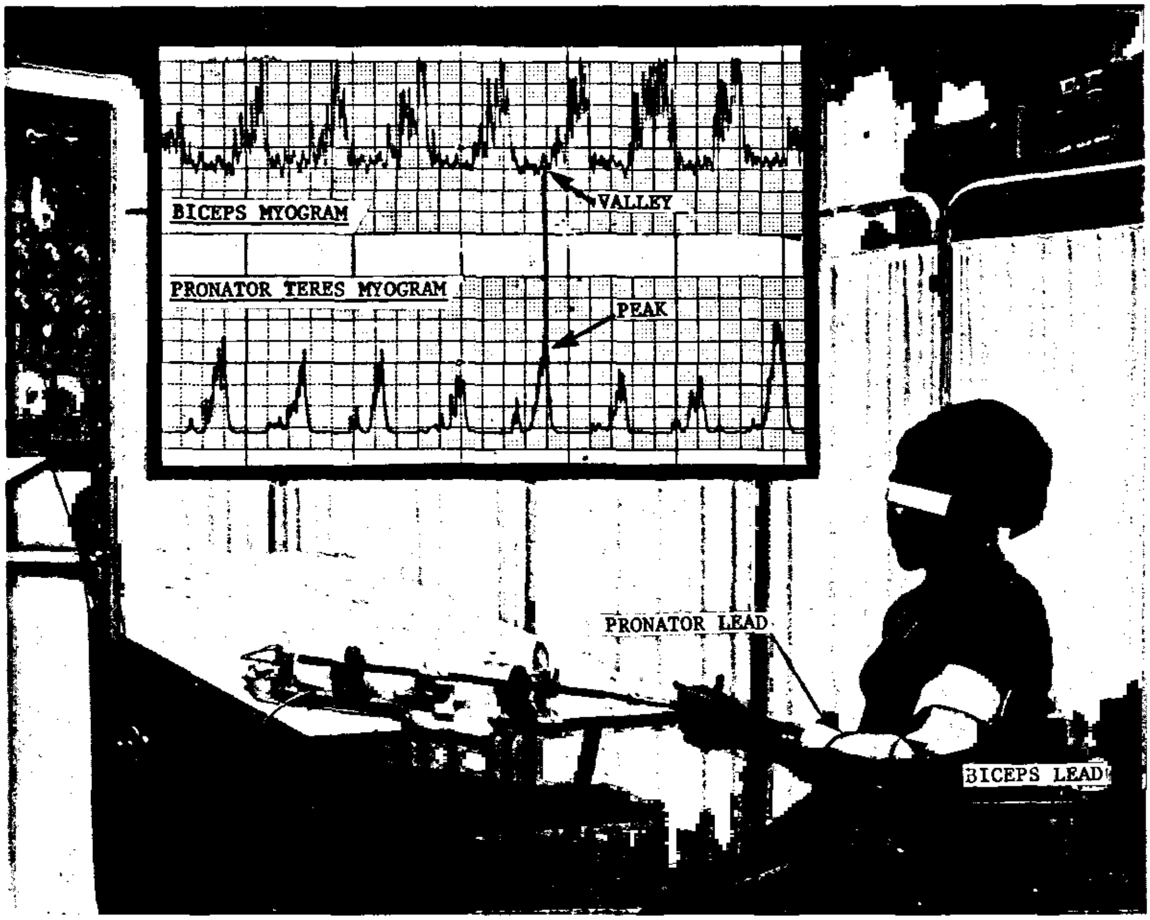


Figure 32-54. Simultaneously recorded integrated myograms of biceps (supinator) and pronator teres (antagonist) show peak and valley phasing indicative of proper sequencing of muscle conducive to high work tolerance.

sirable to record simultaneously myograms and the readouts from dynamometers. The resulting tracing constitutes a "Biomechanical Profile" indicative of the nature of muscular effort-work output-work tolerance relationships. Such Biomechanical Profile permits the objective evaluation and prognostication of changes in functional capacity resulting from modifications of man-equipment interfaces.

Figures 32-55 and 32-56 illustrate the comparative evaluation of two machine controls. First a T-handle was attached to a rotating dynamometer, and subjects were asked to pronate the supinate against a set resistance. A biceps myogram, as indicative of the main supinatory effort, was recorded simultaneously with an electrical signal proportional to the amplitude of the rotation of the shaft. This then constituted a Biomechanical Profile in simplest form (Figure 32-56). Then a straight handle was substituted. This straight handle forced the wrist into ulnar deviation (Figure 32-55). The resulting Biomechanical Profile (Figure 32-56) now shows that, when a machine control requires the wrist to be rotated while in ulnar deviation, that the operator must expend twice the force to obtain half the output because the myogram is now twice as high while the displacement signature shows only half the amplitude. In other words the operator, when using the straight handle instead of the T-handle, would have to apply twice the effort to produce rotation. As the range of excursion of the shaft is halved, he would also have to perform twice as many maneuvers to achieve the same output. Clearly the T-handle is much superior and less injurious to operator health (Figure 32-57).

Projective Evaluation

Whenever possible, a job should be ergonomically evaluated while it is still in the planning phase. This makes it possible to "design out" of

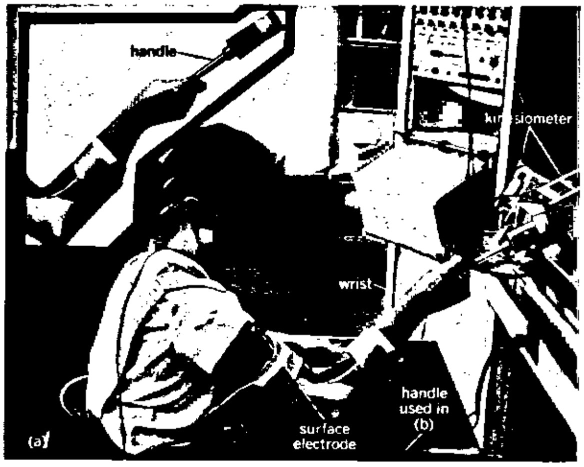


Figure 32-55. Kinesiometer Measuring Rotation of the Forearm Using (a) a Tool Handle Which Permits the Wrist To Be Kept Straight. A surface electrode simultaneously picks up a myogram of the biceps, which is one of the muscles rotating the forearm, and a potentiometer attached to the end of the tool shaft measures rotation of tool. (b) A tool handle which forces the wrist into deviation, which is uncomfortable and fatiguing.[36]

the task, features, equipment and maneuvers which are potentially traumatogenic. It also makes it possible to make reliable predictions with respect to the work tolerance of a specific industrial population, duration of training, and counselling procedures which should be employed while training is in progress.

All projective evaluation, be it theoretical or experimental, must include an analysis which shows how sensory input from the workplace is transferred by the musculo-skeletal structure into manipulative output. The ergonomist, under such circumstances, should direct his efforts towards the development of the optimal kinetic chain for the performance of a given task.

