

Industrial Workplace Design and Physiological Consideration of Work in Developing Countries.

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Abstract

Over the years many theories, principles, methods and data relevant to the workstation design have been generated through research in ergonomics. An ergonomics approach to the design of an industrial workstation attempts to achieve an appropriate balance between worker's capabilities and work requirements to optimize workers' productivity and the total system, as well as provide workers' physical and mental well-being, job satisfaction and safety. Good ergonomic design principles must be applied to give the operator or a range of operators the optimum man-machine interface and the adjustability required to prevent discomfort and prevent workplace injuries. To help in the design or redesign of a workstation it would be helpful to know in advance the postural stress consequences of a wide range of body postures. Postural analysis tools have been shown to be a valuable technique for reducing injuries and increasing productivity in industry. The goal of this paper is to offer a practical guide to interpreting published ergonomic guidelines and the anthropometric data that can be used to create a user friendly, ergonomically correct work environment.

Keywords: workstation design, ergonomics, human factor, anthropometric, productivity.

1. Introduction

Ergonomics is concerned with making the workplace as efficient, safe and comfortable as possible. Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance operator productivity, provide worker safety and physical and mental well-being and job satisfaction. Many research studies have shown positive effects of applying ergonomic principles in workplace design, machine and tool design, environment and facilities design [(Das & Shikdar, (1999), Hasselquist, (1981), Schnauber, (1986), Ryan, (1989), Das, (1987), Resnik& Zanotti, (1997)].

Today, both workers and management are concerned about the quality of work lives, ergonomics and occupational safety and health. Ergonomics focuses on human beings and their interaction with machines, materials, information, procedures and environments used in work and everyday living Dempsey and Mathiassen, (2006). The "human-machine" interface is often referred to as micro ergonomics. In most developing countries, especially in Africa, organisations were not cognizant of the fact that ergonomics deficiencies such as poor workstation design and awkward or constrained working postures are a major contributing factor to poor quality and performance decrements. Knowledge and practical evidence of this relationship would be instrumental for optimizing organisational performance particularly in industrially developing countries (IDCs) where the discipline is still in its developmental stages.

Although ergonomics applications have gained significant momentum in developed countries, awareness remains low in developing regions. Presently there are few practical examples to illustrate the benefits of an ergonomics intervention programme in IDCs. The reason for this paucity is a lack of awareness and recognition in IDCs of the potential benefits of ergonomics [O'Neill & Haslegrave (1990)]. This demonstrates that much is yet to be done in raising awareness about the benefits of ergonomics in IDCs. However, for this to be effective, tangible evidence of these purported benefits is required. Although the awareness of ergonomics in the industries of industrially developing countries (IDCs) has significantly grown in the last decade (Scott, 2005) there still seems to be a lack of knowledge regarding how ergonomics can positively contribute to the economic success of an organisation in these countries. The enormity of the problem of heavy physical workloads in IDCs is worthy of greater attention than it currently gets, particularly when one considers that the risk factors are greater due to the low level of automation, suboptimal work organization and lack of recognition of the benefits of establishing ergonomic principles within most activities [Kawakami and Kogi (2005)].

Ergonomics studies staff psychology and physiology at work which is a complicated system of humans, machines and work [Shaliza, et. al (2006)]. Most ergonomic analysis of human activities originates from work and time [Shikdar and Sawaqed, (2003)], which establishes the basis of production engineering; as a result, it is natural to analyse and consider ergonomics and productivity together. A thorough understanding of the various factors affecting industrial work design is necessary for improving worker productivity, job satisfaction, safety, health, and well-being Wilson, (2000). With the increased objective of creating more efficient Man-machine systems, the need to collect extensive anthropometric data becomes more important. Consequences of designing systems that do not accommodate for worker populations include user fatigue, task inefficiency, and work-related muscular disorder (WRMSD).

2. WHAT IS ERGONOMICS?

"Ergonomics is the scientific discipline concerned with the fundamental understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance" (International Ergonomics Association (IEA), 2000).

Jeje E. Fernandez (1995) defined ergonomics **as** the design of the workplace, equipment, machine, tool, product, environment, and system, taking into consideration the human's physical, physiological, biomechanical, and psychological capabilities, and optimizing the effectiveness and productivity of work systems while assuring the safety, health, and wellbeing of the workers. In general, the aim in ergonomics is to **fit** the task to the individual, not the individual to the task. In a phrase, the task/job must 'fit the person' in all respects, and the work situation and environment should not compromise with human capabilities and limitations. Fig 1 shows the goals of ergonomics. If an object, system or surrounding is intended to be used or occupied by a human being; its design must be based on the capacities, physical and mental characteristics of that user.

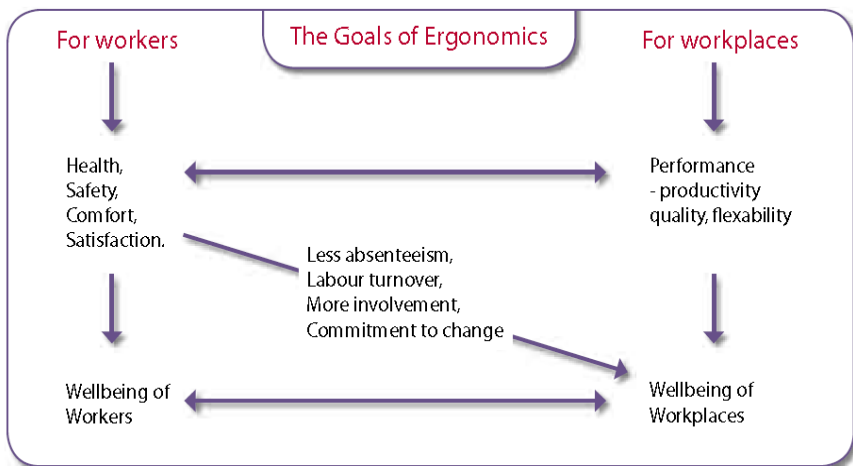


Figure 1- The goals of Ergonomics.

