CHAPTER - 1

INTRODUCTION
1.1. HISTORICAL BACKGROUND:

The history of human civilization witnessed many successful and unsuccessful attempts to develop tools and equipments for fulfilment of human needs. Technological development during the World War II produced many equipments and devices for waging war or for civilian use which were found to be not designed appropriately for human use and led to many unhappy experiences. It became essential, in this situation, to consider the limitation of human capabilities in the design process and gave birth to a new discipline. This discipline has come to be known as 'Ergonomics' in European countries and 'Human Factors Engineering', or Human Engineering', 'Bioengineering' and the like in Western countries. Application of this concept has improved many work situations and equipment and during the last decade has found its way in the improvement of rehabilitation aids.

Locomotion is one of the essential activities of life in the animal kingdom, without the benefit of which it may be almost impossible for animals of the higher orders to sustain themselves and propagate their species. Even with the reasonable advances and proliferation of mechanical transportation, men is obliged to walk for normal day-to-day
living at his home or his work place. Human locomotion is achieved through the alternate flexion and extension of various joints, specially the joints of the lower limbs. These joint movements produced by the contraction and relaxation of different muscles, enable man to move forward or change his position. Disorders of muscle contraction due to diseases like poliomyelitis and various other acquired or inherited nerve and muscle diseases, give rise to impairments of the joint movements which, in turn, create various degrees of difficulties in locomotion. Often, traumatic injuries produce the loss or damage of certain portions of the body, specially of the extremities and bring about locomotor disabilities.

In short, various defects of the nervous system, muscles and the supporting skeleton or loss of extremities, particularly of the lower extremities, hinder normal locomotion of a person. To overcome the problems of locomotion, various kinds of aids have been in use since long ago. Instances of locomotor aids have been recorded in ancient scriptures of the Orient (e.g., Rigveda) as well as of the West (e.g., Holy Bible). Among the various locomotor aids, the wooden stick must be the oldest, locally, indigenously and immediately available. Walking with the help of a stick has been illustrated in an Italian vase of the 4th century B.C. \(^1\) Uses of artificial legs made up of bronze, iron and
wood have been recorded in many ancient manuscripts, potteries and paintings dating back to the 3rd century B.C. Design and development of crutches and prostheses, some of which are very similar to the devices in use today, was made by Ambroise Pare in 16th century A.D. Further advances in design and development of these aids are credited to Scarpa in 1803. Orthoses, like calipers, are probably the modification of the straightening devices used in the mid-sixteenth century. Wheeled locomotor aids, like tricycles, are possibly the successors of pedicabs used extensively in China, Japan, Vietnam and other Asiatic countries.

Not much development of the aids for the disabled persons was observed to have occurred until the end of the World War II. It was reported that in 10 to 15 countries of Europe and in several other countries identifiable prosthetic and orthotic research centres were established since 1946. As a result of extensive research in the field, marked improvements have been made in prostheses and orthoses designs, even at the level of myoelectrical control of activities. Powered wheelchairs have also been emerged out for long distance travels as also ramp and stair climbing.
1.2. CLASSIFICATION OF LOCOMOTOR AIDS - CLINICAL AND MAN-MACHINE SYSTEM GROUPS:

Locomotor aids are now-a-days gaining much in sophistication of their structure and functions but as yet, there are no good criteria available for classifying them. Clinically, locomotor aids are classified into three groups, prostheses, orthoses and assistive devices. The term 'Prosthesis' includes the artificial replacement of body parts, as for example, artificial legs, hands, and the like. The term 'Orthosis' is a more recent introduction and is defined as a supportive or corrective aid, as for example, crutches, braces, and the like. Assistive devices include other devices such as, wheelchairs, tricycles, ramps, etc. The demarcation between orthoses and assistive devices is not clear even now.

Since the emergence of Bioengineering/Ergonomics the interaction between man and machine is being studied in greater detail and greater emphasis is being laid on the behavior of man-machine integrated systems. The handicapped-locomotor aid system may be looked upon as a typical man-machine system. Hence, it would be logical and rather scientific to classify the locomotor aids according to a man-machine system classification. Ganguli (1973), considered that according to Biomedical Engineering principles, man-machine systems should be classified according to the
characteristics of the machine component. Considering the characteristics of the machine component, such as, cosmesis, the nature of attachment of the machine with the user's body, whether temporary or permanent coupling used and so on, the systems were classified in ten simple numerical orders.

The system of zero order include the combinations performing a non-physiological or non-biomechanical task, such as, the physician's stethoscope, surgeon's surgical instrument systems, etc.

The combinations, in which the machine component is permanently coupled with the user for cosmesis only, but not for functional replacement, such as, a cosmetic hand, an artificial eye ball, etc., are included in the system of the first order.

The systems of second order include those replacing a physiological function and not coupled with the user's body but brought in contact for emergent or special use, as for example, an artificial respirator. The components of the system of third order are also not coupled and are specially used for a temporary period, but gives total replacement of some physiological functions, e.g., the heart-lung machine.

The systems of fourth order include the systems in which the machine component is not coupled with the user but brought in contact with it regularly, for part replacement of
a physiological function. The wheelchair/tricycle-handicapped systems and crutch-handicapped system are among the incumbents of this order.