If projective evaluation demands experimentation, then the results of laboratory or field work should be presented in the form of a Biomechanical Profile, which, however, is far more complex than the one described in Figure 32-56. Also, unless the task studied is physically heavy, the dynamometer will only be rarely used in projective evaluation. Instead the kinesiometer is employed.

The kinesiometer measures the biomechanical parameters of manipulative movements. These are output measurements describing quantitatively the performance elements of a man-task system. In manipulative movement, most commonly displacement, velocity and acceleration of the object handled, are used as measures of output efficiency.

Displacement is indicative of range and pattern of motion. Velocity serves as an index of both speed as well as strength. Finally, acceleration reflects control over precision and quality of motion.[16] Abnormal acceleration and deceleration "signatures" are invariably associated with im-

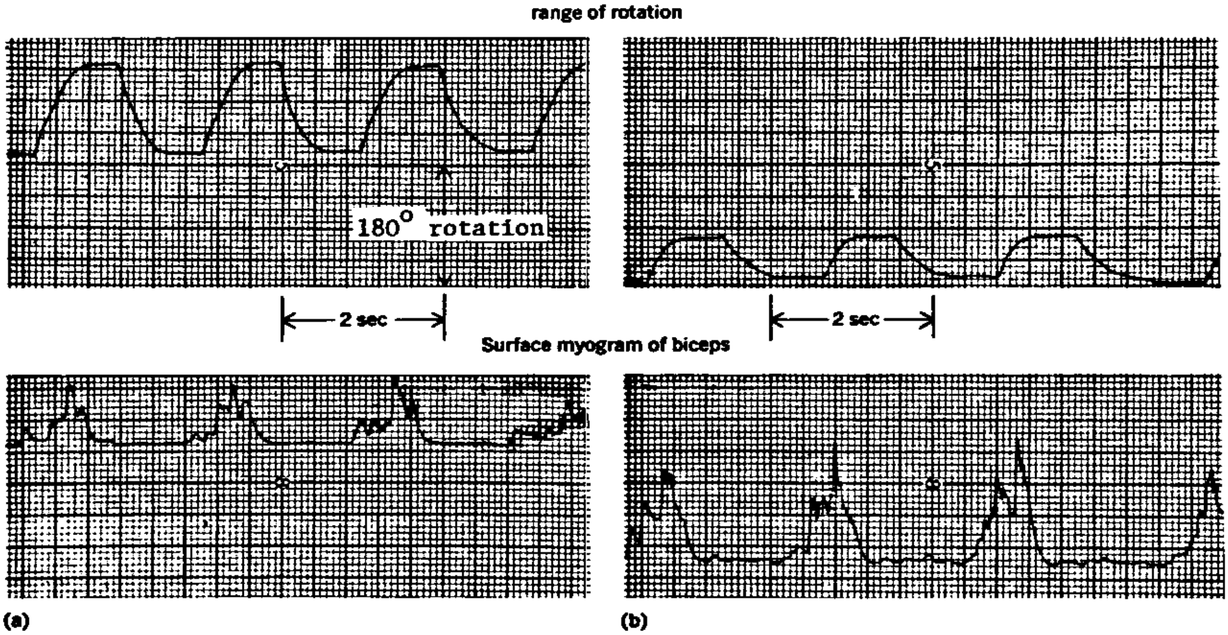
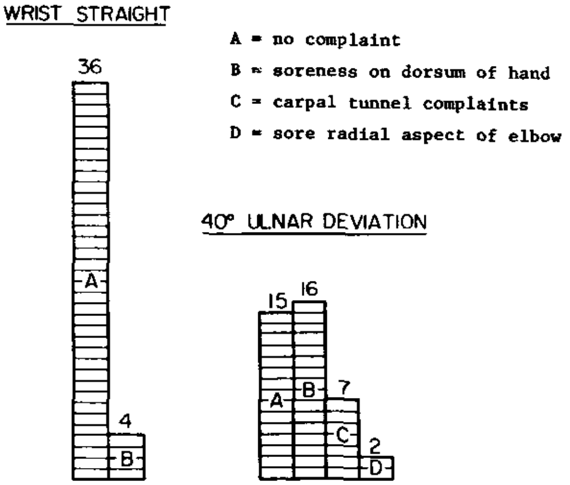


Figure 32-56. Biomechanical Profile of Forearm Rotation Using Tracing of Tool Rotation and Surface Myogram of Biceps. (a) Wrist straight. (b) Wrist deviated.[36]



Tichauer, E. R.: Potential of Biomechanics for Solving Specific Hazard Problems. Proc. 1968 Professional Conference, American Society of Safety Engineers, Park Ridge, Illinois, 1968, pp. 149-187.

Figure 32-57. Subjective Physical Response Obtained from a Sample of 40 Volunteers Performing the Task Described in Fig. 56.[35]