2.1. Domains of Ergonomics

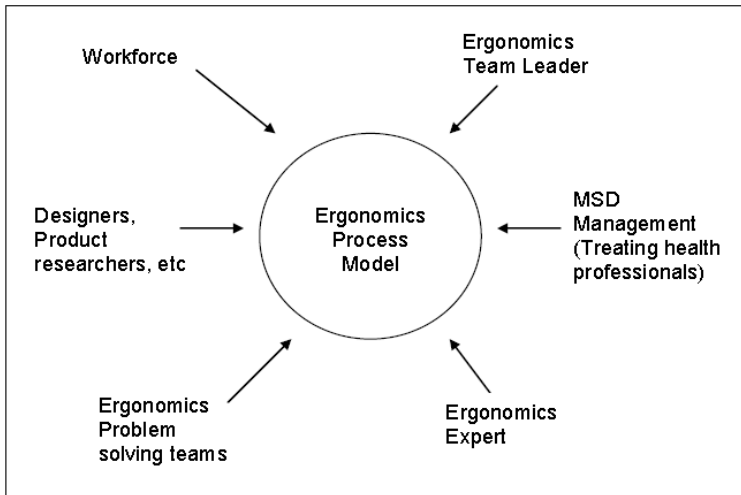
The International Ergonomics Association (IEA) divides ergonomics broadly into three domains:

Physical ergonomics: is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity).

Cognitive ergonomics: is concerned with mental processes, such as perception, memory reasoning, and motor response, as they affect interactions among humans and other elements of a system.

Organizational ergonomics: is concerned with the optimization of socio-technical systems, including their organizational structures, policies, and processes.

Both physical and cognitive ergonomics focus on the users' closest surrounding and these two fields are called Micro-Ergonomics. They stand in contrast to organisational ergonomics or Macro-Ergonomics, which have a wider context and emerged more recently during the 1980s. Figure 2 shows Participatory Ergonomics Process Model.



(Source: UOW: Adapted from Kodak's Ergonomic Design for People at Work, 2004)

Figure 2.1. – Participatory Ergonomics Process Model

2.2. Ergonomics can be applied to improve (at the least):

1. Organizational management methods (organizational ergonomics)
2. Production metrics (physical, cognitive, organizational ergonomics)
3. Safety, health and wellness (physical, organizational ergonomics)
4. Product design (physical, cognitive ergonomics)
5. Sales, marketing and customer service (cognitive, organizational, physical ergonomics)

Anatomy	
Anthropometry	Dimensions of the body (static and dynamic)
Biomechanics	Application of forces by gravity and muscles
Physiology	
Work physiology	Expenditure of energy
Environmental physiology	Effects on humans of the physical environment
Psychology	
Skill psychology	Information processing and decision-making
Occupational psychology	Training, motivation, individual differences, stress

Figure 2.2. - The domains ergonomics deals with.

3. WORKPLACE DESIGN

Common features of industries in developing countries are improper workplace design, ill-structured jobs, mismatch between worker abilities and job demands, poor human-machine system design, inappropriate management programs and adverse environment. This leads to workplace hazards, poor workers' health, injuries and disabilities, and in turn reduces worker productivity and increases cost. Shikdar & Sawaqed, (2003). Research studies in ergonomics have also produced data and guidelines for industrial applications. The features of ergonomic design of machines, workstations, and facilities are well known [Schnauber, (1986), Ryan, (1996), Resnik & Zanotti, (1997), Konz, (1990), Salvendy, (1987), McLeod, (1995), Das, (1987), Ayoub, (1990)]. However, there is still a low level of acceptance and limited application in industries, especially in developing countries.

The main concern of work system design is usually the improvement of machines and tools. Inadequate or no consideration is given to the work system design as a whole. Therefore, poorly designed work systems are a common place in industry [Das, (1987) and Konz, (1995)]. Neglect of ergonomic principles brings inefficiency and pain to the workforce. An ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work (Ayoub, 1990).

In a well-designed workplace, workers can achieve more output with less effort and fewer risks to their health and safety. To design better jobs we need to know about the work and how it will be done. We also need to know about the people who will do the work and their capabilities and limitations. Not only do we need to consider physical and cognitive aspects but we also need to take into account individual aspirations and needs - the social component. As work changes over time reviews and modifications are constantly required if systems and people are to work harmoniously and efficiently. Figure 3.1 and 3.2 shows the human-machine interface.

