"ergonomics can contribute greatly to improving working conditions and environments."

Industrial Application of Ergonomics

by

Sadao Horino*

WHAT IS ERGONOMICS?

The problems of working conditions and environments are multi-complex and cross sectoral in nature, and can be solved through a multi-disciplinary approach with participation of various parties and experts. In this context, the inter-disciplinary science and technology which is known nowadays as ergonomics can contribute greatly to improving working conditions and environments, and should become one of the major components of any efforts in this field.

Ergonomics is defined by the Ergonomics Research Society as the "scientific study of human factors in relation to working environments and equipment design". The International Labor Organization (ILO) defines it as the "application of the human biological sciences to achieve the optimum mutual adjustment of man and his work, the benefits being measured in terms of human efficiency and well-being."

Ergonomics aims at promoting safety, comfortability and efficiency at work situation in industry through arranging better relationships between man, machines and environment. Ergonomics achieves its aims by applying such disciplines as industrial psychology, work physiology, anatomy, anthropology, engineering sciences and sociology in an integrated approach. It facilitates, if appropriately applied, the utilization of human capability and prevents any unnecessary waste in the use of human resources. Therefore, the task of ergonomics is to develop the most comfortable conditions for the worker as regards climate, noise level and lighting, to reduce the physical workload, to improve working postures and reduce the effort of doing certain movements to facilitate psycho-sensorial functions in reading instrument displays, to make the handling of machine levers and controls easier, to make better use of spontaneous and stereo-typed reflexes, to avoid unnecessary information recall efforts, and so on.

ERGONOMIC APPROACH TO PROBLEMS

To fulfill the general aims, and consequently, to produce well-integrated man and machine, and man and environment combinations, the ergonomic approach has three sections, namely system analysis, workstation analysis and evaluation. Some or all of them are implemented according to the type and complexity of the task, machine or system being considered.

The first process which is referred as system analysis, defines the system aims and the various

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*Associate Professor, Kanagawa University, Yokohama, Japan.

functions needed to achieve those aims and then to examine and decide which functions within the whole system should be assigned to human elements and which to machine elements. When examining optimum allocation of functions to either man or machine, it is very important to utilize the best features of each element as shown in Table 1.

Table 1. Man vs. Machine (Woodson and Conover, 1970, pp. 1-23)

Man Excels In	Machines Excel In
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Detecting signals in high noise levels	Exerting great force, smoothly and with precision
Ability to store large amounts of information for long periods – and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time-periods
Ability to exercise judgment where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improvising and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves, etc.).
Ability to react to unexpected low-probability events	Doing many different things at one time.
Applying originality in solving problems i.e., alternate solutions	Deductive processes
Ability to profit from experience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipulation, especially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period
Ability to continue to perform even when overloaded	Operating in environments which are hostile to man or beyond human tolerance
Ability to reason inductively	

Secondly, for each machine or for each part of a system where a human element is used, the interaction between man and the equipment must be optimised. The ergonomic approach at this man-machine level, which is referred to as workstation analysis, is to examine the task and the operational sequence which the man will have to do, considering his interaction first, with the machine, next with the immediate workspace around him and finally with the general environment in which he and the machine are to work. Workstation analysis expands outwards involving bigger sectors (Figure 1) – from man to machine, workspace and environment, but always with man at the center as the frame of reference.

Thirdly, the proposed and final design of a completely new machine system or a redesign of an existing working situation should be evaluated by mock-ups and trials to test its effects on human factors. Such evaluation trials should be so arranged as to be of use to the expected final users.

If the above three processes are appropriately followed in the design and development stages, they will help to counteract the tendency to piecemeal design, which is the most common cause of design imperfections.

MAN-MACHINE-ENVIRONMENT INTERACTION

Workstation analysis is taken as the first step to define the profile of the workers (man) likely to use the workstation being analyzed. Items to be defined include the range and limits of age, sex, body size, intelligence, experience, training etc., of the expected users. Then, the range and types of tasks, and the abilities and limitations of the expected users, have to be considered.

The next step is to understand fully the operation of any machines involved and the interaction of man to them. "Machine" is used here in the general sense to mean a physical component or set of components which assists a human being in the performance of some action. When considering man-machine interaction, it is useful to think of them as a complete information flow loop.

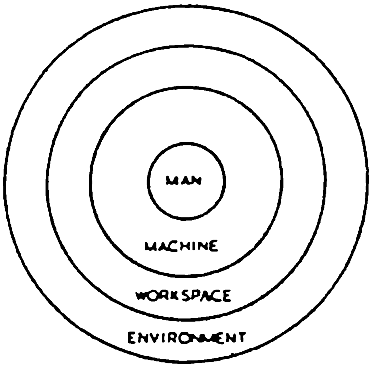


Figure 1. **The simple but important frame of man, machine, workspace and environment. (B. Shackel, 1974).**

Figure 2 illustrates a schematic model of information-decision-action concept. This concept is helpful in determining whether the operator is receiving the information needed for the decision to be made, whether it is presented adequately by the displays, whether his decision can be signalled easily and efficiently, whether better controls are needed, and whether the displays and controls are compatible with each other and are located appropriately by good panel and machine layout. Thus, the areas related to man – information (sensory input), decision and action (motor output) – are usefully matched by those related to machine – displays, controls, and panel and machine layout.

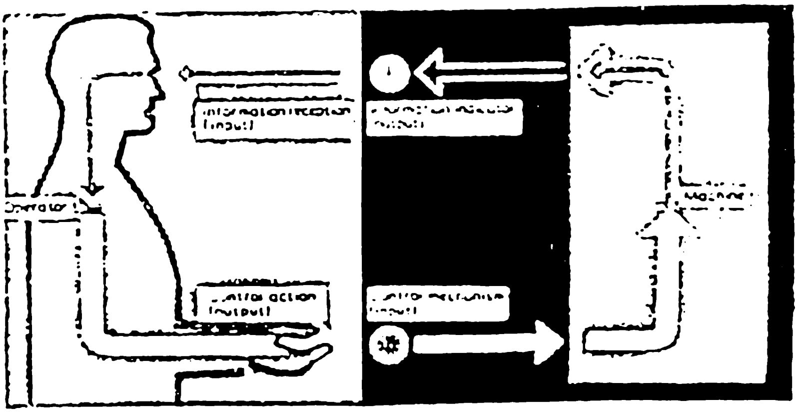


Figure 2. Schematic model of information-decision-action concept. The communication between man and machine can be viewed as an information loop. (B. Shackel, 1974)

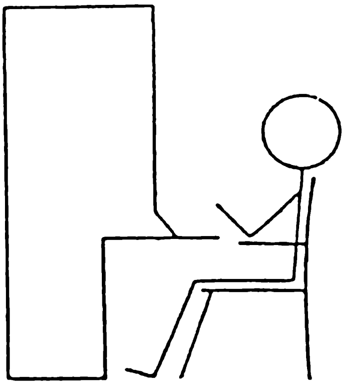


Figure 3. Man-workspace interaction: the machine, chair, desk, etc., and the adjacent machines, etc., influence the man's position, posture and reach and thus his comfort and efficiency. (B. Shackel, 1974).

Next to machine sector, the interaction of man with the immediate workspace around him is considered. Everything should be studied which may affect the position, posture and reach of the expected range of users and thus their comfort and efficiency. This will include such items as the size and the position of chairs, desks, machines, consoles, bins of waiting and finishing workpieces, gangways and adjacent machines. (Figure 3).

Moving farther away from the workspace area, the interaction of man with his general environment should be considered. This is pursued under such headings as physical aspects (e.g., lighting, noise, heat, ventilation, dust), chemical, biological and psychological aspects (e.g., workteam, command structure, shift conditions, socio-psychological factors, etc.) The measured characteristics of the actual environment under study, or the expected or specified characteristics for the new design, are first detailed and then compared with the available ergonomics data about human performance under various environmental conditions (Figure 4).

Like the workspace, the environment has many examples of imperfect situations. In foundry workshops, for instance, workplaces are often noisy, dusty and dark, and often little is done to protect workers from those harmful health hazards such as hearing loss or silicosis. In control room, lighting is poor; in daylight, glare from badly sited windows or onto badly sited consoles may interfere with instrument reading, and artificial lighting may cause glare and shadows in different places.

DISPLAYS AND CONTROLS – DESIGN TO ELIMINATE HUMAN ERRORS

The effectiveness of a machine depends on its efficiency and reliability, and on the ability of the human operator to control it easily and accurately. His ability is greatly influenced by the design of machine; for example, by the way it presents information, and the degree of force and accuracy required to operate it. Unlike machines, man is not rigidly constructed. On the contrary, he posesses great adaptability. It is this very adaptability which, often as a result of machine-oriented design of equipment and economic pressure, has in many instances forced man into work situations to which he really is not adjusted, to the detriment of both his well-being and his performance.

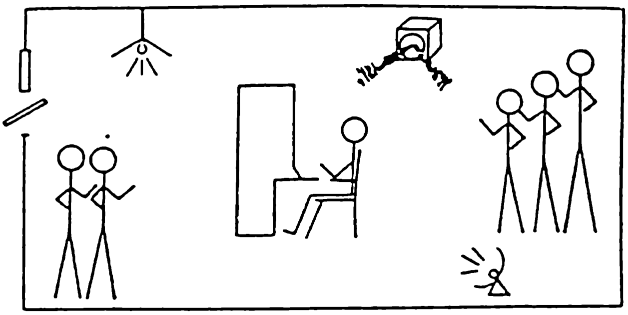


Figure 4. Man-environment interaction: both the physical and psychological environment may influence greatly man's behavior and performance.