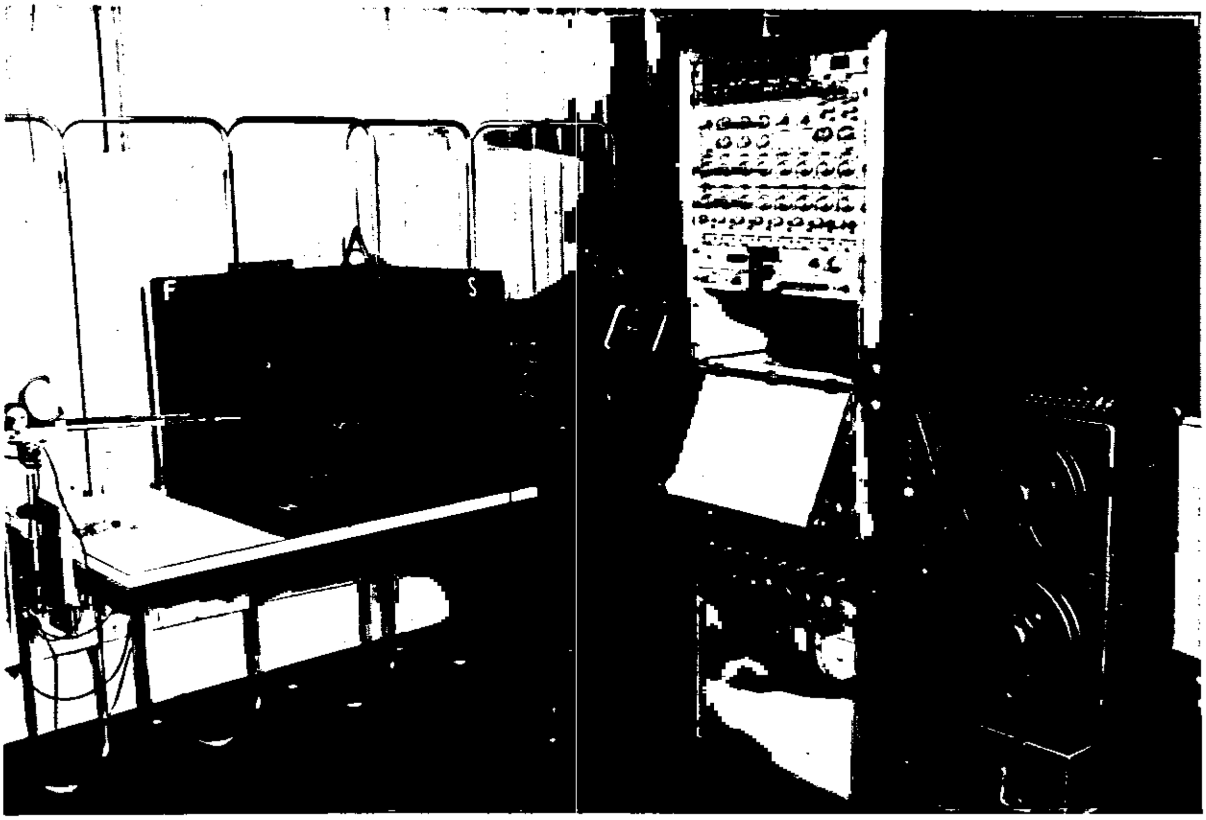
precise and unsafe movements due to the inability to terminate a motion at the correct place and time. A kinesiometer is described in Figure 32-58. It comprises a task board with lights installed on it and wired so that only one light is on at a time. A metal-tipped "tool" is mounted on a lightweight rod. As soon as the light is touched by the tool, it is extinguished and another bulb automatically switches on. With the help of a programming board, it is possible to generate a sequence of motions simulating an actual job closely, thus avoiding an expensive mock-up of a workplace which may exist at that stage only on the drawing board. The rod attached to the tool is connected to a set of potentiometers so that the movement of the tool in space generates voltage signals which are converted into electrical analogs of the vector sums of each displacement, velocity and acceleration of the "tool tip" at any instant. Motion inventories can be programmed through interchangeable patchboards to simulate occupational motion patterns for a wide range of industries, such as food processing, electronic assembly, or the needle trades.

These biomechanical parameters are recorded simultaneously with the electrophysiological parameters of the kinetic chain of the task (Figure 32-59). These represent activity of the muscles moving the eyes, the head and neck, the shoulder and the extensors of the wrist. These tracings — altogether seven in number — displaced on the chart recorder constitute the complete Biomechanical Profile for this task. Figure 32-60 shows a subject completely electroded for testing. Optimal positioning of electrodes can be easily obtained when consulting standard reference works.[78, 79]

The profile makes it possible to distinguish between individuals likely to develop either low or high work tolerance (Figure 32-61). In the example shown in Figure 32-61, two workers performed exactly the same task, a number of forward reaches in identical sequence. Although their production times were approximately equal, the effort required to produce these outputs was markedly different. The activity rate in the deltoid muscle, particularly at low velocity, was generally far higher in the individual with low work tolerance while, at the same time, the wrist extensor signal remained unstructured. This is indicative of high effort, but disproportionately low output, and predictive of early fatigue. Also, it was seen from the tracings of neck muscle activity that too much scanning was done by the head instead of by the eyes. The lack of purposeful anticipatory eye scanning following a single head movement is also indicative of inferior performance and great discomfort when performing the task over lengthy periods of time. The remedy, of course, is training for proper motion habits, after potentially discomfort-causing performance features have been identified.

The Biomechanical Profile can also establish status and quality of the individual's training as well as identify many improper work mannerisms which can be eliminated through proper instruction. Figure 32-62 shows "before practice" and "after practice" performance of the same individual reaching sideways away from body and back. The untrained worker lacks coordination between scanning and wrist movements; the deltoid muscle is in constant tension, indicating that there is a violation of one of the basic prerequisites of work tolerance: Keep the Elbows Down (Table 32-2). The worker was counselled to look straight at the target, then to proceed to reach for it without further dependence upon further visual correction, reserving the strongest activity of the wrist for the end of the sequence when time positioning takes place. In the "after practice" profile recorded, eye and wrist movement are now in proper sequence. Deltoid activity has declined; thus, the level of effort has substantially decreased, work tolerance has increased, and productive output has nearly doubled.

A kinesiometer can take many forms and can be adapted to a wide variety of jobs, from handtool operation to the measurement of the potential traumatogenic effects of equipment displays, and to the measurements of lifting operations. This bridges the gap which since the beginnings of scientific management, industrial psychology and work physiology has plagued most practitioners in industry. Workers as early as the Gilbreths had already fully established the scientific rationale behind the disciplines of ergonomics and biome-



Tichauer, E. R., Gage, H., Harrison, L. B.: The use of Biomechanical Profiles in Objective Work Measurement. J. Ind. Eng. IV: 20-27, 1972.

Figure 32-58. The kinesiometer used in this experiment consists of a task board (A) and a metal-tipped tool (B). When any of the 19 lights on the task board is touched by the tool it is extinguished and another bulb switches on. The tool movement generates voltage signals in three potentiometers (C). The output of this kinesiometer is converted by an analog computation module (D). Also at (D) are the interchangeable patch boards which program the light patterns to simulate any occupational motion pattern. The chart recorder (E) displays the complete Biomechanical Profile. Signals are stored in analog form on a multi-channel tape recorder (F) for computer processing.[16]

chanics as practiced today. Nevertheless, they lacked instrumentation adequate to conduct experimental investigations into the physical effort expended by individual muscles in the performance of a specific task. Likewise, the sequencing of action and effort levels of the various muscles involved in manipulative and other maneuvers were beyond the investigative technologies available then. These pioneers were simply fifty years ahead of their time. True enough, the second industrial revolution, due to the fact that the worker in industry is no longer a "free roaming animal" but is constrained to a relatively rigid posture and repetitive motion pattern throughout a long working day, has produced, or aggravated, numerous known and previously unknown industrial ailments and complaints. However, the new technologies, as a by-product, also produced the means of disability prevention. The solid-state technologies perfected during recent years and the ensuing miniaturization and improvements of instrumentation have made it possible to develop kinesiometers and biomechanical techniques which are effective tools of disability prevention raising both the levels of physiological and emotional well-being of the working population as well as the productive levels and the competitive posture of American enterprise.