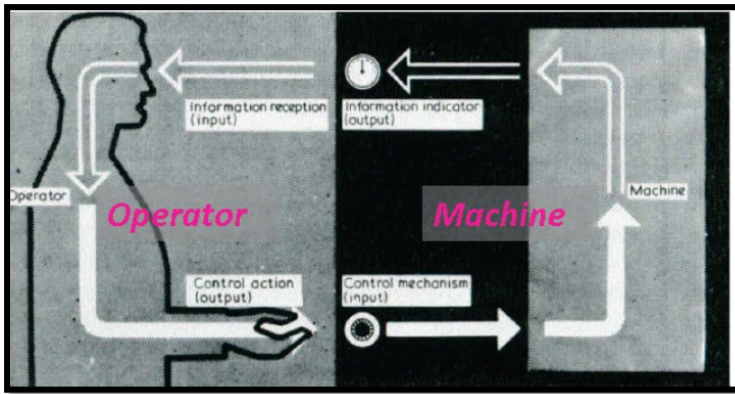


Figure 3.1- Human Machine interface

(Shows that the outputs of one are the inputs of the other, and visa versa).

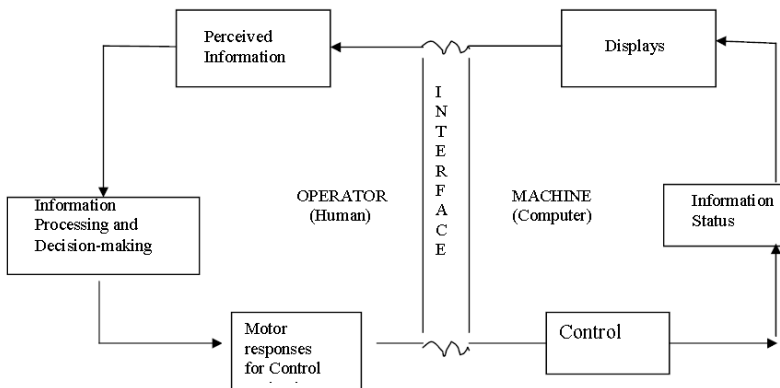


Figure 3.2 – Analysis of the human-machine interface requires interdisciplinary knowledge of biomechanics, Cognitive Ergonomics and systems design methodology. Mohammad et.al (2011)

3.1. The Five Elements to Consider in Ergonomic Analysis of Work

Figure 3 below shows the elements to be considered in the Ergonomic Analysis of Work.

- Worker:**
The human element of the workplace
- Job/task design:**
What the employee is required to do, and what they actually do
- Equipment design:**
Work stations, tools and equipment
- Workplace design:**
Overall, work environment
- Work organisation:**
The broader context of the organisation and the work and how this affects individuals

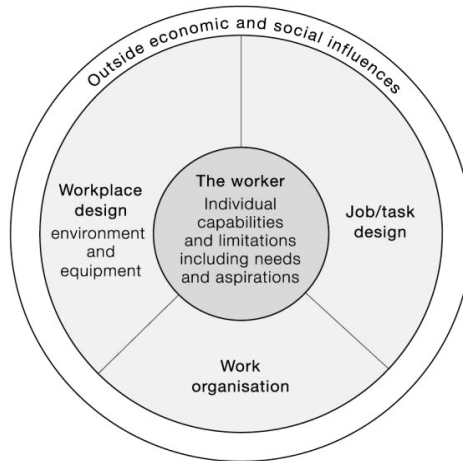


Figure 3.1 – The Five Elements to Consider in Ergonomic Analysis of Work. McPhee, (2005)

3.2. ERGONOMIC PRINCIPLES IN WORKPLACE DESIGN

Some ergonomics principles that should be applied to the workplace, whether in an industrial or an office environment, include the following:

1. Aim at dynamic work; avoid static work (work where there is no movement). Static work or static loading of the muscles is inefficient and accelerates fatigue. Static work can occur when the workplace is too high or too low, when holding a weight in one's arms for an extended period, or when there is constant bending of the back to perform a task.
2. Adjust work surface heights to the size (anthropometry) of the worker and the type of task performed (precision, light assembly, or heavy manual).
3. Work within 30 per cent of one's maximum voluntary contraction (strength). Avoid overloading of the muscular system.
4. Place primary controls, devices, and work pieces within the normal working area. Secondary controls should be placed within the 'maximum working area so as to reduce extended reaches and fatigue.
5. Strive for best mechanical advantage of the skeletal system.
6. Work with both hands. Do not use one hand (non-preferred hand) as a biological holding device.
7. Hands should move in symmetrical and opposite directions.
8. Use the feet as well as the hands.
9. Design knowing the capacity of the fingers. Do not overload the fingers.
10. Use gravity. Do not oppose it to dispose of unbreakable products.
11. Avoid unnatural posture. Bend the handle of the tool not the wrist.
12. Permit change of posture. Maintain a proper sitting posture.