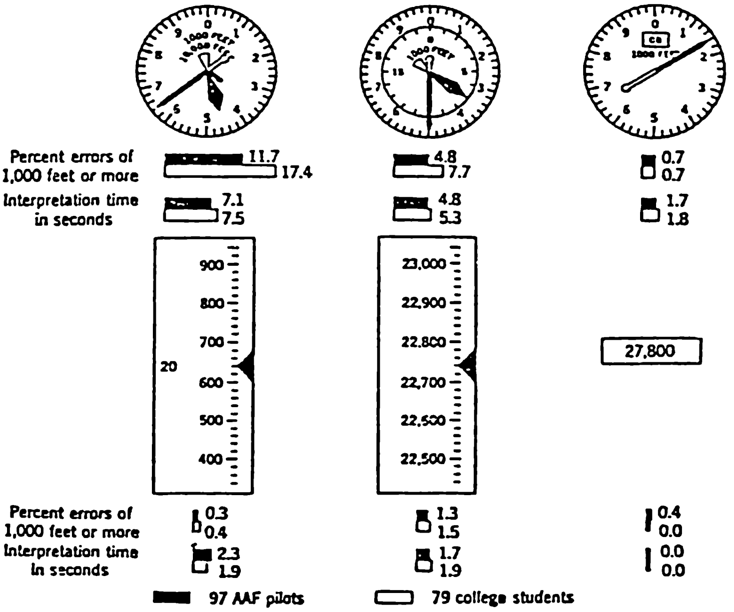


Figure 5. The conventional three-pointer altimeter (upper left) and the five best experimental altimeters found in a study by Grether. The number of large errors and the average reading time for pilots college students are shown beneath each dial. (Data of Grether from Chapanis, Garner, and Morgan)

Altimeter design gives us a good example of this. Comparative study on reading accuracy and speed of aircraft altimeter design by Grether (1949) showed that the conventional design having three pointers, which was used most commonly and caused accidents frequently during the last war days, took longer time to read than any other design, and that the errors, even for experienced U.S. Air Force pilots, were high. The other design having one pointer combined with digital counter on the same dial or complete digital counter type clearly showed, under experimental conditions, to be the best in both speed and accuracy, (Figure 5). Although the counter type showed fewest errors in this study, its potential use as an altimeter might be limited, since in a high speed dive or climb, the counter might change so fast that the pilot could not see the readings. Consequently, the design of altimeter having one pointer combined with digital displays was chosen, and this type is still applied to the current air bus such as Jumbo B-747.

In controlling electric room heater, the conventional design of the heat control having a fixed pointer with moving scale causes users' confusion in directing the rotation of the knob when controlling heat. But a new design of heat control having a moving pointer with fixed scale will eliminate any possible ambiguities found in the former design. The new type dial will not cause additional costs if this type is chosen at the initial design stage. It will cost more, however, if the design should be changed after installation of equipment due to some inconvenient troubles (Figure 6).

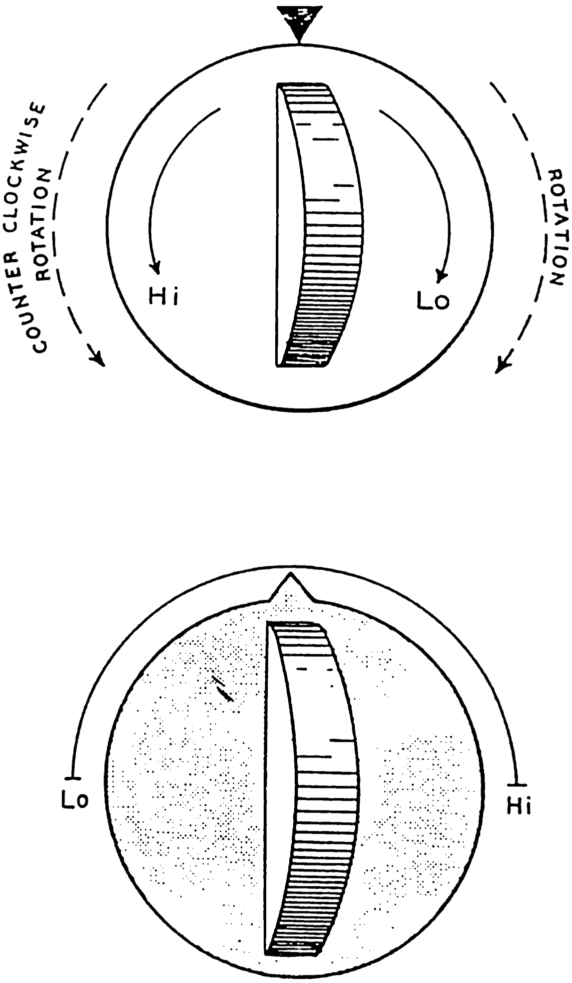


Figure 6. Schematic illustration of the heat control on an electric room heater. The lower heater control eliminates ambiguities found in the upper one (A. Chapanis, 1965).

The correct identification of controls and other devices is of course necessary in order for them to be used properly. In many operating circumstances, the correct and rapid identification of controls or other devices is important, in some cases in terms of life and safety, or in any event in terms of time, accuracy, or economy. As an example of the importance of such identification, over 400 aircraft accidents in the US Air Force have been attributed to confusion between landing gear and flap controls in a 22-month period during World War II. The U.S. Air Force has developed through studies standard knob shapes which in addition to being distinguishable from each other by touch include some that have also symbolic meaning. In Figure 7 it will be seen, for example, that the landing gear knob is like a landing wheel, that the flap control is shaped like a wing, and that the fire-extinguishing control resembles the handle on some fire extinguishers. This kind of concept is very widely applicable to various kinds of levers, locks, knobs and handles which are easily identifiable by touch to be pushed or pulled quickly and accurately.

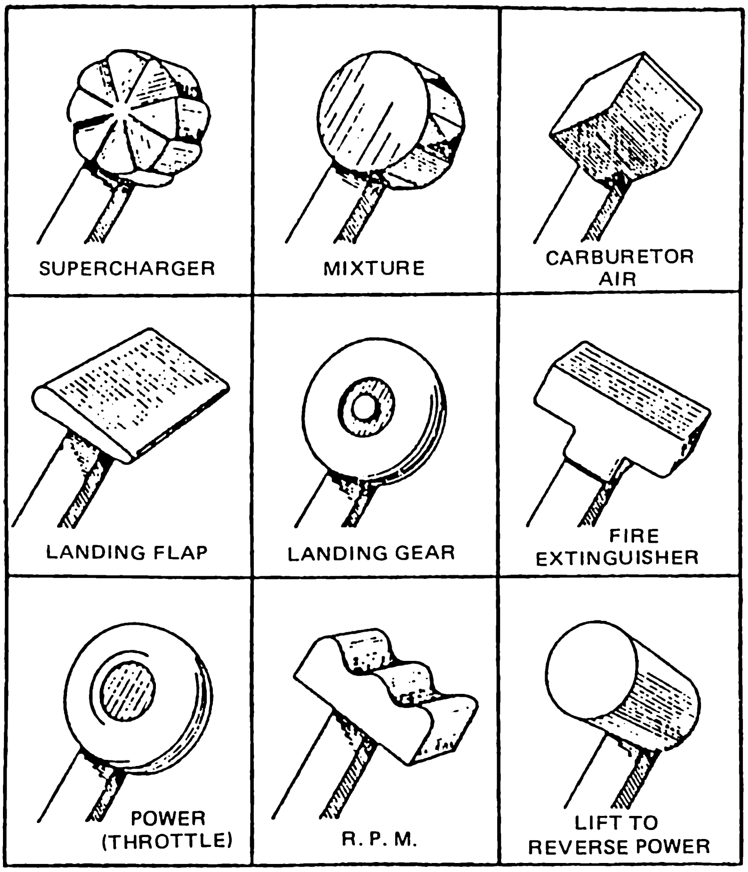


Figure 7. Some shape-coded controls for use in the U.S. Air Force. (A. Chapanis, 1965).

When steering an unfamiliar motor-car, it is to be expected that turning the steering wheel clockwise will turn the wheels to the right: no one would expect to turn the wheel to the left in order to steer it to right. Similarly, it is reasonable to expect that when the control knob is turned to the right, the pointer of the corresponding instrument will also move to the right. Such expectations depend on so called stereotyped reactions. Stereotypes are conditioned reflexes which have become subconscious and "automatic". Therefore, controls and instruments that are functionally