ACKNOWLEDGEMENTS

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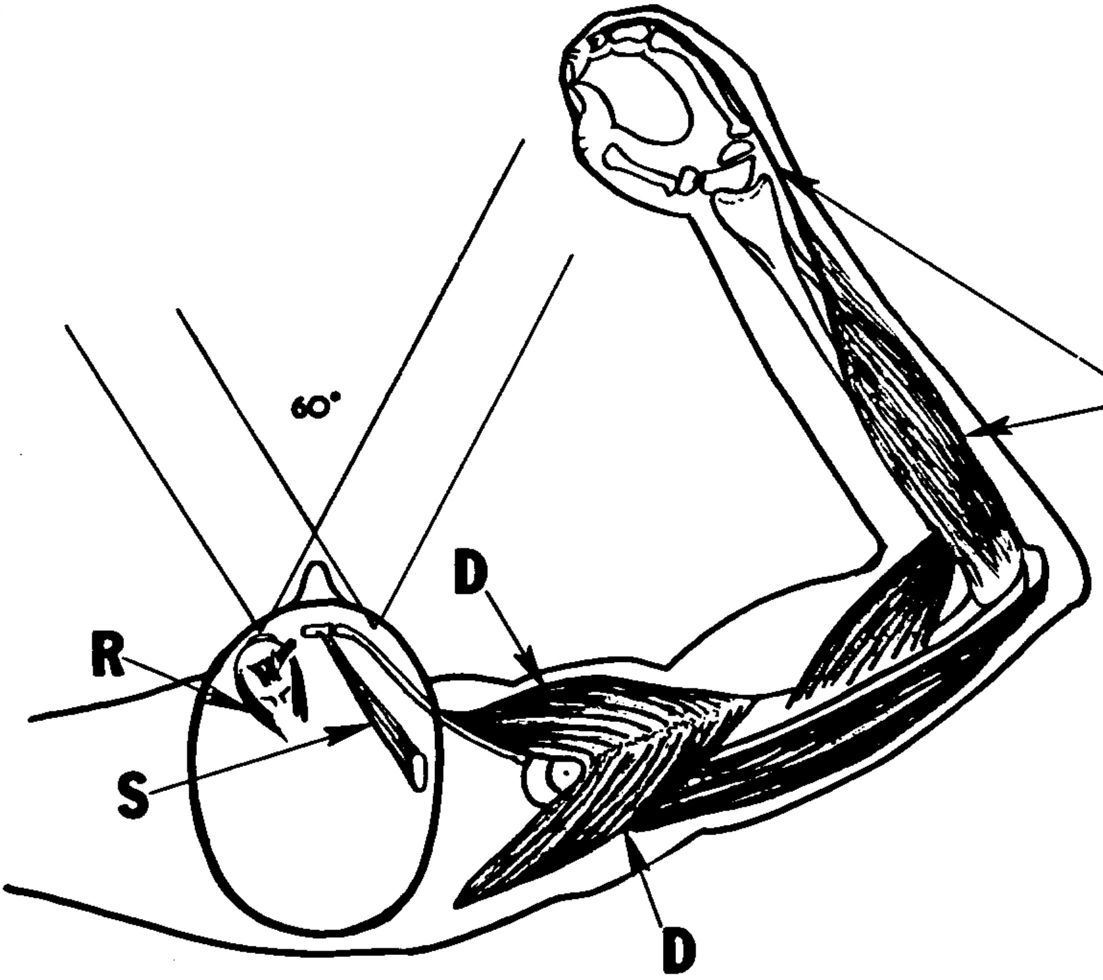

Tichauer, E. R., Gage, H., Harrison, L. B.: The use of Biomechanical Profiles in Objective Work Measurement. J. Ind. Eng. IV: 20-27, 1972.

Figure 32-59. The kinetic chain constructed for industrial practice links the major sensory organs and key muscles required to perform a task. In Eye-Hand coordination, sensory input to the eyes is inferred by monitoring the small muscles (R) which rotate the eyeball. To see objects outside a binocular visual cone of 60 degrees, the head must be moved, using (S) the sternomastoid muscles of the neck. Arm movement at the shoulder is produced by (D) the deltoid muscle. Wrist movement is produced by (W) the extensor muscles of the forearm.[16]

C. Gold designed much of the electronic instrumentation described. My wife, Mrs. Helen Tichauer, was of great help in literature search and in the drawing and development of illustrations. Finally, the subsection on Projective Evaluation is based upon a paper[16] "The Use of Biomechanical Profiles in Objective Work Measurement" by Tichauer, Gage and Harrison. The painstaking care of Miss E. Schipper in preparation and revision of the manuscript is gratefully acknowledged.

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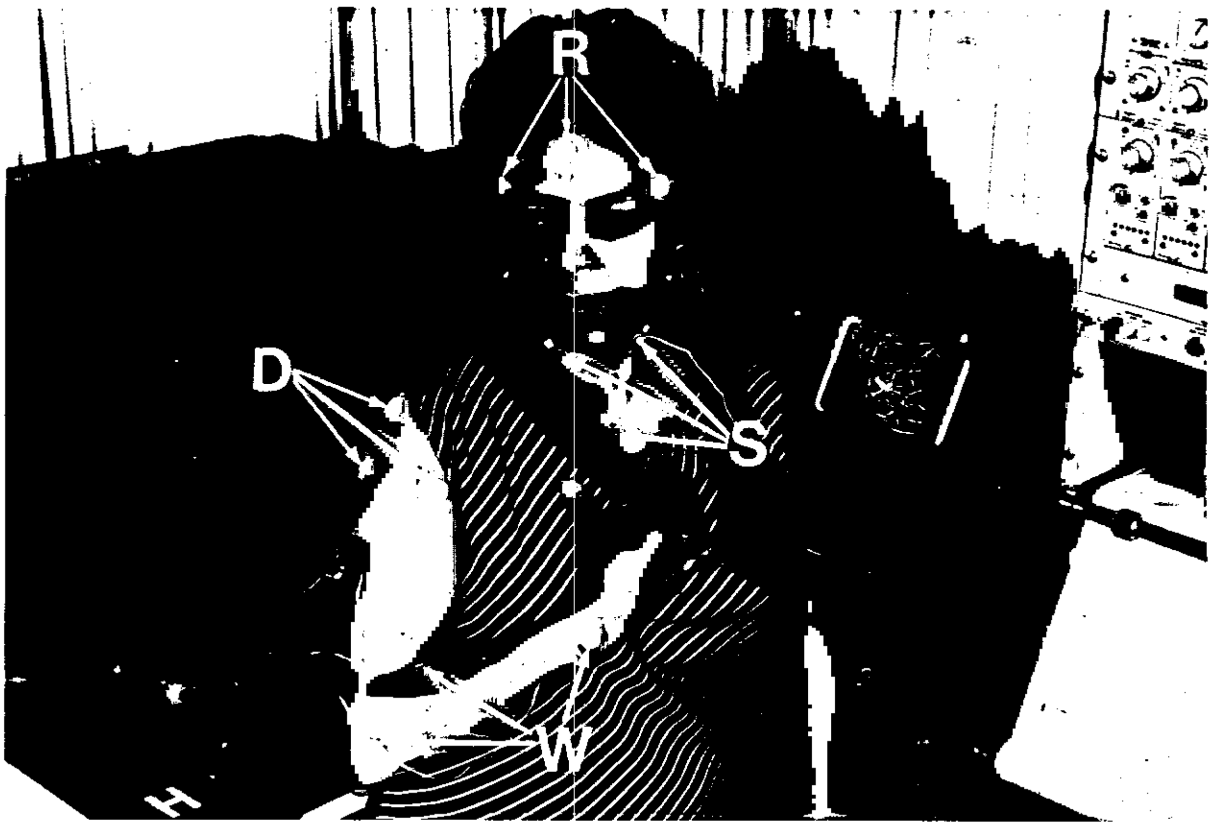