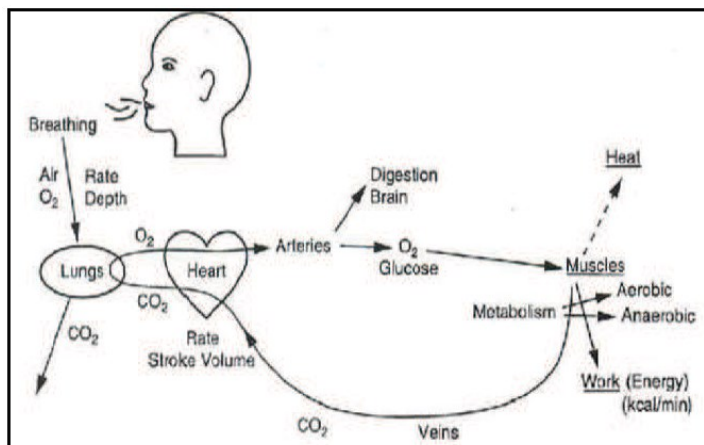
13. Counter-balance tools when possible to reduce the weight and forces.
14. Accommodate the large individual and give him or her sufficient room.
15. Use bins with lips for storage and manual retrieval of small parts instead of boxes. Incline containers so as to reduce awkward postures of the body.
16. Train the individual to use the workplace, facility and equipment properly. Fernandez,& Goodman, online accessed (04/01/2014)

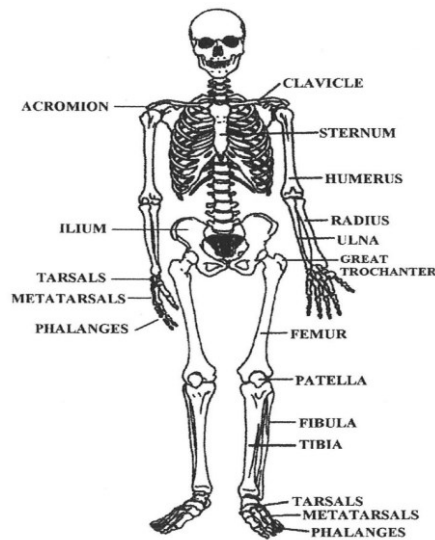
4. What is Work Physiology?

Work physiology is the science that studies how the human body responds to the physical stress of work or activity demands. Kadiri, (2006). Physiological considerations of work such as strength, endurance, and susceptibilities to fatigue, stress, or disease are of importance in workplace. As far as body functions are concerned these involve the neurological, muscular, respiratory, vascular and sensory systems.

4.1. Body Systems

Simply put, the human body is a complex system of framework (skeleton), moving parts (bones, joints, muscles, ligaments and tendons), energy conversion system (metabolism and physiology), movement control system (nervous system), feedback and decision-making system (senses and brain). From an ergonomics perspective, we need to understand how these systems work, what they are capable of and requirements for optimum function before we can effectively design work systems, equipment and interfaces which rely on their capacity. Health and nutrition, previous injuries, lifestyles and natural abilities also play a part in contributing to person's capabilities to undertake a specific task. Workstation should be laid out such that it minimizes the working area so that while carrying out the operations the worker could use shorter motions and expend less energy and thus reduce fatigue.





Metabolism and Physiology
Front View of Human Skelton (Stevenson, 1999)

Figure 4.1 Physiological elements of human body at Work.

4.2. The Physiological Fitness

When people work, their output is determined by both their physical and cognitive capacity. Cognitive capacity/behaviour in turn, is affected by intrinsic personal characteristics such as age, experience, training, personality and motivation; as well as extrinsic factors such as work organisation (shift patterns, workloads, morale, etc) and environmental factors which may act as a distracter to the task at hand (e.g.: excessive noise, poor lighting, etc). The Physiological Fitness is determined by the following.

Strength

– Is the ability of a muscle to produce force (power is strength + speed)

• Muscular endurance

– Is the ability of a muscle to produce force repeatedly over a period of time

• Cardiovascular endurance

– Is the capacity of the respiratory system and the circulatory system to supply oxygen and nutrients to the muscle cells so an activity can continue for a long period of time

• Flexibility

– Refers to the range of motion possible in the joints. This is controlled by muscles, tendons and ligaments

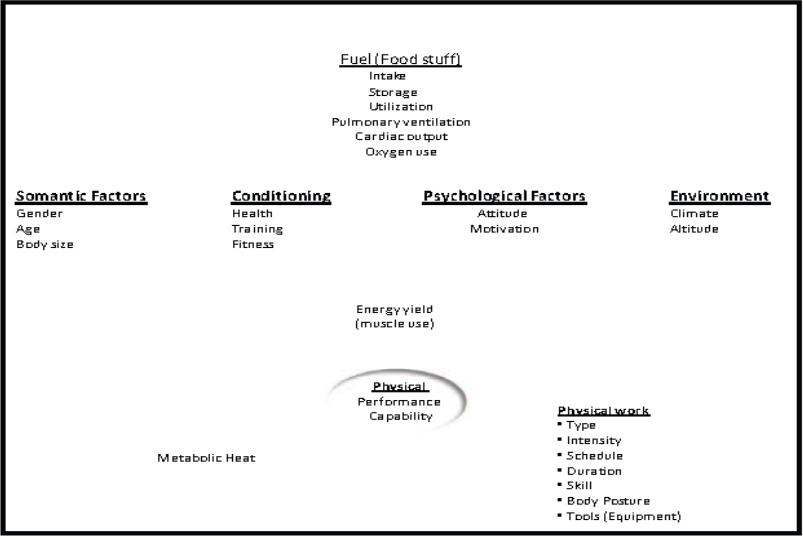


Figure 4.3-The Psychological Fitness. Kadiri, (2006)

Figure 4.3 below, adapted from Bongers et al, (2002) is a useful model for understanding the interaction, where it can be seen that individual factors interact with psychosocial load, physical load and physiological response to produce chronic musculoskeletal symptoms.