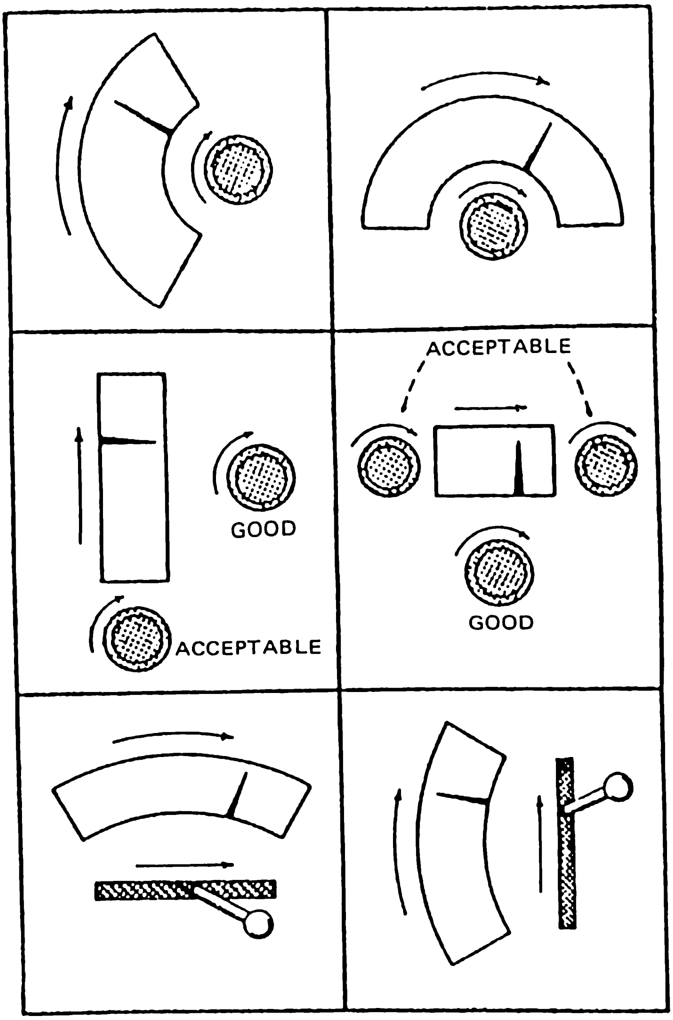


Figure 8. **Some dependable stereotypes for controls and displays mounted in the same plane. (A. Chapanis, 1965).**

linked ought also to make corresponding movements that are in accordance with our own stereotypes. Figure 8 shows examples of sensible coordination between the direction of movement of knobs or levers and instruments on the same plane. A generally accepted principle is that with a rotary control in the same plane, a clockwise turn of a control device is associated with an increase in values.

Most drivers driving large size trucks in Japan suffer from the difficulty or even impossibility of receiving all the necessary visual information when they turn to the left at cross-sections. Bicycle riders or pedestrians are often hit by these turning trucks. In most instances, these accidents are caused primarily by poor visibility of truck driving cabins. Visibility of trucks on the ground was measured by the fish-eye-lens phototechnique which was developed by the author. Results clearly showed that the dimensions of driving cabin structure particularly in terms of frontal and side window position from the ground level greatly influenced driving visibility as shown in Figures 9 and 10. It was disclosed that the truck had a wider dead angle around the front and side of the cabin in comparison with other vehicles such as a sight-seeing bus and a fire-engine which had front and side windows at much lower positions. Further truck accidents could be avoided by redesigning the cabin structure to make window positions lower.

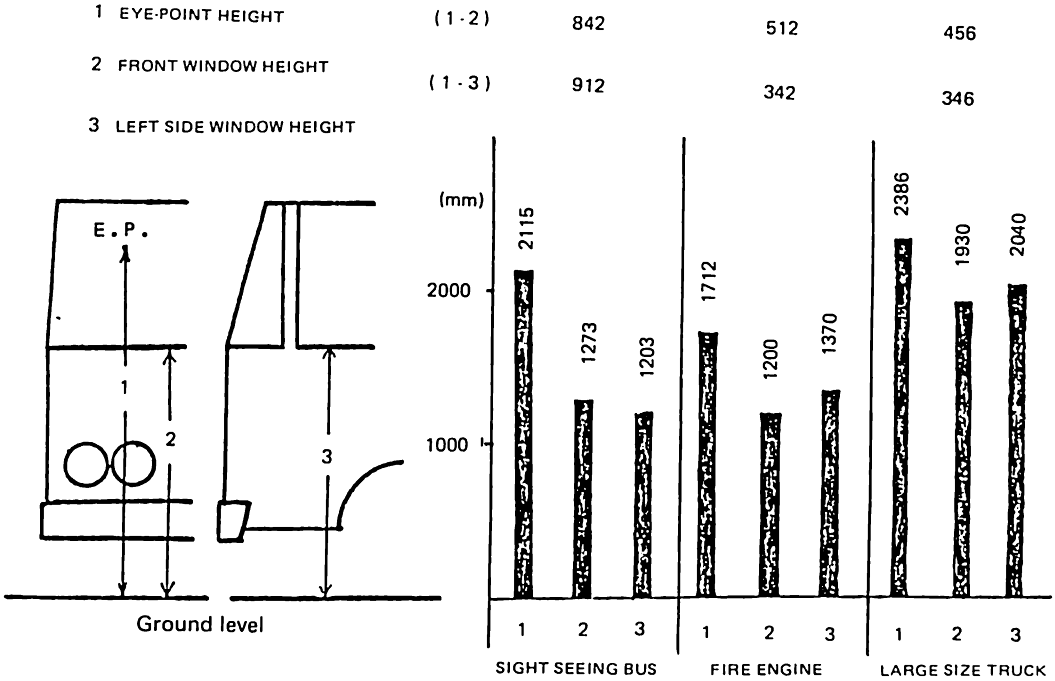
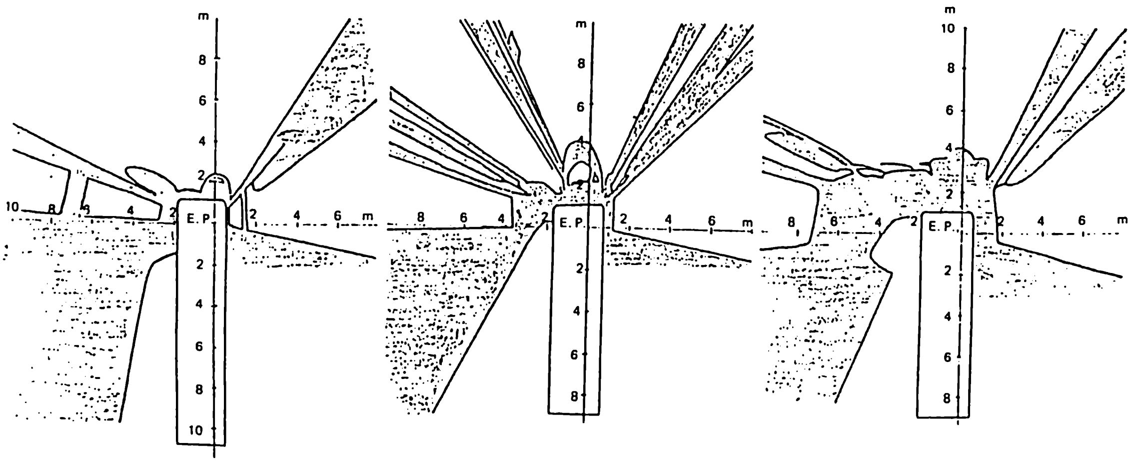


Figure 9. A comparison of the driving cabin structure dimensions between a sight-seeing bus (West German-made), a fire engine (Japanese-made) and a large size truck (Japanese-made) in terms of the eye-point height, the front window height, and the left side window height. (1-2) or (1-3) indicates the level differences of the front and side left window height from the eye-point level for each vehicle. (S. Horino, 1978).



a. a sight-seeing bus (West German made)

b. a fire engine (Japanese made)

c. a large size truck (Japanese made)

Figure 10. The driving visibility projected on the 1.0m level above the ground for a sight-seeing bus, fire engine with low position of a driving cabin and a large size truck with high position of a driving cabin. (S. Horino, 1978)

WORKPLACE AND BODY SIZE

Working postures are limited by the need to reach controls, to keep the feet on pedals, or to keep the eyes in a position from which the task can be seen. Since natural postures and movements of the trunk, arms and legs are necessary in performing work efficiently, it is therefore essential that the work place should be suited to the body size of the operator.

It is not enough, as a rule, to design a work place to suit an average person. More often, it is necessary to take account of the tallest persons (e.g., to provide enough leg room under a table), or of the shortest persons (e.g., to make sure they can reach high enough). Since it is not usually possible to design work places to suit both the tallest and the smallest workers, we must be content with meeting the requirements of the majority. Thus, a science which deals with the measurement of the physical features of the body including linear dimensions, circumference, weight and range of movement is known as "anthropometry". The mass of anthropometric data is available for equipment design or work place arrangements. For illustrative purposes, some of the basic body dimensions are shown in Figure 11, and Table 2.