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Figure 32-60. Four sets of surface electrodes were placed on each subject, over the muscles comprising the kinetic chain, as pictured in Fig. 59. In each set, the third electrode acts as the ground. Electrodes were positioned according to standard muscle testing procedures, so that each myogram obtained represented a maximum amount of contracting muscle mass. All subjects were representative of the female working population commonly found performing manual production work in industry.[16]

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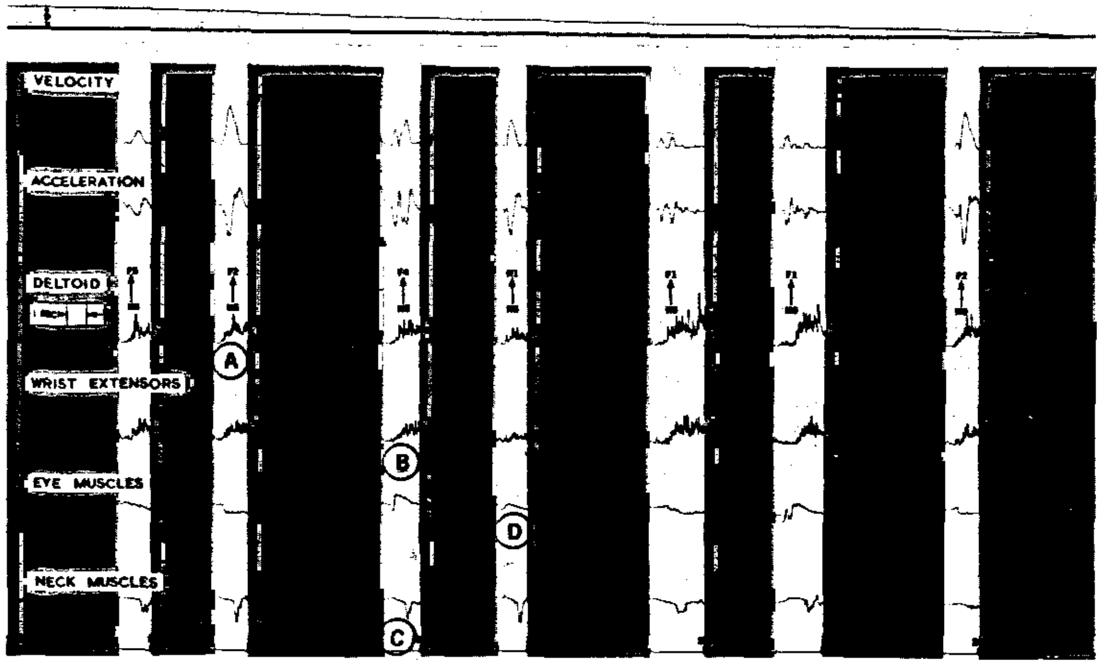
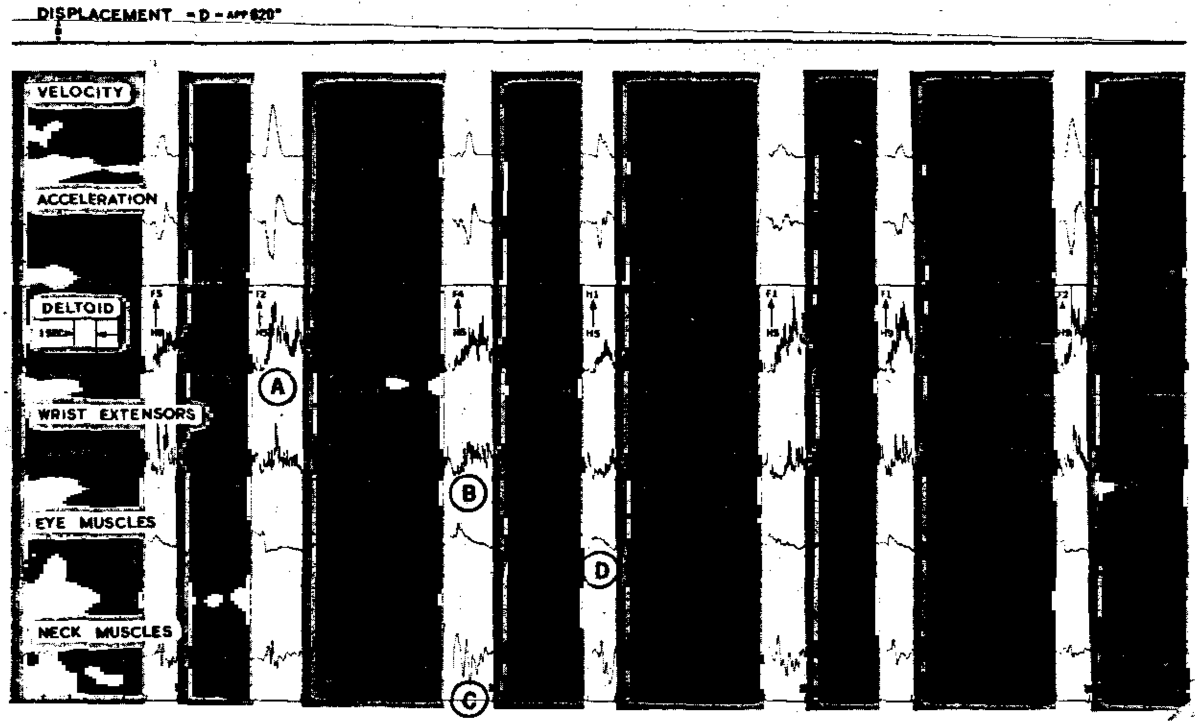


LOW WORK TOLERANCE



Tichauer, E. R., Gage, H., Harrison, L. B.: The use of Biomechanical Profiles in Objective Work Measurement. J. Ind. Eng. IV: 20-27, 1972.