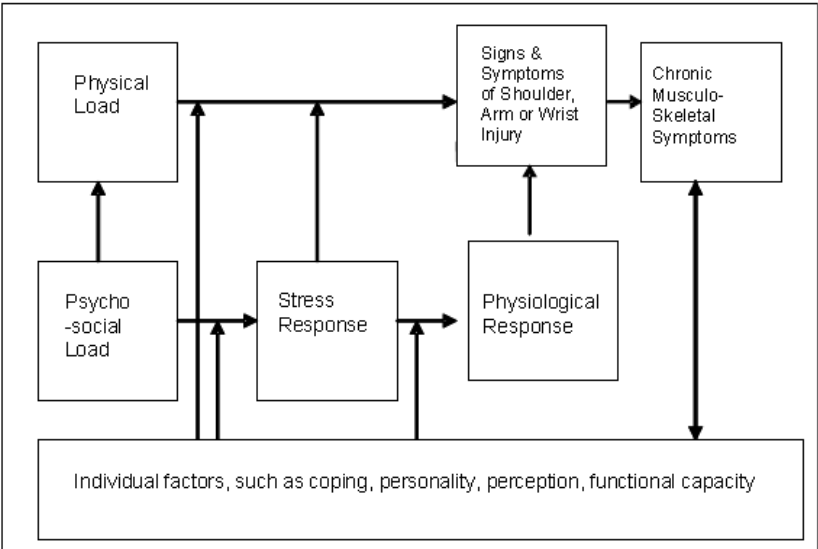


Figure 4.3 - Interaction between Psychosocial Load, Physical Load and Individual Factors and Symptoms and Signs of Shoulder, Arm or Wrist Injury (Bongers et al 2002)

5. Work organization

Work organization is defined as the way work is structured, distributed, processed and supervised (Hagberg et al., 1995). According to the US NIOSH (2000), work organization deals with subjects such as the following: the scheduling of work (such as work-rest schedules, hours of work and shift work), job design (such as complexity of tasks, skill and effort required, and degree of worker control), interpersonal aspects of work (such as relationships with supervisors and coworkers), career concerns (such as job security and growth opportunities), management style (such as participatory management practices and teamwork), and organizational characteristics (such as climate, culture, and communications). The objective of ergonomics is to improve both performance and health and safety. Therefore, the concept of work organization is at the core of ergonomics.

According to the Balance Theory of Job Design (Smith and Carayon-Sainfort, 1989), work organization results in the design of a work system that has "five elements: the individual, task, tools and technologies, physical environment and the organization. The five elements of the work system interact to produce a 'stress load'. The interplay and interactions between these different factors can produce various (physical and psychosocial) stressors on the individual that then produce a stress load', which has both physical and psychological components.

The essence of Balance Theory is to improve motivation and performance and reduce stress and the negative health consequences by `balancing the various elements of the work system to provide positive aspects to counter the negative ones (Table 1). The `best job design can be achieved by providing all characteristics of each element of the model that can meet recognized criteria for worker needs fulfillment and that set proper physiological and psychological loads to eliminate stress and strain. (Figure 5.1 & 5.2) In reality such a perfect job is not attainable. Balance Theory proposes using good elements to compensate for poor aspects in other elements to balance the "loads", to reduce stress and health and safety problems, and enhance motivation and performance.

Balanced work system	
Theoretical basis	Job design theories Occupational stress theories Ergonomics
Main concepts	The work system has "ve elements: environment, task, technology, organizational factors, individual. Two types of stress load: physical and psychological dimensions Positive and negative aspects of the elements of the work system The work organization de"nes the di!erent elements of the work system. Balance of the total work system Compensatory balance

Table 1- Balance Theory of Job Design (Smith and Carayon-Sainfort, 1989),

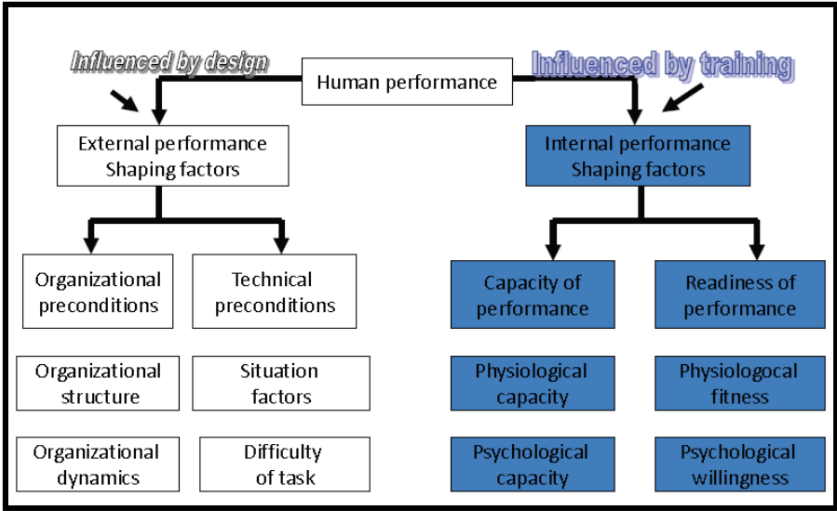


Figure 5.1 - The structure of Human Performance (Drury, 1998)