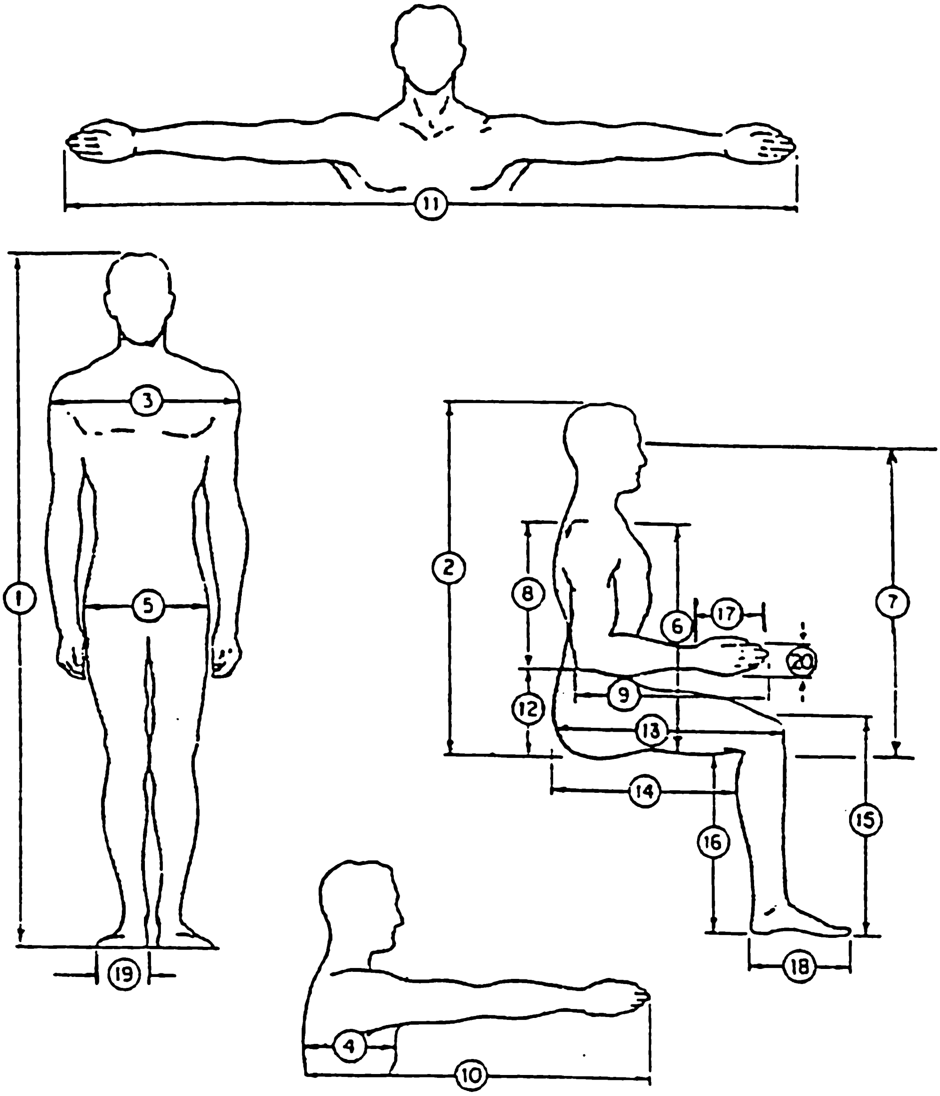


Figure 11. Examples of some body dimensions. For corresponding measurement data, see Table 2.

Table 2. Selected Body Measurements of Japanese Adults

(in cm)

	Body dimensions	male			female		
		source	mean	SD	source	mean	SD
1.	Height		162.1	5.7		151.8	4.9
2.	Sitting height		88.7	3.2		84.1	2.6
3.	Shoulder breadth	a	40.1	2.1	a	37.1	1.5
4.	Chest depth	b	17.4	1.4	c	17.2	1.3
5.	Hip breadth: standing		30.8	1.4		31.8	1.4
5.	Hip breadth: seated		33.1	1.7		33.3	3.2
6.	Shoulder height	d	59.0	2.2	d	56.2	1.8
7.	Eye height	d	80.2	3.0	d	75.4	2.3
8.	Shoulder-elbow	e	34.4	1.6		–	–
9.	Forearm-hand		43.8	2.2		39.7	1.8
10.	Arm reach		79.5	3.2		73.9	3.2
11.	Arm span	d	168.2	5.5	d	156.7	6.1
12.	Elbow height: sitting		25.1	2.3		25.7	2.1
13.	Buttock-knee		54.3	2.4		52.0	2.3
14.	Seat length		41.9	2.4		39.4	2.2
15.	Knee height: sitting		47.0	2.2		43.6	1.9
16.	Seat height	d	42.0	1.9	d	37.9	1.9
17.	Hand length	f	18.6	0.9	f	17.2	0.8
18.	Foot length		24.3	1.9		22.4	0.9
19.	Foot breadth		9.8	0.5		8.9	0.4
20.	Hand breadth	f	8.4	0.4	f	7.6	0.4

Note: Sources refer to Takeichi et al. (1968) for no marks, Kohara et al. (1965) for "a", Matsuno et al. (1964) for "b", Nishi (1952) for "c", Kimura et al. (1965) [age: 18] for "d", Nagamachi (1966) for "e" and Industrial Product Institute data for "f". (Gendai Ningenkogaku Gairon-*Introduction to Modern Economics* edited by Kiyoji Asai, p. 47)

If we know the mean value ($\bar{x}$) and standard deviation (σ) of any group of measurements, confidence interval at 95 percent or 90 percent is calculated easily by the following equations:

$$C_i\ 95\% = \bar{x} + 1.95\,\sigma$$

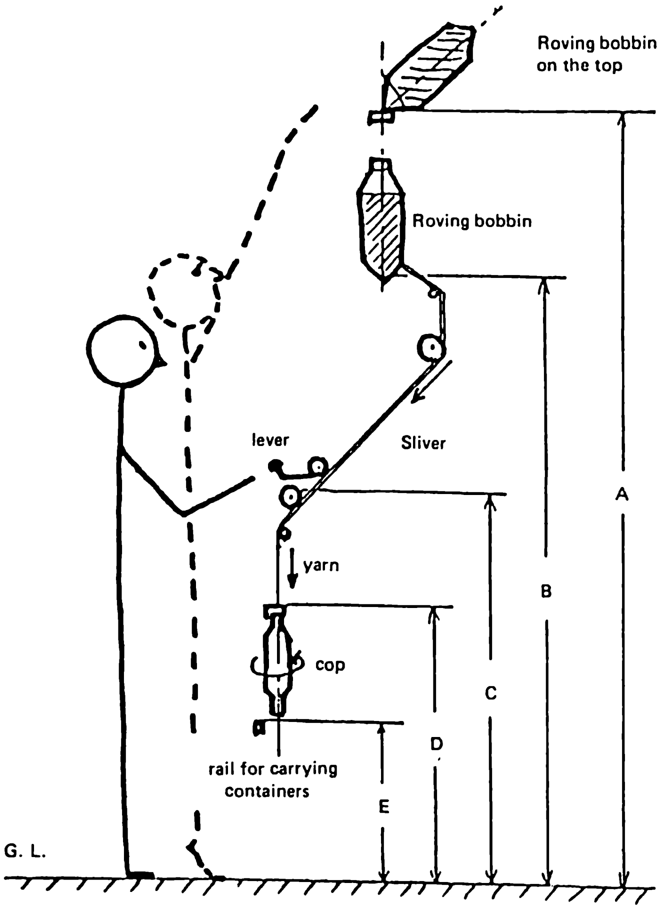
$$C_i\ 90\% = \bar{x} + 1.65\,\sigma$$

Confidence interval at 95 percent means that the smallest 2.5 percent and the largest 2.5 percent are excluded from consideration.

Anthropometry has enabled manufacturers to develop passenger cars easy and comfortable enough to be driven even by beginners, movie cameras compact enough to fit snugly in one hand, more fully rounded typewriter keys that are kinder to secretaries' fingernails and elevator buttons that are within the reach of tall and short people alike.

There are many jobs which require workers to remain in unnatural postures such as bending forward or standing very high with arms stretched. These awkward postures may cause back-aches, painful cramps at the neck and shoulder level, and may hasten fatigue and eventually lead to misoperation. Examples of these are observed in various work shops such as operation of lathe, drilling, milling, or spinning machines and other related machines in textile mills. Three different heights of spinning machine frame (dimension A in Figure 12) were observed to be used in a spinning workshop in one large textile factory in a Southeast Asian country. Two of them were designed for European workers and the other was designed for the Japanese. The European made spinning machines required female workers to jump from the floor to get bobbins which were stored on top of the machine frame. As comparative data on the measurement of "vertical reach" between American and Japanese would show, European machines are too high to reach by hand for Asian people. Thus, imported machines frequently pose problems of ill adaptation of machines to man. Therefore, anthropometry now has become one of the major subjects for work safety and efficiency, particularly in terms of technology transfer.

The work table must be of such a height that it suits the elbow-level height of the operator, whether he stands or sits at his work. Abnormal table heights reduce efficiency and hasten fatigue. Insufficient leg and foot room causes poor posture and constant irritation. So, important dimensions to remember in the design of any table or desk are: (1) working height, (2) working width and depth, (3) knee room height and depth and (4) kick room. The correct height of the work area is dependent upon the required distance from the eyes to the work area in relation to the nature of the work itself. The most favorable working height for hand-work while standing is 5-10 cm



	I	II	III
A	196	207	212
B	185	192	200
C	120	126	124
D	92	98	98
E	63	64	70

(cm)

I : Japanese made
II : U. K. made
III : Swiss made

Vertical reach

	5%	50%	95%
American* (1)	195.1	209.6	224.8
Japanese **(2)	193.8	205.2	217.8

*grasping, **stretching fingers

Figure 12. Major dimensions of three different types of spinning frame.
(1) Herzberg, et al. (1956), (2) JASDI Aeromedical Lab. (1972).

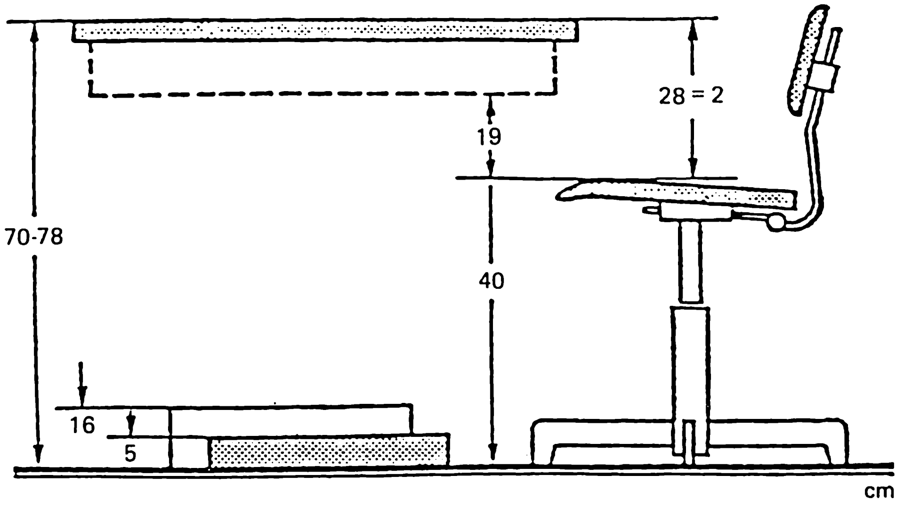


Figure 13. Recommendations for the dimensions of work tables work seats and foot rests. (E. Grandjean, 1973).