Figure 32-61 (A & B). Biomechanical profiles can be used to distinguish between individuals who are likely to have low or high work tolerance. Two workers performed a number of forward reaches. The firing rate in the deltoid (A) muscle, particularly at low velocity, is commonly far higher for individuals of low work tolerance, left, while the wrist extensors' myograms (B) of such workers are continuous and unstructured. Both of these factors are likely to be indicative of relatively high effort accompanied by poor efficiency of performance — the worker manipulates for fine positioning before arriving at the target. Neck muscles' activity (C) show that the low tolerance worker does too much of the scanning with the head. The lack or presence of purposeful anticipatory eye scanning (D) is also a good predictor of sustained performance ability.[16]

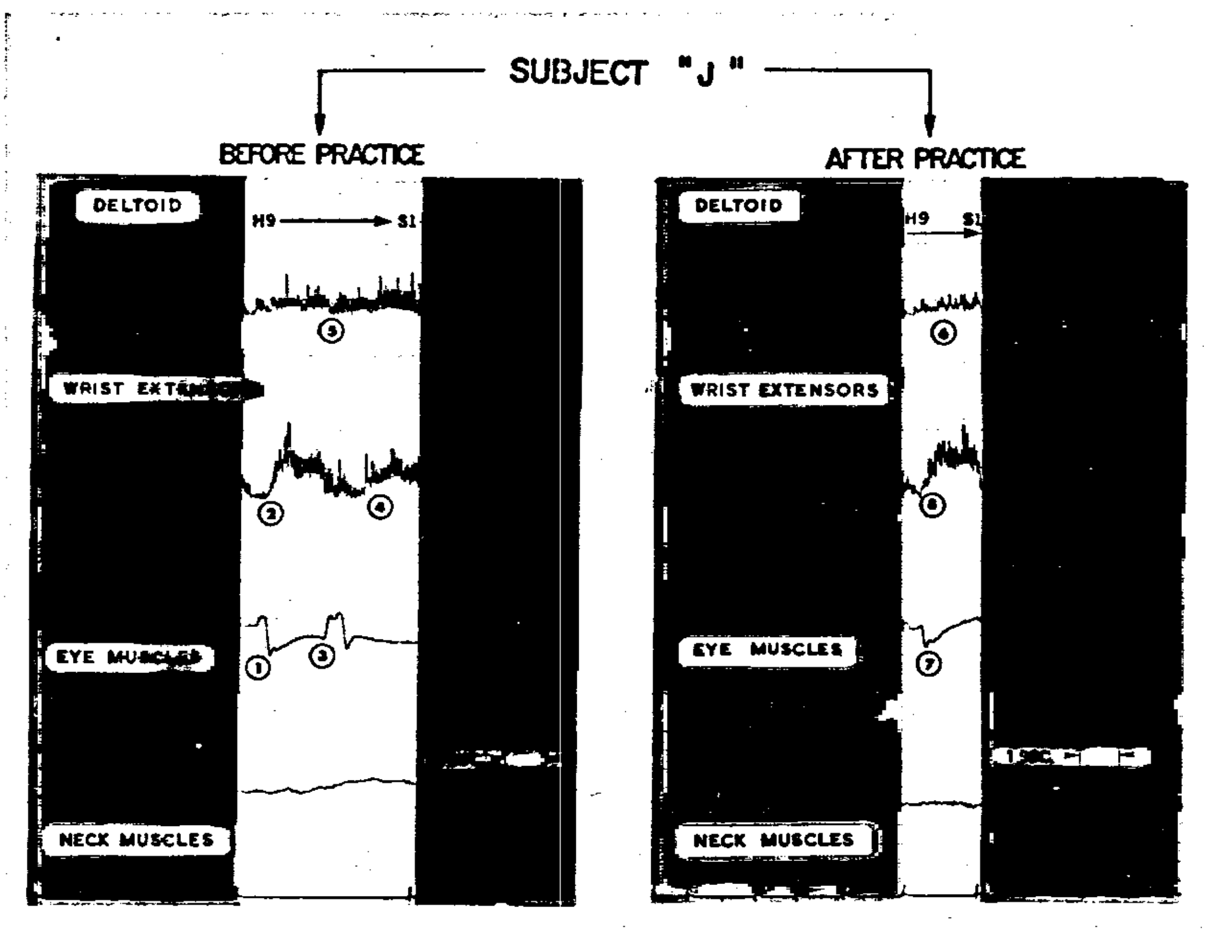


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Figure 32-62. The state and quality of worker's training can be measured by electromyographic kinesiology, and the work habits which need retraining can be pinpointed. Before practice (left), the subject moves her eyes to search (1), then moves her wrist (2), looks again (3), finally does useful work with her wrist as she positions a second time (4). During the entire motion (which goes from the horizontal to a side target point), the deltoid (5) is under constant tension since the elbows are kept high as the shoulder is moved. The total motion consumes 4.7 seconds. The practiced performance (right) resulted from proper training. The subject carried out instructions such as: "keep the elbows down." Deltoid activity is minimal (6); eye movement (7) is purposeful and efficient — Subject "J" looks first, scanning the entire visual field; the wrist (8) is then moved to the located target. The trained subject needs less than half the reach time.[15]

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Important Notice: The American Industrial Hygiene Association (Technical Committee on Ergonomics) publishes from time to time "Ergonomics Guides" each one concerned with a specialized aspect of the field (e.g., *Ergonomics Guide to Manual Lifting*); all these should be considered indispensible references for daily practice.

GLOSSARY

Angle of Abduction Angle between the longitudinal axis of a limb and a sagittal plane (q.v.).

Antagonist A muscle opposing the action of another muscle. An active antagonist is essential for control and stability of action by a prime mover (q.v.); e.g., the biceps and pronator teres are antagonists in pronation and supination.

Anthropometry The measurement of man's body dimensions, generally performed with calipers which measure the distance between specific anatomical reference points. For more details, see Dreyfuss: "The Measurement of Man," Whitney Library of Design.

Axis of Rotation The true line about which angular motion takes place at any instant. Not necessarily identical with anatomical axis of symmetry of a limb nor necessarily fixed. Thus, forearm rotates about an axis which extends obliquely from lateral side of elbow to a point between the little finger and ring finger. The elbow joint has a fixed axis maintained by circular joint surfaces, but the knee has a moving axis at its cam-shaped surfaces articulate. Axis of rotation of tools should be aligned with true limb axis of rotation. Systems of predetermined motion times often specify such axes incorrectly.

Axis of Thrust Line along which thrust can be transmitted safely. In the forearm, it coincides with the longitudinal axis of the radius. Tools should be designed to align with this axis. Ulnar or radial deviation which produces misalignment causes bending stress acting on the wrist.

Biceps Muscle The large muscle in the front of the upper arm.

Bicipital Tuberosity A protuberance on the medial surface of the radius to which the biceps attaches.

Biomechanics The study of the human body as a system operating under two sets of laws: the laws of Newtonian mechanics and the biological laws of life.

Brachialis Muscle Short, strong muscle originating at lower end of the humerus (q.v.) and inserting into ulna (q.v.). Operates at mechanical advantage, powerful flexor of forearm, employed when lifting.

Camber Generally refers to a tilt or curve. In seating design, the camber, or slope of the chair with respect to the horizontal is optimally 8° from front to back.