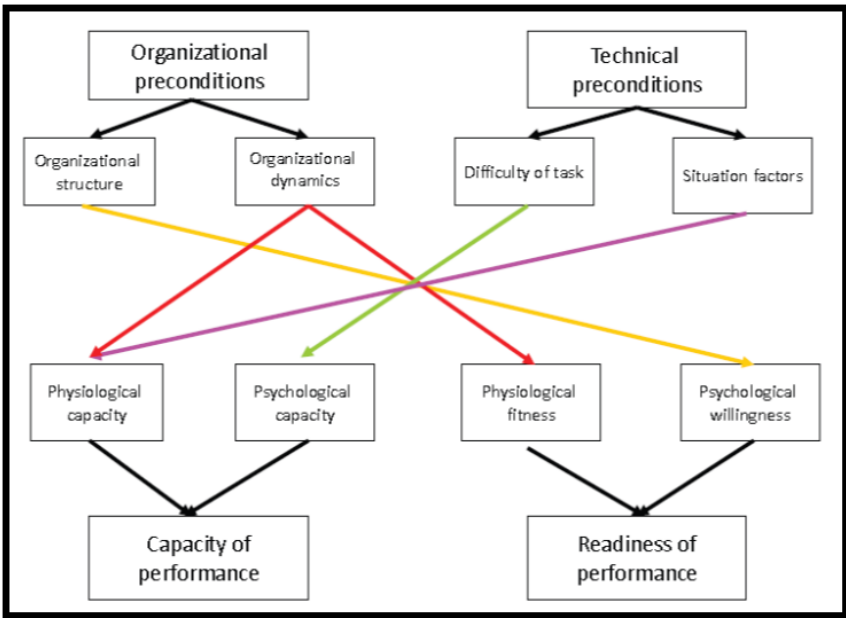


Figure 5.2- The inter-dependencies of human performance (Drury, 1998)

6. Anthropometry

Anthropometry comes from the Greek and is associated with the measurement of humans. It is the branch of the human sciences that deals with human body measurements, including body size and shape (Pheasant & Haslegrave, 2006). Bridger (1995) and Chou and Hsiao (2005) believed anthropometry is a research area in ergonomics dealing with the measurement of human body dimensions and certain

physical characteristics.

Anthropometric data can be used in ergonomics to specify the physical dimensions of workspaces, workstations, and equipment as well as applied to product design. According to Wang et al. (1999), anthropometry has been considered as the very basic core of ergonomics in an attempt to resolve the dilemma of “fitting people to machines”. Therefore, it is important for the product designer and manufacturer to use anthropometric data and ergonomic knowledge in making decision during designing of machines, equipment, products and systems (Mattila, 1996).

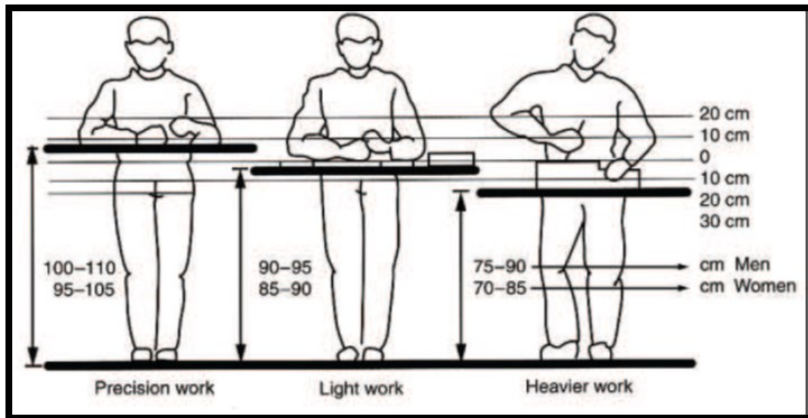


Figure 6.1- Recommended work surface height for standing workstations. The reference line (+0 cm) is the height of the elbows above the floor. Grandjean, (1988)

Importance of Anthropometry

Every worker is characterized by a unique array of physical and mental capabilities. Our opportunity is to ensure that all work processes and systems (whether manual or automated) include considerations for the range and limits of these human characteristics in order that we gain maximum utilization of the resource. The application of anthropometric data to equipment, workplace and job design is to enhance the efficiency, safety and comfort of the operator. Anthropometric data include:

- Nature, frequency and safety of task.
- Position of body during task.
- Mobility or flexibility.

6.1. Anthropometry Measurements

Anthropometric measurements are used to evaluate the interaction of workers with tasks, tools, machines, vehicles, and personal protective equipment, especially in regard to determining degree of protection afforded against hazardous exposures, whether chronic or acute. Designs that are incompatible with normal anthropometric measurements of a workforce could result in undesired

incidents. The misfit of a heavy equipment cabin to a worker could produce operator blind spots that expose workers on foot to struck-by injuries. Inadequate length or configuration of seatbelts could lead to non-use of seatbelts, which will affect post-crash survivability. Inadequate fit of personal protective equipment cannot provide workers with sufficient protection from health and injury exposures ([Hsiao and Halperin, 1998](#)).

Diverse workforces in many occupations, as well as new roles for women in the workforce, require body size data for designing adequate workplaces, systems, and personal protective equipment. In the past, variance in body dimensions was typically reported as means and standard deviations for various body segments ([Roebuck et al., 1975](#)). This approach was successful in generating general, broad parameters for personal protective equipment (PPE) sizing but was deficient in generating the detailed fit information needed for workplace, PPE, and other equipment design.

