

# **Biomechanics and the Design of Industrial Jobs**

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## **In any work environment, poor design can lead to accidents, ill health and low productivity.**

Most industrial jobs are designed on the basis of engineering convenience, with little consideration as to the physical capabilities and limitations of the men and women who will perform them. As a consequence, many jobs exist in which the workers' physical structure and capabilities are incompatible with the demands of the task situation. The result of these poorly designed work situations is low productivity, accidents and ill health. A little known area of knowledge called occupational biomechanics can be used as a tool to analyze and design or redesign jobs so that they are more compatible with the physical characteristics of people.

### **What is Biomechanics?**

Biomechanics is the study of the anatomy of function or structural basis of human performance. It borrows heavily from kinesiology, the study of the mechanics of human movement. It is concerned with the physical body and its capabilities and limitations as applied to the demands of work.

Biomechanics can be used to identify poorly designed work situations that are likely to lead to occupational disease, accidents and low levels of productivity. Con-

versely, it can be used to design or redesign jobs to capitalize on man's physical characteristics, so as to minimize strain and maximize productivity.

### **Job Design Analysis**

The most obvious signs that a job is poorly designed are employee complaints of pain or discomfort that are clearly related to the demands of the job. Other obvious clues are recurrent types of accidents or injuries on a particular job.

Of greater prevalence, however, are the less obvious signs of a poorly designed job. These subtle clues might include excessive absenteeism or turnover, excessive break time, frequent rest pauses, and the general tendency to look for any excuse to take time away from the job. Excessive fatigue and the frequent putting down of tools are also indications of poorly designed work. A very common but usually unrecognized clue is the general dislike of a job by many employees. It may not always be clear that this dislike is actually due to the design of the job and the physical demands it makes on the workers.

There are three biomechanical features to look for when analyzing the design of a job. First, look for static effort, which is muscular effort that is not accompanied by movement. Second, look for strain which results in excessive pressure, torque, tension or friction on some bodily structure(s). Third, consider the various structural characteristics of the human body that impose limitations or constraints on perfor-

mance. Each of these biomechanical ideas is described in detail below, and some specific job design principles are recommended.

## Static Effort

Static effort is the prolonged state of the contraction of muscles. The muscle pressure created by static effort constricts blood flow. Consequently, the muscles get no sugar or oxygen and waste products accumulate, which causes pain. The converse is dynamic effort, the rhythmic alteration of contraction and extension of the muscles. Here the muscles act like a pump to enhance blood flow. Static effort should be reduced in the design of work situations to the extent possible, since long-term and extensive static work can lead to a deterioration of joints, ligaments, and tendons.<sup>1</sup> Five rules or principles to follow in the design of jobs to reduce static effort are listed below.

*Avoid bent, twisted or unnatural postures.* For example, do not use foot pedals for standing work, do not require a worker to maintain a bent-over posture, and do not require that the head be bent backwards for long periods. Most people do not realize that the postural requirements of many jobs are far more taxing on the body than the work actually being performed.

*Allow the worker to change posture frequently.* This will enhance blood flow and reduce fatigue. Alternate sitting, standing and walking if possible. Ideally, a job should be designed to let the worker sit or stand.

*Avoid keeping the arms elevated,* either forward or sideways. These postures not only lead to rapid fatigue, but they reduce the precision or skill of hand movements.<sup>2</sup> Work for an extended task should be designed so that the individual can keep his or her elbows down and near the sides of the body.

*Design work that allows movement of the muscles.* The muscles should not be used for holding or fixation.

## Excessive Strain

The biomechanical implications of excessive strain are probably the most obvious. Any job demand that places excessive pressure, torque, tension, friction or other form of stress on some body component or connection between components is likely to produce adverse affects. Excessive physical

strain can lead to injury as well as to premature fatigue. Some job design principles to minimize excessive strain are presented below.

*Minimize pressure on the spine.* Incorrect lifting practices create excessive strain on the spine and often result in lower back injuries. Lifting with the legs is always recommended since it reduces the concentration of forces on the lower back.

Excessive pressure on the spine can also be created by poor working postures. For example, bending over almost doubles the pressure on the vertebrae as compared to standing erect. Unnatural postures can ultimately result in a pathological degeneration of the discs which lie between the vertebrae and act as a cushion. The outcome is frequent backaches, the number one cause of occupational disability in industry.<sup>3</sup>

*Do not overload the muscles.* The job should not require more than 30% of the worker's maximum dynamic strength for extended periods. For very short periods, dynamic strength required should not exceed 50%. Static effort required for long periods should not be more than 15% of the maximum the worker can exert.<sup>4</sup> The key is to load the worker optimally, not too much and not too little. Optimality depends on the characteristics of the workers, such as age, sex, constitution, fitness and motivation.

*Keep wrists straight as much as possible.* Inside the wrist is the carpal tunnel, through which pass major tendons, nerves, and blood vessels. When the hand is required to perform any operation with a bent wrist, excessive friction is created within the carpal tunnel. In the short run this leads to pain and fatigue, in the long run it can lead to a chronic condition known as "carpal tunnel syndrome,"<sup>5</sup> which is painful, disabling and often permanent. Avoid hard floors for the standing worker. This can cause premature fatigue and pain in the feet. A soft floor mat is advisable.