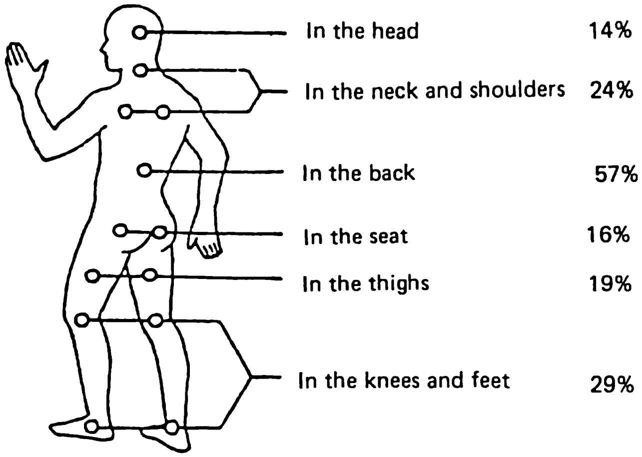


Figure 14. Somatic troubles of 378 office employees. Multiple answers were accepted. (E. Grandjean and W. Hunting Ergonomics of posture – Review of various problems of standing and sitting posture, Applied Ergonomics, 1977, 8-3, 135-140).

below elbow level and for sedentary work, a few cm below the elbow level. Standing work, however, is resorted to only when sitting is impossible owing to the nature of the work. Recommended dimensions of work table, work seats and foot rests are illustrated in Figure 13.

A study of E. Grandjean (1962) on sitting postures and somatic troubles in office workers revealed that people with pains in neck and shoulder (24 percent) were mainly those whose work tables were too high. These people tended to lift their shoulders. Furthermore, the group with pains in knees and feet consisted mainly of smaller people, who tend to sit on the front edge of the chair. The frequency of backaches (57 percent) and the common use of a back rest (42 percent) showed the need to relax the back muscles from time to time, and may be quoted as evidence of the importance of a well-constructed back-rest (Figure 14).

In various foundry workshops, a motion and time study was undertaken in order to study the relative frequency of various working postures in relation to working surface height. Figure 15 shows the relative frequency of various postures during manual work in different situations. The manual molding on the floor (W_1 – W_3) was being done mostly (70–90 percent) in bending forward and squatting postures, while work which is performed at a table with a fixed height was being done mostly in standing (50 percent) and bending forward. When a newly developed work bench for manual molding which is adjustable in height, direction, and inclination is used, the operator could make his working postures more natural and easier. Thus, working postures are very highly related to working surface height. Therefore, an arrangement of work space, particularly, work surface height, is one of the most important ergonomic subjects in work design process.

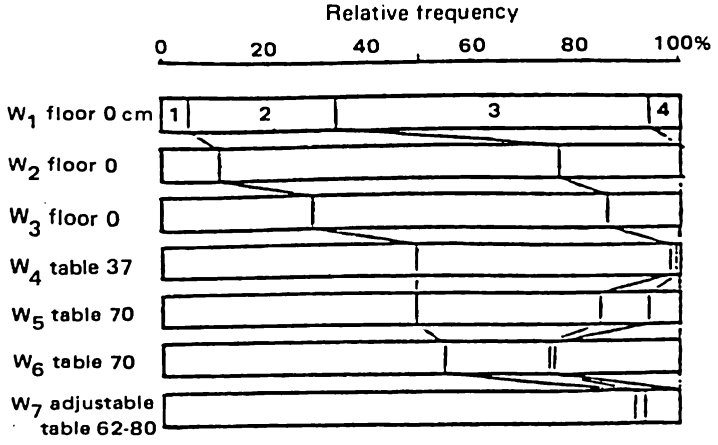


Figure 15. **Comparison of the relative frequency of working postures when work is performed on the floor level, at a table of fixed height, and at an adjustable table of optimum height. W_1-W_6, different workshops, work station height being indicated, W_7, experimentally simulated work using the adjustable table. 1, standing posture; 2, bending forward; 3, squatting; 4, others.**

WORKLOAD ASSESSMENT IN INDUSTRY

Mechanization has reduced the demand for strength and energy of the operator in many kinds of work; nevertheless, in many industries there are still jobs which require much human muscular work and which lead frequently to overstrain. Furthermore, modern industry has provided increased opportunities for workers to have much light work with less stimulation on the other hand. Consequently, it has become very important to determine the strength of work load of various industrial activities so as to design an optimum work method and optimum schedule of work and rest to reduce unnecessary fatigue and to get better work efficiency. It is well recognized recently in ergonomics that adequate workload should not include neither overstrain nor understrain.

When work is being performed, mechanical energy is exerted through muscle contraction. Large muscles, such as those in the thighs, are capable of exerting considerable force, while smaller muscles, such as those in the fingers, are capable of more rapid contraction. As soon as physical work is performed, energy consumption rises sharply. The greater the demand made on the muscles, the more the energy consumed. This contraction is done by blood circulation. As shown in Figure 16, we can see much difference between demand for blood by the muscles and its supply depending upon working conditions. Prolonged contraction of muscles, i.e., static work, soon results in distress symptoms and fatigue. This type of fatigue occurs because of insufficient blood supply due to continuous contraction of muscular fibers in spite of much demand for blood. In case of

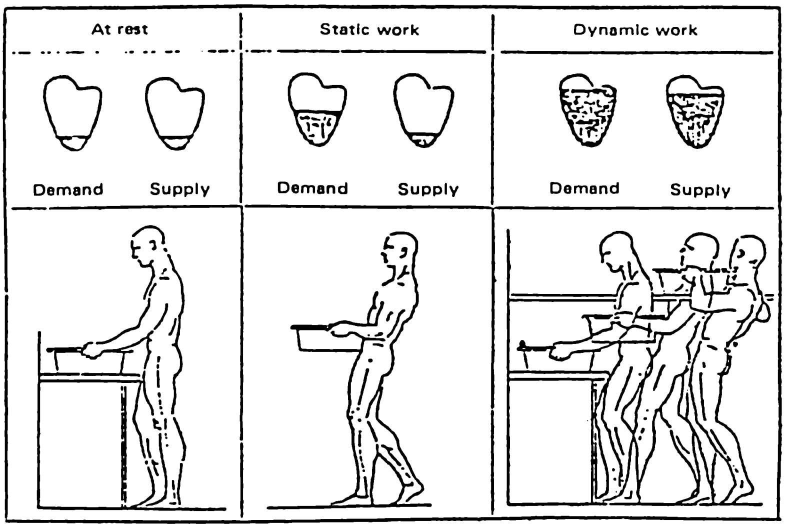


Figure 16. Difference between demand for blood by the muscles and supply under various conditions. (F. Kellermann, P. van Wely and P. Willems, 1963)

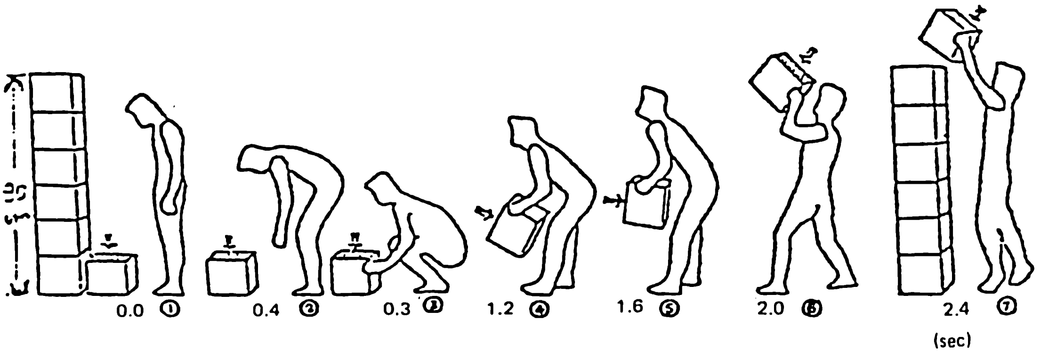


Figure 17. Working posture analysis taken by 8mm movie film.

dynamic work, demand and supply for blood can be balanced. Thus, it is desirable, generally speaking, to alternate contraction and relaxation of muscles and to avoid static work wherever possible. Dynamic work is the most advantageous and agreeable process. Examples of actions involving mainly static loading of the muscles are: a) standing, b) holding or checking objects, e.g., workpieces or tools, c) bending down, e.g., cutting grass with shears, d) pushing or pressing against resistance, as when stirring a viscous compound, e) carrying, say, containers of materials (pay atttention to hand and shoulder muscles), f) working with arms extended and unsupported, as when whitewashing a ceiling, g) movements that are too slow.

Manual handling is one typical heavy work which still remains as human muscular work and has been reported by many researchers as the principal source of low back pain. The author and a colleague have conducted experimental studies to assess physiological work load of lifting and lowering beverage containers (32x45x36.5 cm) which has become one of the popular packages in the distribution process under condition of 2-26.5 kg in weight and 2-180 cm from floor in lifting and lowering height. Figure 17 shows a schematic diagram of lifting plastic containers onto the sixth container stacked up of which total height is about 180 cm from floor. From step (4) to (5) dorsal muscles are required to exert more mechanical energy to lift up the weight.