In ergonomic design, one can use anthropometric data in three different ways. The first is designing for a range (the smallest to the largest, usually from the 5th percentile to the 95th percentile), such as the design of adjustable height chairs based on popliteal height. The second is designing for the extremes (the smallest or the largest, usually for the 5th percentile or the 95th percentile), such as the design of the doorpost height for the largest person's stature (plus ample clearance) or the design of a shelf for the smallest person's functional reach. The third is designing for an average. This method is only acceptable when one is using the workplace for a very short duration. This method is usually avoided by ergonomists, as it does not accommodate a large segment of the user population. An example is designing work surface heights in a bank for customers' elbow height

Body measurements vary as a function of age, sex and for different countries. Also there are differences in anthropometrics of male and female...

There are two types of body measurements:

1. Static
2. Dynamic

STATIC (structural) dimensions are measurements taken when the body is in a fixed (static) position. These consist of:

- a. Skeletal Dimensions (between dimensions of joints)
- b. Contour Dimensions (skin surface dimensions). Figure 6.1

DYNAMIC (functional) dimensions are taken under conditions in which the body is engaged in some physical activity. Functional anthropometric data are useful for designing workspaces and positioning objects within them, particularly in the design of aircraft cockpits, crane cabs, vehicle interiors and complex control panels in the process industries

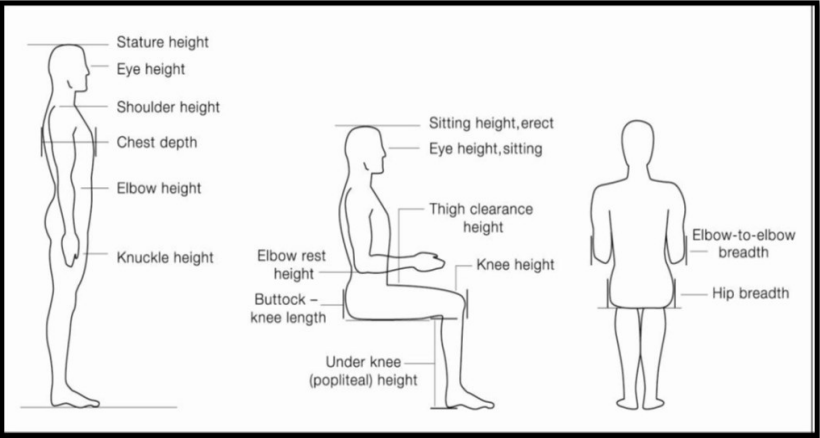


Figure 6.1 – Static Anthropometric Body Measurements (McPhee, 2005)

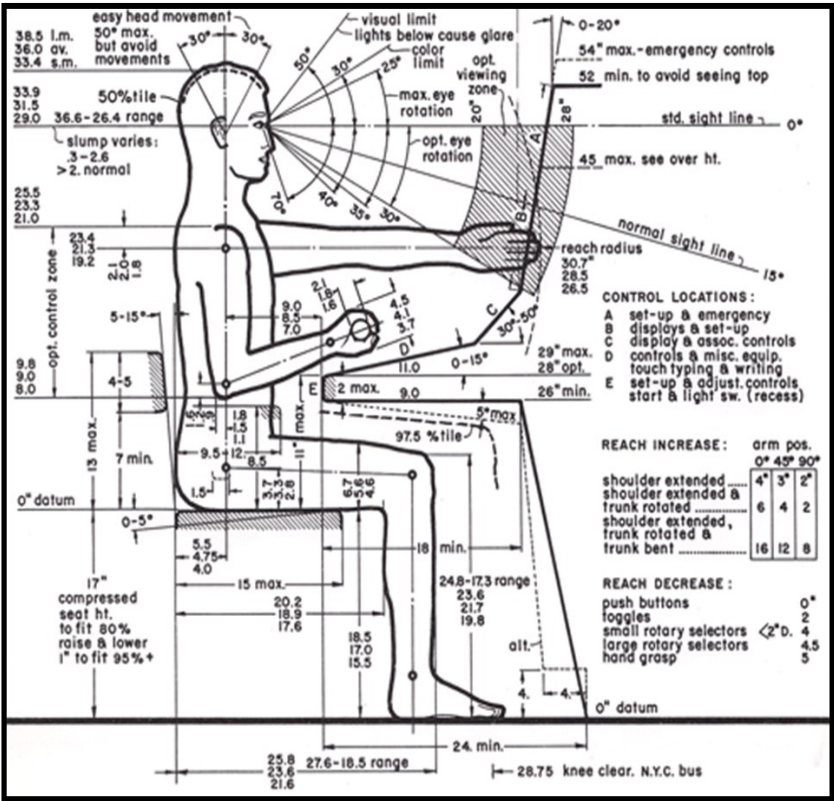


Figure 6.2 - Dynamic Dimensions

Body dimensions

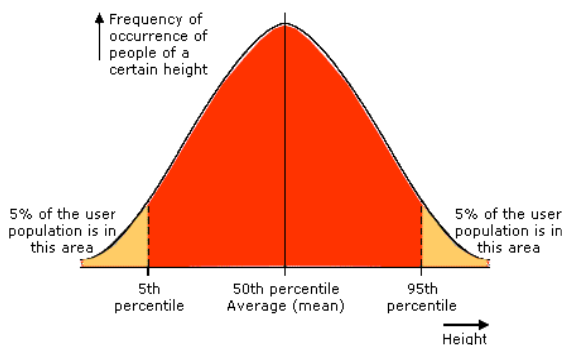
Body dimensions and definitions can be found in numerous publications (AS 4024.1704, 2006, and Pheasant & Haslegrave, 2006,). These include:

- Stature (body height) - The vertical distance from the floor to the crown of head
- Chest (bust) depth – Maximum horizontal distance from vertical reference plane to the front of the chest in men or breast in women
- Shoulder-Grip Length – Distance to the center of an object gripped in the hand with the elbow and wrist straight
- Head breadth – Maximum breadth of head above the ears
- Hand Length – Maximum breadth across the palm of the hand
- Hand thickness (metacarpal)
- Hand thickness (including thumb)

It is usually assumed that human anthropometric characteristics are normally distributed as shown in Figure 6.3. This figure shows the heights of a group of people or the frequency of occurrence of a certain height of a population (Pheasant & Haslegrave, 2006,). The curve is symmetrical about its highest point also known as the mean and is the most probable height of this population. This means that 50% of these populations are shorter than the average and 50% are taller. The mean of this population is said to be equal to the fiftieth percentile (50th %ile). There also two other percentiles shown in this figure. On the left-hand side of the horizontal axis there is the fifth percentile (5th %ile) at which point 5% people are shorter than this. Similarly, on the right-hand side there is the fifth percentile (95th %ile) at which point 5% people are taller than this.

Values such as for the 5th percentile are different for other populations such as for Chinese industrial workers shown in Table 6.1 and table 6.2 shows anthropometrics data for other regions of the world.

Figure 6.3. Normal or Gaussian distribution curve for the height of a population. (Pheasant & Haslegrave, 2006,).



Body Dimensions	Indi ana	Chine seb	Japan ese c	Germ and	Briti she	Americ an f
Stature	161.40	168.82	165.80	174.50	173.81	175.54
Eye height	-	158.53	-	-	-	164.31
Acromial height	132.70	142.10	134.50	146.40	-	143.51
Sitting height	84.80	89.65	90.40	92.10	91.90	91.28
Sitting eye height	-	79.40	78.50	80.20	80.27	79.94
Sitting acromial height	58.80	-	-	-	62.11	59.07
Popliteal height	41.70	40.13	40.20	45.40	-	43.10
Buttock popliteal length	34.90	42.29	-	-	-	-
Fore arm hand length	40.90	-	-	-	46.87	47.91

Table 6.1 – Comparison of anthropometric data of male workers population of the world

(a)Agrawal, Singh and Satapathy (2010). (b)Shao and Zhou (1990), (c)Yokohori (1972). (d)Jurgens et al. (1972), (e)Haslegrave (1980). (f)Hertzberg et al. (1954).

Average Anthropometric Data in millimetres estimated for 20 region of the World.						
	Stature		Sitting Height		Knee Height, sitting	
	Females	Males	Females	Males	Females	Males
North America	1650	1790	880	930	500	550
Latin America						
Indian Population	1480	1620	800	850	445	495
European and Negorid population	1620	1750	860	930	480	540
Europe						
North	1690	1810	900	950	500	550
Central	1660	1770	880	940	500	550
East	1630	1750	870	910	510	550
Southeast	1620	1730	860	900	460	535
France	1630	1770	860	930	490	540
Iberia	1600	1710	850	890	480	520
Africa						
North	1610	1690	840	870	500	535
West	1530	1670	790	820	480	530
Southeast	1570	1680	820	860	495	540
Near East	1610	1710	850	890	490	520
India						
North	1540	1670	820	870	490	530
South	1500	1620	800	820	470	510
Asia						
North	1590	1690	850	900	475	515
Southeast	1530	1630	800	840	460	505
South China	1520	1660	790	840	460	505
Japan	1590	1720	860	920	395	515
Australian						
European extraction	1670	1770	880	930	525	570

Table 6.2 – Anthropometric data estimated for 20 regions of the world. Juergens, et.al ., (!990).

Concluding Remarks

Our factories and warehouses appear to have gained a firm grasp on the marketplace survival demand for optimum productivity. Managements are implementing programs to improve planning and scheduling, space utilization, product quality and equipment output. An integral component of each of these innovative concepts and installations continues to be the worker. Human factor consideration is a productivity philosophy, which must be applied in the workplace if optimum productivity is to be achieved. The use of ergonomics is consistent with the proactive approach, and the interventions presented in this paper are examples of this approach to enhancing workers’ health. Simple tools for conducting a systematic evaluation of working conditions are needed in our context. Therefore, more collaborative research and knowledge transfer between industry and ergonomics researchers is a necessity particularly in industrially developing countries where ergonomics is still in its developmental stages.

Fit the Right Operator to the Job: It would be an ideal ergonomic approach to assign jobs based on the individual's anatomical or physiological characteristics.

1. Managers must be knowledgeable and aware of the benefits of ergonomics, and the prevention of injuries through ergonomics implementation. They should be trained in ergonomics to acquire skills in implementing it in the workplace.
2. Employees need to be trained systematically in ergonomics in order to improve ergonomic conditions and OHS and hence improve human performance. This would be beneficial to both employees and management.
3. The work and workplace design should be carried out using ergonomic guidelines, acts and recommendations considering user population.
4. Effective implementation of specific written policies concerning health and safety must be ensured through inspection, periodic reporting and enforcement of appropriate regulatory instruments.

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