## Structural Considerations

There are many structural characteristics of the human body which are relevant to the design of work. These pose certain limitations and constraints on how work can be designed to minimize discomfort and fatigue and, therefore, maximize productive potential. Many of these result

in strain as defined above. A few job design principles relevant to human structural characteristics are given below.

*Avoid compression ischemia.* Ischemia refers to the obstruction of blood flow to tissues. Many work situations are unwittingly designed such that pressure is placed on arteries or blood vessels, thus reducing blood flow. An example is the design of hand tools which put pressure on the ulnar artery in the palm of the hand. The result is numbness and tingling of the fingers. Another example is the design of high work chairs without foot supports. This causes compression of the thighs and reduced blood flow to the lower legs and feet. Much productivity is lost when workers put down tools or get up for a walk because of these poorly designed work situations.

*Avoid muscular insufficiency.* Muscles are designed to function only within a certain range of movement, beyond which they cannot be further shortened or extended. As an example, bend your wrist fully inward and then try to squeeze a rod or make a fist. You cannot do it because the extensors of the fingers are overextended. Tasks should be designed with consideration of the range of muscle movement required of the human operator, and extreme muscle positions should be avoided.

*Use movements around the middle ranges of the joints.* Frequent or extended use of extreme positions of a joint when a limb is under a load can cause strain and early fatigue. Further, repetitive reaches should be kept short.

*Repetitive movements along a straight line should be avoided.* Since most joints are like hinges, their natural movement is curved and can usually be accomplished by the contraction of a single muscle. Straight line movements are more fatiguing, since they require the movement of more joints and more muscles.

*Work chairs should be designed to take into account the structural characteristics of humans.* Since pressure on the spine is greater when sitting than when standing, work chairs should provide support for the lower back. Further, work chairs should be designed to avoid compression ischemia of the thighs (discussed above). It is clear that work chairs should be adjustable to accommodate the particular dimensions of each individual worker. At a minimum, the height and angle of the back rest should be

adjustable, as well as the height of the seat.

*Differences in sizes and dimensions between workers should be considered.* Since there is no such thing as an average worker, the ranges of sizes and dimensions must be taken into account. This includes consideration of the sizes of hand tools, the visual layouts, the heights of the work tables, the reach distances to controls, clearance requirements, and so on. Typically, one should design to accommodate the range from the 5th percentile woman to the 95th percentile man. Another often heard rule is to design clearance requirements for the largest man and reach requirements for the smallest woman. Certainly, designing for adjustability is a wise idea.

### **Designing for Men and Women**

Besides the fact that women tend to be shorter and not as strong as men, there are other structural differences with implications for job design. One relevant structural difference has to do with the alignment between the spine and the hip joint. In a man, they are in the same plane. In a female, however, the hip joint is located further forward. Consequently, the lifting stress in the back muscles in women, for the same object, can be as much as 15% greater than in males.<sup>6</sup>

Another relevant structural difference is in the relative proportions of body segments. Women's torsos constitute a greater proportion of their body length relative to men's. So in a lifting task, the pressure on the spine is considerably greater for women. However, this difference can be greatly reduced if the lifting is from a slightly raised surface rather than the floor.

A final example of a male-female structural difference has to do with the carpal tunnel discussed earlier. Women generally have smaller carpal tunnels and, therefore, may be more susceptible to carpal tunnel syndrome. This is unfortunate since women are often employed in assembly-type jobs which require much manual manipulation. It should be noted that often jobs can be easily modified to accommodate the structural features of women. There are many cases where women are at a structural advantage, such as where a lower center of gravity is beneficial, or where work space is small.

## Final Considerations

There is one last recommendation that does not fit into any of the above categories. Workers should be trained and supervised to use good working postures and to use equipment correctly. Many workers adopt poor working postures or use equipment incorrectly due to ignorance of the deleterious effects of these practices on their bodies. Examples include improper lifting procedures, improper adjustment of work chairs, and the improper use of hand tools.

Before concluding, two points should be noted. First, it is not the intent of this paper to argue that all fatigue is bad. Obviously there is nothing wrong with work that makes you tired. In fact, it is good for you. But there is a difference between being tired and being hurt, and hurt workers are less productive. Second, although productivity is important, the prevention of occupational illness is also important, and prevention is not beyond control. The proper design of work situations can reduce occupational illness, as well as increase productivity. □

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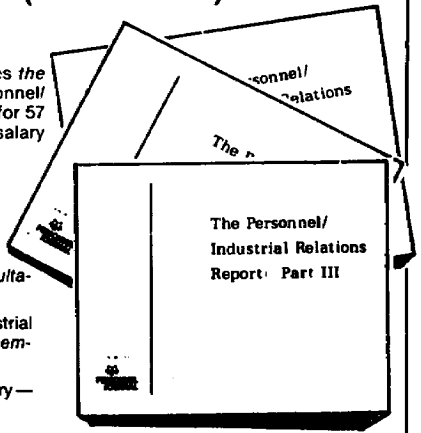
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