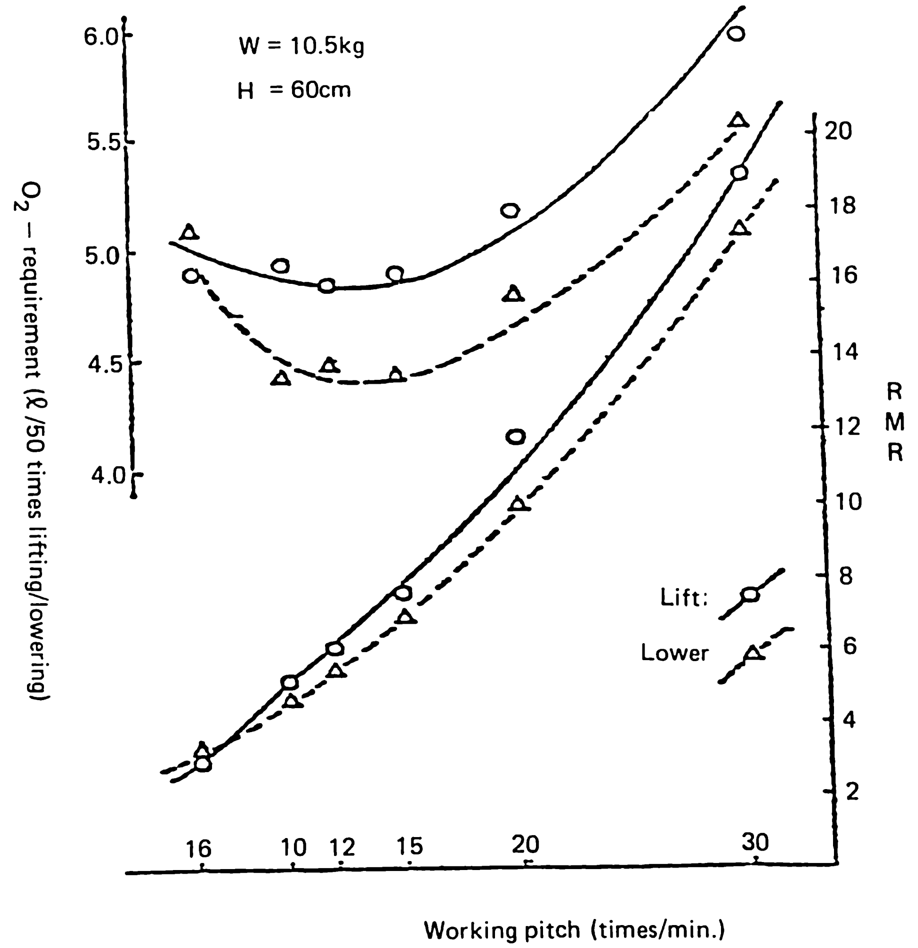


Figure 18. Working pitch (times/min.) and RMR and also working pitch and oxygen-requirement (1/50 times of lifting/ lowering).

Table 3. Oxygen intake per working minute and average heart rate increase from the resting level for main types of work on the dam surface.

Type of work	Subject	Stature (cm)	Body weight (kg)	0_2 intake (ml/min. STPD)	Average heart rate increase (beats/min)
Vibrating roller operation	A	177	69	511	6.3
Finisher adjusting	A	177	69	1000	10.5
Amending	B	158	47	596	20.3
Raking	C	175	65	1330	34.2
Ascending 1.3 m/sec	A	177	69	2150	75.6
1.2 m/sec	C	175	65	2290	101.9
0.7 m/sec	D	165	60	1770	78.7
Descending 1.4 m/sec	A	177	69	1170	40.0
1.4 m/sec	C	175	65	1040	71.3
0.4 m/sec	D	165	60	836	40.1
Level walking 1.4 m/sec	C	175	65	820	30.4
1.5 m/sec	D	165	60	1210	29.7

Figure 18 shows the oxygen requirement and relative metabolic ratio (RMR) which is defined as a ratio of energy requirement to the basal metabolism of the subject in lifting and lowering beverage containers by various working pitch. Subjects were six university students. In measuring the oxygen requirement, expired air collected into Douglass bag was analyzed by an electric respirizer. There was little difference of physiological load in the average of RMR between lifting and lowering task, because of working posture in this working condition. The most economical working pitch with the least oxygen requirement, when measured continuously 50 times of each lifting and lowering, was observed to be at around 10-15 times per minute under condition of 10.5 kg in container weight and 60 cm in lifting height.

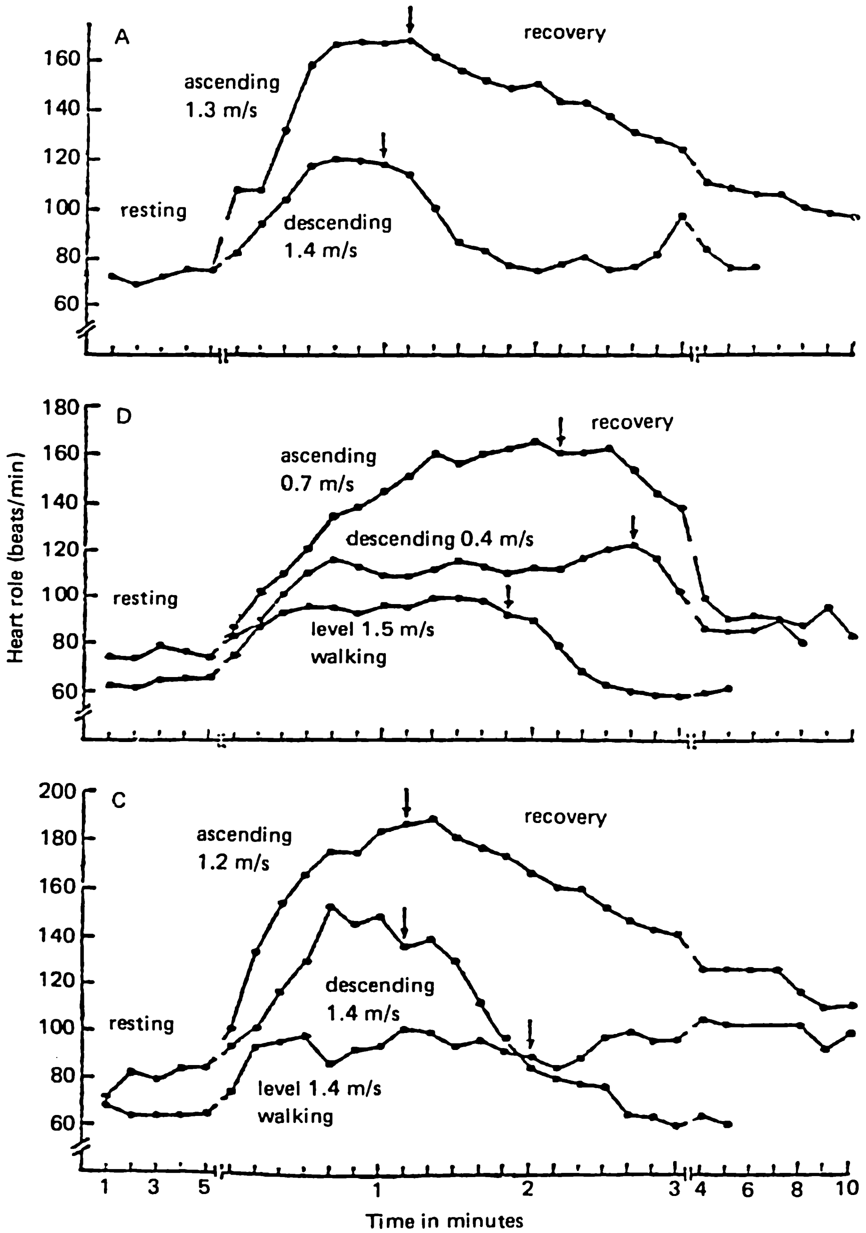


Figure 19. Heart rate change during ascending and descending on the slope, compared with level walking, for subjects A,D, and C. Arrows show end of walking.

In paving and finishing work on the slope surface with an inclination of 27.5^{0} at a rock-filled dam, peculiar physiological work load was imposed on standing workers in relation to keeping postures, peculiar to such a slope. According to oxygen-requirement and heart rate measurements, work by standing workers was moderate and ascending and descending on the smooth slope on foot were much more heavier than level walking. (See Table 3 and Figure 19.) Ascending the slope on foot demanded high oxygen intake of around 2 1/min., producing a markedly high heart rate level exceeding 160 beats/min. within 1-2 min., so that recovery took over one hour. The strenuous ascending task happened some times when the finishing machine on the slope was at a standstill caused to fetch tools from down the slope. Descending task produced a heart rate level reaching about 120-140 beats/min. which was higher than that in usual level walking, presumably because particular control of the walking posture and of leg motions may be required.

It should be noted that inadequate work space arrangement, which can be seen frequently in line processed foundry workshops, clearly presents problems due to constantly fixed unnatural standing postures while dealing with paced work. Table 4 shows the average rates of subjective

Table 4. Mean rates of subjective feeling of fatigue for the manual moulding workers and the line process moulding workers before and after work.

