CHAPTER - 1

INTRODUCTION

Technical progress has played an important role in the development of society. Machines have increased the productive capacity of man in practically all the areas of human activity. However, in spite of this technical progress, the need for human muscular work has not been eliminated. The average man still produces mechanical energy in order to perform almost any operation. In our production systems, man functions not only as a source of mechanical power but also as a control device. Most, perhaps all, operations require power as well as control. Many operations which require appreciable outlays of power have been mechanised, especially where the control requirements are simple. Examples of the resulting machines are tractors, combines and forage harvesters. In addition to being an extremely versatile source of mechanical power, man is also a highly dependable non-linear servo-mechanism system capable of summing up several signals according to instructions and making the appropriate responses. He will, therefore, be a functional part of our production systems for a long time to come.

In order to make the best use of a man-machine, man-animal or a man-animal-machine system associated with any task, it is essential to know the ranges and the limitations of the man component in relation to the whole system. The ranges and limitations of men are best described by such factors as comfort, safety, fatigue, force output, power output and others.

Since the turn of the century, interest in work physiology has increased with the practical objective of developing an effective methodology for measuring human physical work and predicting

the performance of operators engaged in different tasks under varying environmental conditions in order to determine the optimal conditions for obtaining maximum efficiency and to retard the onset of fatigue.

Work physiology offers methods of work measurement which can be viewed as an alternative to the traditional methods such as the time study, work sampling and time-and-motion study. As the latter methods are based upon time and not on physiological measurements, they fail to measure a worker's physical capacity to perform strenuous work and also to measure the rest periods required to permit the body to recover from fatiguing work as also the spacing of rest periods. Work physiology has been used successfully in the selection and placement of workers, in evaluating the effect of environmental factors on the performance of workers, in determining the need for equipment, in the design of tools and equipments and in many other spheres.

Mechanization of agriculture is quite advanced in many countries of the world especially the U.S.A., Japan, West Germany, etc. In these highly developed countries, the human muscles are being used more and more for the purpose of controlling powered equipment and being used less and less for doing physical work. Indian farming, on the other hand, is still largely dependant on human and animal power. Table- 1.1 gives some idea about different forms of farm power available in India.

With the costliest source of energy being used, the crop production per farm worker in India is about the lowest in the world. One of the reasons for low productivity is the use of farm tools and equipments which can neither use the human energy efficiently nor are themselves suitably designed. There is an urgent need to bring out

new designs of tools and equipments and also to redesign the tools and equipments already in use in order to make an efficient use of human muscular energy, thus increasing the users productivity and also removing the drudgery of farming. If the worker could accomplish a task in lesser time with improved tools and equipments, it is evident that he would have time left to improve his farm and also to make his personal life better and more satisfying for which presently he neither has the time nor the energy after the days work. With increased productivity, the farmer would also have more money which he can use on his farm and in his home.

TABLE - 1.1 SOURCES OF FARM POWER IN INDIA(138a)

Forms of power	Numbers, million	Estimated power, million kw	Per cent of gross power available
Animals	80	32	65.30
Human-beings	150	12	24.50
Oil engines	0.5	2	4.08
Power tillers and tractors	0.08	2	4.08
Electricity	-	1	2.04

As quoted by Pandya (111 a)

New tools and equipments cannot be designed nor can the existing ones improved without a knowledge of the ranges and limitations of the operator as a source of mechanical power while working independantly or as a part of a man-machine, man-animal or a man-animal-machine system. In a developing country like India where there is an attempt to get quick results by designing, reshaping and improving the tools and equipments using power from men, speculation goes on among the designers regarding the range of human performance. There is always a tendency to overestimate

the power a man can produce. It must be realised that men differ considerably in their physical attributes from region to region in a vast country like India. A man from Punjab or Haryana is better endowed in physique compared to men from other states. Hence, one standard of performance will not suffice for all. Another wrong assumption used often is that a man can produce power at the rate of 75-watt over an 8-hour day. This figure does not specify the type of task performed. Legs can produce more mechanical power over a longer period than the arms. The author had come across a hand-driven pump to be operated by two men for lifting water from ponds, in the design of which the power output from both the arms of each man had been assumed to be 75-watt. The pump when installed could hardly be operated for 5 minutes before the workers reached a state of fatigue where they just quit the job. The designer, thus, needs to know what forces and rates of work can be derived from the various groups of human muscles and the physiological stress that would be imposed by the various tasks.

The only way to know the ranges and limitations of man with respect to mechanical work output, is to study his performance on the task under appropriate conditions. Work physiology is of great use in studying human physiological performance. Research in India in the field of work physiology has been mostly confined to factories but the area of agriculture involving the largest working population is yet untouched.