Capitulum of Humerus A smooth hemispherical protuberance at the distal end of the humerus articulating with the head of the radius. Irritation caused by pressure between the capitulum and head of the radius is called tennis elbow.

Carpal Tunnel A passage in the wrist through which important blood vessels and nerves pass to the hand from the forearm. Ulnar or radial deviation cause misalignment of the carpal tunnel and irrigation of structures passing through it.

Carpal Tunnel Syndrome A common affliction of assembly workers caused by compression of the median nerve in the carpal tunnel. Often associated with tingling, pain or numbness in the thumb and first three fingers. Reduces manipulative skills, particularly if thumb is involved, and frequently reduces work output.

Deltoid Muscle The muscle of the shoulder responsible for extending the arm sideways, and for swinging the arm at the shoulder. Overuse of the deltoid muscle may cause fatigue, pain in the shoulder and unwarranted fear of heart disease.

Distal Away from the central axis of the body.

Distal Phalanx Colloquially known as the "knuckle," the long bone of the finger or toe away from the central axis of the body (distal). Frequently used as an anatomical reference point in work analysis.

Dynamometer Apparatus for measuring force or work output external to a subject. Often used to compare external output with associated physiological phenomena (electromyography, spirometry, etc.) to assess physiological work efficiency.

Epicondylitis Inflammation or infection in the general area of an epicondyle; e.g., tennis elbow.

Ergonomics A multidisciplinary activity dealing with the interactions between man and his total working environment plus such traditional environmental elements as atmosphere, heat, light and sound as well as all tools and equipment of the workplace.

Extensor Muscles A muscle which, when active, increases the angle between limb segments; e.g., the muscles which straighten the knee or elbow, open the hand or straighten the back.

Extensor Tendon Connecting structure between an extensor muscle and the bone into which it inserts. Examples are the hard, longitudinal tendons found on the back of the hand when the fingers are fully extended.

External Mechanical Environment The man-made physical environment; e.g., equipment, tools, machine controls, clothing. Antonym: internal (bio)mechanical environment, q.v.

Flexor Muscles A muscle which, when contracting, decreases the angle between limb segments. The principal flexor of the elbow is the brachialis muscle. Flexors of the fingers and the wrist are the large muscles of the forearm originating at the elbow. Cf., extensor muscle.

Foot-Pounds of Torque A measurement of the physiological stress exerted upon any joint during the performance of a task. The product of the force exerted and the distance from the point of application to the point of stress. Physiologically, torque which does not produce motion nonetheless causes work stress whose severity depends on the duration and magnitude of the torque. In lifting an object or holding it elevated, torque is exerted and applied to the lumbar vertebrae.

Humerus The bone of the upper arm which starts at the shoulder joint and ends at the elbow. Muscles which move the upper arm, forearm and hand are attached to this bone.

Iliac Crest The upper rounded border of the hip bone. No muscles cross the iliac crest and it lies immediately below the skin. It is an important anatomical reference point because it can be felt through the skin. Seat backrests should clear the iliac crest.

Inertial Moment Related to biomechanics, that moment of force-time caused by sudden accelerations or decelerations. Whiplash of the neck is caused by an inertial moment. In an industrial setting, side-stepping causes application of a lateral inertial moment on the lumbosacral joint, which may cause trauma, pain, and in any case will lower performance efficiency. The inertial moment is one of the seven elements of a lifting task.

Internal Biomechanical Environment The muscles, bones and tissues of the body, all of which are subject to the same Newtonian force as external objects in their interaction with other bodies and natural forces. When designing for the body, one must consider the forces that the internal mechanical environment must withstand.

Ischemia Lack of blood flow. Loss of sufficient replacements to maintain normal metabolism in the cells. Caused by blockage in the circulatory system or failure of the cardiac system. Blockage may be by internal biological agents such as arterial wall deposits or by external environmental agents such as poorly designed tools or workplaces which press against arteries and occlude them. Depending on the degree of ischemia, numbness, fatigue and tingling may be evidenced in the limbs. At the workplace, loss of precision in manipulation may lead to reduced efficiency, poor quality and possibility of accidents.

Ischial Tuberosity A rounded projection on the Ischium. It is a point of attachment for several muscles involved in moving the femur and the knee. It can be affected by improper design of chairs and by situations involving trauma to the pelvic region. When seated, pressure is borne at the site of the ischial tuberosities. Chair design should provide support to the pressure projection of the ischial tuberosity through the skin of the buttocks.

Isometric Work Referring to a state of muscular contraction without movement. Although no work in the "physics" sense is done, physiologic work (energy utilization and heat production) occurs. In isometric exercise, muscles are tightened against immovable objects. In work measurement, isometric muscular contractions must be considered as a major factor of task severity.

Kinesiology The study of human movement in terms of functional anatomy.

Kinetic Chain A combination of body segments connected by joints which, operating together, provide a wide range of motion for the distal element. A single joint only allows rotation, but kinetic chains, by combining joints enable translatory motion to result from the rotary motions of the limb segments. Familiarity with the separate rotary motions and their limitations is necessary for comprehension of the characteristics of the resultant motion. By combining joints whose axes are not parallel, the kinetic chain enables a person to reach every point within his span of reach.

Man-Equipment Interface Areas of physical or perceptual contact between man and equipment. The design characteristic of the man-equipment interface determine the transfer of information and motor skill. Poorly designed interfaces may lead to localized trauma (e.g., calluses) or fatigue.

Latissimus Dorsi A large flat muscle of the back which originates from the spine of the lower back and inserts into the humerus at the armpit. It adducts the upper arm, and when the elbow is abducted, it rotates the arm medially. It is actively used in operating equipment such as the drill press where a downward pull by the arm is required.

Lumbar Spine Lowest section of the spinal column or vertebral column immediately above the sacrum. Located in the small of the back and consisting of five large lumbar vertebrae, it is a highly stressed area in work situations and in supporting the body structure.

Lumbosacral Joint The joint between the fifth lumbar vertabrae and the sacrum. Often the site of spinal trauma because of large moments imposed by lifting tasks.

Mechanotactic Stress Stress caused by contact with a mechanical environment.

Mechanotaxis Contact with a mechanical environment consisting of forces (pressure, moment), vibration, etc. One of the ecological stress vectors. Improper design of the mechanotactic interface may lead to instantaneous trauma, cumulative pathogenesis, or death.

Median Nerve A major nerve controlling the flexor muscles of the wrist and hand. Tool handles and other objects to be grasped should make good contact with the sensory feedback area of this nerve located in the palmar surface of the thumb, index, middle, and part of ring finger.

Mid-Sagittal Plane A reference plane formed by bisecting the human anatomy so as to have a right and left aspect. Human motor function can be described in terms of movement relative to the mid-sagittal plane.

Moment Magnitude of the force times distance of application.

Moment Concept The concept based on theoretical and experimental bases that lifting stress depends on the bending moment exerted at susceptible points of the vertebral column rather than depending on weight alone.