Category	Item	Manual workers		Line process workers	
		before	after	before	after
I (Dull-drowsy factor)	Feel heavy in the head	16.3%	14.3%	8.0%	8.0%
	Feel tired in the whole body	15.4	15.9	8.0	16.0
	Feel tired in the legs	21.1	34.9	26.0	56.0
	Yawning	13.0	4.0	24.0	20.0
	Feel hot headed or muddled	16.3	11.1	10.0	14.0
	Become drowsy	23.6	8.7	8.0	14 0
	Feel eye strain	23.6	41.3	16.0	42.0
	Become rigid or clumsy in movement	11.4	12.7	10.0	6.0
	Feel unsteady while standing	11.4	9.5	4.0	6.0
	Want to lie down	13.8	19.0	6.0	14.0
II (Factor of difficulty in concentration)	Feel difficulty in thinking	8.9	9.5	2.0	4.0
	Become weary of talking	6.5	4.8	4.0	2.0
	Become nervous	10.6	17.5	6.0	8.0
	Unable to concentrate	11.4	11.9	6.0	6.0
	Unable to show interest in things	11.4	7.9	4.0	4.0
	Become forgetful	15.4	16.7	8.0	14.0
	Lack of self-confidence	5.7	4.0	0.0	0.0
	Anxious about things	17.1	18.3	8.0	18.0
	Unable to straighten up posture	9.8	11.9	4.0	2.0
	Lack patience	13 8	13.5	12.0	12.0
III (Factor of physical disintegration)	Have a headache	14.6	12.7	4.0	8.0
	Feel stiff in the shoulders	26.8	42.9	20.0	26.0
	Feel pain in the low back	26.8	46.0	28.0	36.0
	Feel constrained in breathing	8.1	11.1	8.0	8.0
	Feel thirsty	14.6	37.3	22.0	34.0
	Have a husky voice	19.5	19.0	6.0	8.0
	Experience dizziness	6.5	3.2	4.0	4.0
	Have eyelid spasm	3.3	5.6	12.0	8.0
	Have tremor in the limbs	2.4	7.1	0.0	0.0
	Feel ill	7.3	9.9	2.0	10.0
	Number of cases	123	126	50	50

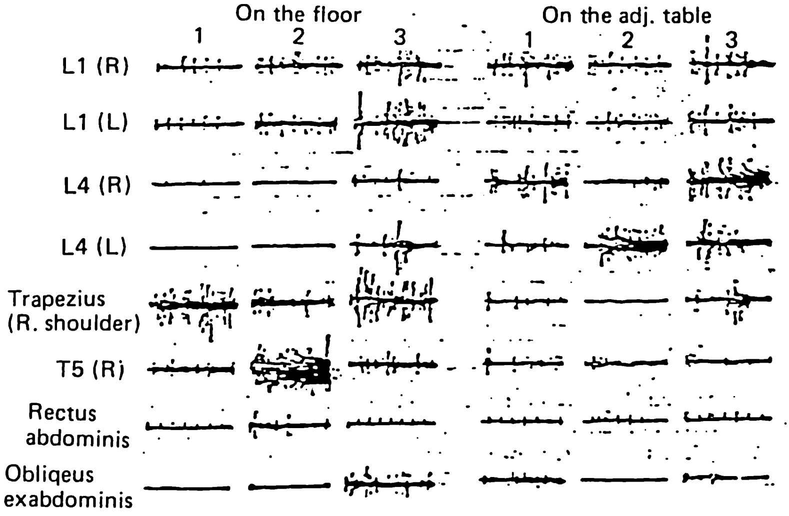


Figure 20. Comparison of EMG patterns during simulated work on the floor and on the adjustable table. 1, setting molded parts; 2, adjusting the dimension of molded parts; 3, setting a jig preparing for pouring.

feelings of fatigue before and after work for manual workers and automated line workers. The 30 items listed are those proposed by the Japan Association of Industrial Health. The mean frequency of complaints of fatigue after work was 16.1 percent for the manual workers, higher than the 13.6 percent of automated workers. The manual workers complained mostly of eye strain, stiff shoulder and low back pain. On the other hand, the frequency of the complaints was higher for the automated line workers with respect to tiredness in the legs, yawning and drowsiness. It can be regarded that these differences between two groups resulted from a difference in the major working postures as well as difference in type of work. Mechanization or automation, as these data imply, do not necessarily reduce workload, but induce different types of locally intensifed workload.

As described above with Figure 15, operator could make his postures more natural and easier when molding work was performed at the newly developed adjustable work bench. Figure 20 shows how the adjustable work bench is effective in reduction of work load, illustrating the electromyogragraphic (EMG) activities of the back, shoulder, and abdominal muscles for three types of simulated work either according to traditional molding methods on the floor or using the adjustable table whose height can be changed by means of operating a hydraulic system by footpedals. The activities of the back extension muscles at L4 level were less for the traditional method than for new method, while those of the trapezius and at the thoracic level were larger for the former. Because the smaller activities at the L4 level meant suppression of the muscle activities due to deep bending forward, both the lower back and shoulder muscles proved to be in a more favorable condition when the adjustable table was used.

Illustration of work performance assessment of intercity truck drivers may be a good example to show how to assess an optimum schedule of work and rest in combination with assessing mental work load. The number of intercity truck drivers who are engaged in long hour night driving is increasing in Japan. Continuous driving for a few hours or more particularly on the expressway is known to produce advanced fatigue linked with monotonous strain. A field study which was conducted by the author showed that the short rests had favorable effects on the recovery from functional deteriorations, (Figure 21), and the limit for a continuous driving period would be no longer than two hours and possibly as short as around 1-1.5 hours, as suggested by the results of dual task method analysis and critical fusion frequency analysis in this study. Figure 21 shows a general tendency for the level of the critical fusion frequency (CFF) value to decrease until a long rest and again to decrease to a level lower than the level before the rest. The task of driving at a constant speed along the expressway in the darkness may be an important factor causing the decrease of the cerebral activity level in driving. The similar variation has been reported in railway locomotive driving. Significant recovery of the arousal level after the long rest confirms the necessity of taking sufficient rest. Consequently, a combination of frequent short rests and a long rest in the middle of the route is suggested to prevent the occurrence of advancing fatigue due to midnight drives.

ERGONOMIC CHECKLIST AND ITS APPLICATION IN INDUSTRY

The ergonomic approach using a checklist is generally suited to examine systematically overall ergonomic problems of a work place. It often results in economic and efficient solutions. The ergonomic checklist, if it is well designed and applied, can be used by factory inspectors, health and safety personnel, supervisors and workers concerned with immediate improvements in working conditions. It was found through studies by a joint group including the author that a corrective checklist, in which the user was to select suitable remedies, was easier to answer and more favorable in finding shortcomings than using a descriptive list.

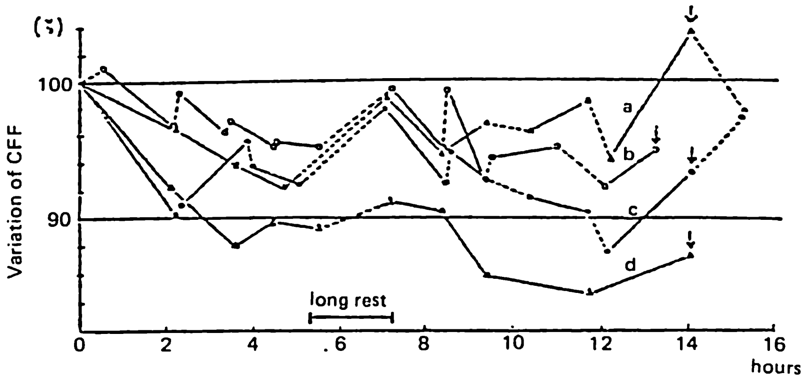


Figure 21. Variations of the ratio of the critical fusion of frequency to pre-work value as a function of time elapsed from the shift beginning in the single driver system. The diagram shows the variations for four truck drivers. The mark ↓ indicates the shift end. Dotted lines indicate rest periods.

Table 5. Example of Ergonomics checklist items.

Working posture

Are unnatural working postures or continuation of the same posture avoided as much as possible?

		SY	UY	N	IMP
a)	Change the work methods so that the workers can alternately stand and sit while at work.	( )	( )	( )	( )
b)	Secure enough space for a natural standing posture of the places where work is done.	( )	( )	( )	( )
c)	Enlarge the working site of individual workers so that they can freely change their posture while at work.	( )	( )	( )	( )
d)	Provide good comfortable chairs for standing workers.	( )	( )	( )	( )
e)	Change the machine structure to avoid continuous holding of unnatural postures such as bendng forward, twisting, or squatting which may occur while working.	( )	( )	( )	( )
f)	Change the place where work is usually done, so as to avoid unnatural work positions.	( )	( )	( )	( )

SY: Surely Yes, UY: Unsure, but probably necessary, N: No, IMP: Important.

Table 6. Major items, improvements of which were regarded as necessary by 10 checkers or more (++), or 7 checkers or more (+) among 12 checkers in combined harvester and tractor. Items checked by less than 6 checkers were showed as "–".