It was with a view to arousing interest in the use of work physiology in farming tasks and in the design of tools and equipments that this pilot study was undertaken. The study does not aim at answering any specific questions for designers nor providing data on the ranges and limitations of farm labour but aims more at establishing

a field of research, laying down lines of experimentation, studying and establishing principles of estimating physiological stress due to various tasks. A report of the experimental work carried out to confirm and establish the relationship of some of the important physiological indices to physical work and to study various modes of work output is presented in this thesis.

The second chapter explains some of the concepts in Work Physiology such as work and effort, chemical and mechanical considerations involved in muscular work, aerobic and anerobic energy available to muscles, steady-state of work, oxygen debt, fatigue, metabolic rate and calorimetry.

The third chapter has been divided into three sections. The association between physiological responses and physical work has been explained in the first section. The second section deals with the measurement of the physiological responses enumerated in the first section. Some of the commonly used indices of physiological stress based on the physiological responses are explained in the third section.

A review of literature on such physiological responses as heart rate, heart rate increase, oxygen consumption and energy expenditure has been made in the fourth chapter. One section has been devoted to gross efficiency of muscular work. The importance of training has also been included. An entire section deals with the research work done in Work Physiology in India.

The three different sets of experiments that were conducted alongwith the instruments and methods of experimental measurements are described in chapter five. The experiments were conducted to study four different modes of work output by humans, namely

1 Pushing with both arms and pulling with shoulders horizontally against three different forces while walking at different speeds on a horizontal motor driven treadmill,

2 Bicycling at a single speed of 80-full-pedal revolutions per minute at three power output levels on a bicycle ergometer, and

3 Leg and two-armed cranking at three power output levels at a single speed of 80-full-crank revolutions per minute on a bicycle ergometer.

The objectives of the first and the second set of experiments which were conducted at the N.C.State University, Raleigh, U.S.A., were: (i) to study the response of the heart rate, heart rate increase and oxygen consumption rate to the forces of pushing and pulling at the three speeds of walking in the case of pushing and pulling, and to power output levels in the case of bicycling, (ii) to compare the modes of work output by pushing and pulling, (iii) to compare the performances of Americans and Indians as a group on the basis of oxygen consumption rate per kg gross body weight, (iv) to bring out the significance of the effects of forces, speeds and power output levels on the heart rate increase and the gross efficiency with the help of analysis of variance. The instruments and equipments used in the two sets of experiments were: treadmill, bicycle ergometer, RKG-100 Biotelemetry system, Max-Planck respirometer, Beckman Model E-2 Oxygen analyzer and Dynograph recorder. Of these, the author had designed and fabricated the treadmill.

The third set of experiments on leg and two-armed cranking was conducted in the Department of Agricultural Engineering, Indian Institute of Technology, Kharagpur-2, India. The objectives of the experiments were to study the response of the heart

rate increase to the range of power output levels and to compare the modes of leg and two-armed cranking. The pulse of the subjects was taken manually. The bicycle ergometer used in these experiments was designed, fabricated and calibrated by the author.

The results of all the three sets of experiments are presented and discussed in the sixth chapter. The conclusions which have been drawn from the results and listed at the end of the chapter are:

1 Each of the three physiological responses - heart rate, heart rate increase and oxygen consumption rate - are linearly related to the force of pushing and pulling at each of the three walking speeds.

2 Separate regression equations are required for each subject to relate each of the three physiological responses studied to the force of pushing and pulling at each walking speed.

3 Pushing horizontally with both arms and pulling horizontally with shoulders are not significantly different from each other on the basis of physiological stress imposed on the subjects and the gross efficiencies of muscular work achieved.

4 Heart rate, heart rate increase and oxygen consumption rate increase with both increasing force and speed.

5 As a group the Americans have a lower oxygen consumption rate per kg gross body weight than the Indians as a group.

6 The American subjects possess a higher work capacity than the Indian subjects.

7 The gross efficiencies achieved by the Americans during bicycling were lower than those achieved by the Indians.

8 For the same amount of energy expended, more work can be accomplished by bicycling than by pushing horizontally with both arms or pulling horizontally with shoulders while walking.

9 Leg-cranking imposes a much lower stress on the worker than the two-armed cranking.

It is strongly recommended that two-armed cranking may be replaced by leg-cranking in such operations as chaff-cutting,water-lifting and others. Where possible, materials should be transported using bicycle-trolleys instead of pushing or pulling the materials along the ground or pushing or pulling loaded trolleys.

It must be mentioned that the results obtained here apply only to the very limited groups and ranges of forces, speeds and power output levels studied and that no claim regarding their universal validity or relevance can be made.