Musculo-Skeletal System The combined system of muscles and bones which comprise the internal biomechanical environment.

Olecranon Fossa A depression in the back of the lower end of the humerus in which the ulna bone rests when the arm is straight.

Palmar Arch Blood vessel in the palm of the hand from which the arteries supplying blood to the fingers are branched. Pressure against the palmer arch by poorly designed tool handles may cause ischemia of the fingers and loss of tactile sensation and precision of movement.

Popliteal Clearance Distance between the front of the seating surface and the popliteal crease. This should be about 5″ in good seat design to prevent pressure on the popliteal artery.

Popliteal Crease (or Line) The crease in the back of the leg in the hollow of the knee when lower leg is flexed. Important anatomical landmark.

Popliteal Height of Chair The height of the highest part of the seating surface above the floor.

Popliteal Height of Individual The height from the crease in the hollow of the knee to the floor is called the "popliteal height" of the individual concerned.

Pronation Rotation of the forearm in a direction to face the palm downward when the forearm is horizontal or backward when the body is in anatomical position. An important element of industrial demanded motions inventory, it is performed by muscles whose efficiency is a function of arm position.

Proximal Describing that part of a limb which is closest to the point of attachment. The elbow is proximal to the wrist which is proximal to the fingers.

Radial Deviation Flexion of the hand which deflects its longitudinal axis toward the radius. It causes the head of the radius to press against the capitulum of the humerus, and may lead to irritation of the elbow ("tennis elbow"). Tool design should minimize radial deviation. Strength of grasp is diminished in radial deviation.

Radius The long bone of the forearm in line with the thumb. It is the active element in the forearm during pronation and supination. It also provides the forearm connection of the wrist joint.

Raynaud's Syndrome Constriction of the blood vessels of the hand from cold temperature, emotion, or unknown causes. Afflicts women predominantly and affects both hands simultaneously. Hands become cold, blue and numb and lose fine prehensile ability. On recovery, hands become red accompanied by burning sensation. Easily confused with one-sided numbness and tingling caused by poor tool design and resulting pressure.

Sagittal Plane A plane from back to front vertically dividing the body into right and left portions. Important in anthropometric definitions. Mid-sagittal plane is a sagittal plane symmetrically dividing the body.

Sensory Feedback Use of external signals perceived by sense organs (e.g., eye, ear) to indicate quality or level of performance of an event triggered by voluntary action. On the basis of sensory feedback information, decisions may be made; e.g., permitting or not permitting an event to run its course; enhancing or decreasing activity levels.

Sensory End Organs Receptor organs of the sensory nerves located in the skin. Each end organ can sense only a specific type of stimulus. Primary stimuli are heat, cold, or pressure, each requiring different end organs. Knowledge of end organ distribution is of importance to the safety engineer. For example, there are few heat receptors on the outer surface of the forearm, so that the skin may be severely burned before heat is sensed.

Sternomastoid Muscles A pair of muscles connecting the breastbone and lower skull behind the ears, which provide support for the head. When operating together, the right and left sternomastoids pull the head forward and downward, and when operating singly, each turns the head to the opposite side. They oppose the semispinalis muscles and stabilize the head. In the workplace, the worker's head position should be nearly vertical to minimize activity of the semispinalis and sternomastoid muscles. The sternomastoid is also functionally important in head scanning.

Supination Rotation of the forearm about its own longitudinal axis. Supination tends to turn the palm upward when the forearm is horizontal and forward when the arm is in anatomical position. Supination is an important element of available motions inventory for industrial application, particularly where tools such as screwdrivers are used. Efficiency in supination depends on arm position. Workplace design should provide for elbow flexion at 90 degrees.

Tendons Fibrous end sections of muscles. It attaches to bone at the area of application of tensile force. When its cross-section is small, stresses in the tendon are high, particularly because the total force of many muscle fibers is applied at the single terminal tendon. The site of many industrial diseases caused by trauma, biomechanically improper movements, or failure of lubrication, the tendon must be protected in tool and workplace design.

Tennis Elbow Sometimes called epicondylitis. An inflammatory reaction of tissues in the lateral elbow region. In an industrial environment it may follow effort requiring supination against resistance (as in screwdriving) or violent extension of the wrist with hand pronated. Can frequently be avoided by assuring that the axis of rotation of a tool or machine control coincides with the orthoaxis of rotation of the forearm.

Tenosynovitis A disease of the wrist. Inflammation of the tendon sheaths of the wrist often associated with continual ulnar deviation during rotational movements (e.g., screwdriving) or by other overwork or trauma. In industry, extensor sheath inflammation is more frequent. Work tolerance is reduced because of pain during wrist and finger movement.

Trauma An injury or wound, generally caused by a physical agent. Cuts, bruises and abrasions are obvious examples of trauma, but trauma may be present even though it is not visible; e.g., strained muscle. The causes of trauma must be anticipated in workplace design or tool design. Protective devices and special clothing (work shoes, gloves) are used to avoid trauma.

Triceps The large muscle at the back of the upper arm that extends the forearm when contracted.

Trigger Finger Also know as snapping finger. A condition of partial obstruction in flexion or extension of a finger. Once past the point of obstruction, movement is eased. Caused by thickening of a tendon or localized reduction of the tendon sheath. In the workplace, flexing against strong antagonists and flexing of the distal phalanx without middle phalanx movement is suspected. Tool handles should be designed for trigger operation by the thumb.

Ulna One of the two bones of the forearm. It forms the hinge joint at the elbow and does not rotate about its longitudinal axis. It terminates at the wrist on the same side as the little finger. Task design should not impose thrust loads through the ulna.

Ulnar Deviation A position of the hand in which the wrist is bent toward the little finger. Ulnar deviation is a poor working position for the hand and causes nerve and tendon damage. It reduces the useful range of pronation and supination by approximately 50%, and work performed in ulnar deviation proceeds at low efficiency. Handtool design should avoid ulnar deviation.

Viscerotaxis One of the ecologic stress vectors. A form of chemotaxis concerned with the internal contact of chemical agents within the body. Chemical exposure via the gastrointestinal tract, the pulmonary system, and the urogenital systems are examples of viscerotaxis.

Work Strain The natural physiological response reaction of the body to the application of reaction of the body to the application of work stress. The locus of the reaction may often be remote from the point of application of work stress. Work strain is not necessarily traumatic but may appear as trauma when excessive, either directly or cumulatively, and must be considered by the industrial engineer in equipment and task design. Thus, increase of heart rate is non-traumatic work strain resulting from physical exertion, but tenosynovitis is pathological work strain resulting from undue work stress on the wrists.

Work Stress Biomechanically, any external force acting on the body during the performance of a task. It always produces work strain. Application of work stress to the human body is the inevitable consequence of performance of any task, and is therefore only synonymous with "stressful work conditions" when excessive. Work stress analysis is an integral part of task design.