Chapter		Major items	Harvester	Tractor
1. Work space	1)	foot step for entrance	+ +	+
	2)	stairways for entrance	+ +	–
	3)	leg and knee space	+ +	–
2. Controls	4)	position of main controls	+ +	+
	5)	prolongation of levers and other controls	+ +	+
	6)	unnatural operating posture	+ +	+
	7)	pedal operation by standing	+ +	–
	8)	displacement of pedals	+ +	+
	9)	counter pressure of pedals	+ +	–
	10)	reach of levers	+ +	+
	11)	displacement of levers	+ +	–
3. Information displays	12)	visibility obstacles	+ +	+
	13)	machine redesign for good visibility	+ +	+
	14)	adequate use of mirror	+ +	+
	15)	suitable work position for good visibility	+ +	+
	16)	avoidance of displays by foreign language	+ +	–
	17)	feedback of instrument disorder	+ +	+
4. Combination of D. and C.	18)	clear marking of controls	+ +	+
5. Environment	19)	heat radiation insulation	+ +	+ +
	20)	wind shield	+ +	+ +
	21)	cabin installation	+ +	+ +
	22)	reflection of sun glare	+ +	+
	23)	illumination of work place at dark	+ +	+ +
	24)	shape coding of controls for operation at dark	+	+ +
	25)	local lighting	+ +	+
	26)	portable lighting device	+ +	+ +
	27)	technical noise and vibration reduction	+ +	+
	28)	absorption of noise and vibration	+ +	+ +
	29)	periodic examination of hearing ability	+ +	+
6. Static work load	30)	continuous standing posture	+ +	–
8. Hours of work & work performance	31)	adjusting overtime work	+ +	+
	32)	check of mechanical danger	+ +	–

An example of working posture questions using the corrective type checklist is given in Table 5. The checklist consists of remedy items from which the user of the list may select suitable recommendations to improve the existing conditions of the work places. For each section, the user relies on his own judgement whether such a measure should be taken or not. If the answer is surely yes, the checker fills in the space under "SY"; if the answer is unsure but probably necessary, fill in the space under "UY"; and if the answer is "not necessary," fill in the space under "N." In the case of "SY" and "UY" the user is to consider if such a measure is essentially important for that particular work place. If so, the user fills in the space under "IMP".

A comparative evaluation of ergonomic aspects of a large combine harvester and a tractor was conducted by means of an ergonomic checklist. The checklist is the corrective type and consists of nine chapters and 339 items was used by 12 ergonomists. Table 6 gives the major items, the improvements of which were regarded as necessary by 10 checkers or more (80 percent ++), or seven checkers or more (50 percent +) among the 12 checkers. The frequency of checked items was higher in the case of the harvester than in the case of the tractor. Major areas where ergonomic countermeasures were considered include those related to approach to the seat, control specifications, dial layout, or control/display relationships. Since the combine harvester was designed for European users, all dimensions of operating controls were too big for the Japanese worker to handle. The checking result was considered to be related to this design aspect.

The ergonomic checklist was also applied to assess ergonomic problems in foundry workplaces. Figure 22 shows percentages of items checked by individual checkers from among a total number of answered items for the manual work and the line process work in molding workshops. Three checker groups, i.e., ergonomists, system engineers, and the engineers of each factory, participated in the

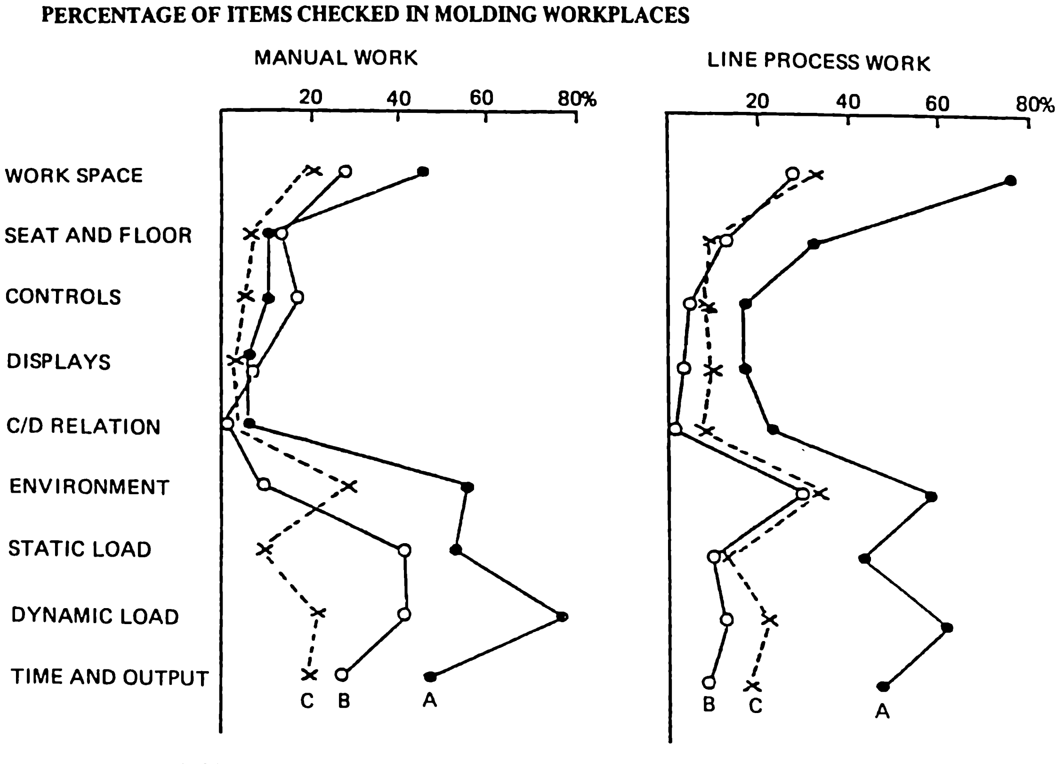


Figure 22. Percentages of items checked by individual checkers to the total number of answered items in each chapter of a corrective list for the manual molding work and the line process molding work.

Table 7. Number of items which were checked by 75% or more of the checkers in each working section of a factory.

A. Number of items, improvement of which was regarded as "surely necessary"

Factory		Blowing			Carding			Spinning			Weaving		
Chapter Number		1	2	3	1	2	3	1	2	3	1	2	3
– N of items		5 (4)	4 (3)	7 (6)	5 (4)	4 (3)	8 (6)	4 (3)	6 (5)	8 (6)	4 (3)	6 (5)	8 (6)
1. Work space	20	2	1	0	6	5	0	3	0	0	5	10	5
2 Work surface & seat	25	1	1	1	1	0	0	0	2	0	2	4	0
3 Controls & tools	25	1	2	0	2	3	0	0	0	0	0	0	2
4 Displays & information	20	0	0	0	1	1	0	0	1	0	0	0	1
5 Working environment	20	5	10	1	11	8	5	7	8	5	7	8	11
6 Fuctional load	25	8	12	0	7	8	0	5	7	2	8	5	6
TOTAL	135	18	26	2	28	25	5	15	18	7	22	27	25

B. Number of items, improvement of which was regarded as "surely necessary" or ' probably necessary".

1 Work space	20	4	7	1	7	9	1	8	8	1	12	12	11
2 Work surfare & seat	25	3	3	1	3	5	0	2	4	1	4	6	4
3 Controls & tools	25	1	2	0	5	8	0	0	3	3	2	3	3
4 Displays & information	20	1	0	0	1	2	1	0	1	0	1	0	2
5 Working environment	20	10	12	6	12	11	10	10	9	11	11	14	15
6 Functional load	25	16	19	4	10	13	6	11	14	14	11	8	11
TOTAL	135	35	43	12	38	48	18	31	39	30	41	43	46

NB. "N" shows number of checkers and 75% of the checkers in each cases in parentheses.

evaluation. Compared with the other two groups, the ergonomists group gave higher ratings of items. Major items which were rated highly in each group were work space, working environment such as noise, dust and illumination, static and dynamic work load and output. Among the three groups, differences in the rates were found with regard to the last three chapters, especially the system engineers who tended to evaluate the automated line positively and to omit many aspects of functional workload.

An ergonomic checklist consisting of six chapters with 135 items was applied to four major working sections in a large textile factory in Thailand. Table 7 gives the number of items which were checked by 75 percent or more of the checkers in each working section. Major common items suggested for improvement include machine layout, working postures, working load related to working time, environmental factors, such as ventilation, noise and dust, and welfare aspects such as resting and toilet facilities.

CONCLUSION

Ergonomics is widely applied to industry to improve the existing working conditions in relation to occupational health and safety and to improve the design of machine and tool for human use. It will be very effective to introduce this interdisciplinary practical new science at the initial design stage of either product or working system. Continuous examination of practical working situations, together with the adoption of ergonomic viewpoints, will assure the promotion of better working conditions in work places.

REFERENCES

1. O.G. EDHOLM, *The Biology of Work,* George Weindenfeld and Nicolson Ltd., London, 1967.
2. K.F.H. MURREL, *Ergonomics,* Chapman and Hall, London, 1965.
3. B. SHACKEL, Ed. *Applied Ergonomics Handbook,* IPC Science and Technology Press, Surrey, England, 1974.
4. F. KELLERMANN, P. VAN WELY & P. WILLEMS, *Vademecum Ergonomics in Industry,* Philips Technical Library, 1963.
5. E. GRANDJEAN, *Fitting the Task to the Man,* Taylor & Francis Ltd., London, 1980.
6. E. GRANDJEAN, *Ergonomics of the Home,* Taylor & Francis, London, 1973.
7. ILO 60th Session, Making Work more Human-Working Conditions and Environment, 1975.
8. A. CHAPANIS, *Man-Machine Engineering,* Wadsworth Publishing Co., Inc. Calif., 1965.
9. A CHAPANIS, *Research Techniques in Human Engineering,* The Johns Hopkins Press, 1962.
10. E.J.McCORMICK, *Human Factors Engineering,* McGraw-Hill Book Company, 1957.
11. Productivity Promotion Council of Australia, Ergonomics in the Australian Workplace, 1971.
12. W.E. WOODSON and D.W. CONOVER, *Human Engineering Guide for Equipment Designers,* Univ. of Calif. Press, 1970.
13. W. E. WOODSON, *Human Factors Design Handbook – Information and Guidelines for the Design of Systems, Facilities, Equipment, and Products for Human Use.*
14. A. CAKIR, D. J. HART, T.F.M. STEWARD, *Visual Display Terminals, A Manual Covering Ergonomics-Workplace Design-Health and Safety-Task Organization,* John Wiley & Sons, 1980.