The systems, for total replacement of physiological function, not coupled with the user but brought in contact regularly are considered as belonging to the fifth order, e.g., hand controlled artificial larynx. The systems coupled with the user's body temporarily for continuous or intermittent use, and for part/total replacement of some physiological function are considered in the sixth and seventh order, as for examples, a Milwaukee brace, a peg leg or a pylon.

In the eighth order, the systems in which the machine component is permanently coupled with the user's body for part replacement of some physiological or biomechanical function, are included, e.g., orthoses like brace or caliper.

The ninth order aids include the permanently coupled systems replacing some physiological function totally, e.g., an artificial leg. In addition to the characteristics of the ninth order, cosmesis is added on in the tenth order system, e.g., a full-fledged functional cum cosmetic prosthesis like cosmetic artificial leg.
1.3. EVALUATION OF LOCOMOTOR AIDS - STATE OF THE ART:

Locomotor aids have a history of several hundreds of years, but the scientific studies on their design, development and evaluation are of quite recent introduction. Need for modifications of the traditional locomotor aids was felt soon after the second world war began, as a large number of war injured persons awaited a proper rehabilitation to restore them to normal life. In such circumstances, studies on different aspects of human locomotion was begun which helped directly or indirectly in the development of the newer aids.

Investigations on the gait pattern of normal and lower extremity disabled persons have been reported by Eberhert et al.\textsuperscript{11} which provided an unique means for evaluation of such disabilities. Asmussen and Molbech\textsuperscript{12} in the same year (1954) worked to set up methods and standards for evaluation of the physical working capacity of lower extremity disabled persons based on the measurement of oxygen consumption and heart rates during rest and activity. Hirschberg\textsuperscript{13} highlighted possibility of the use of stair climbing as one of the methods for exercise testing of the disabled. Drillis\textsuperscript{14} devised a tachographic technique to observe the forward velocity of the trunk of normal and disabled persons. Although these studies, were taken up for objectively evaluating disabilities, they increased the
knowledge about the functions of the locomotor systems and helped indirectly in the development of locomotor aids. An addition to these studies was made by Gordon, who in 1958, studied the energy expenditure during locomotion with the help of wheelchairs.

Comparative evaluation of the stress of walking with crutches and walking with artificial legs in amputees was made by Erdman et al. Peizer et al. in 1964 pioneered the evaluation of wheelchairs by bioengineering methods. This group of scientists evaluated light weight wheelchairs from different view points, such as, mechanical analysis, biomechanical analysis, subject reactions and the like, and established different techniques for such evaluation and also indicated recommendations for improvements. Where a wide range of wheelchairs are available, the selection of a proper design would be able to avoid the time consuming procedure of developing a new design. In this respect, Lauridsen and Lund conducted a survey of the four main groups of wheelchairs, viz., indoor, outdoor, combined indoor/outdoor and special chairs, available from different manufacturers and analysed various general and individual factors which should be considered for selecting a wheelchair for a disabled person. For the purpose of evaluation, it becomes essential to know the correlation between different physiological parameters, such as, maximum work power, muscle
strength, lung capacities, heart rate, and so on, of the disabled persons. Correlations among these parameters have been studied by Asmussen by administering some static and dynamic exercise tests on disabled persons. Voigt and Bahn recorded the energy expenditure and heart rate during propelling wheelchairs up an incline on a treadmill and estimated the work performed for the same. Isherwood conducted a survey on 450 wheelchair users and noted the design requirements of wheelchairs and the practical ways of reaching an adequate design.

The energy cost of propelling wheelchairs at various speeds has been studied by Hildebrandt et al and demonstrated a lower metabolic, but a significantly higher heart rate response than walking at the same velocity. Applications of bioengineering and materials technology in improvement of design and development of orthotic devices for lower limb disabled persons have been described by Lenneis et al. Ganguli et al in 1973 conducted a study to assess the degree of rehabilitation achieved by a Patellar Tendon Bearing (PTB) prosthesis fitted Below-knee (BK) amputee by measuring the heart rate and energy expenditure of certain essential daily activities. Pugh in the same year (1973) investigated a 62 year old patient before and after unilateral hip replacement and observed that functional improvements took place within three months of the operation.
He found that oxygen intake for very fast walking was higher than those for the normal persons and use of crutch and stick did not reduce the oxygen intake. Ganguli et al evaluated above-knee (AK) amputee-prosthesis combinations by measuring different cardiorespiratory parameters and concluded that a high degree of amputee prosthesis integration is possible by regular and long term use of the prosthesis. In the same year he also tried to make functional assessment of the crutches by biomechanical studies. Datta et al compared the performance of two types of rehabilitees, using BK-PTB prosthesis and amputees using crutches, by means of a single step test and a stair ascending test. Engel and Hildebrandt studied the technological and physiological aspects of wheelchair design and highlighted the inherent inefficiency of the common wheelchair propulsion systems. Ganguli et al in 1975, again studied the performance of below-knee amputees using PTB-prostheses and confirmed that below-knee amputees achieves a close to normal performance level with patellar-tendon-bearing method of stump fitting. In 1976 Ganguli introduced an integrated approach to analyse and evaluate the functional status of the lower extremity amputee-appliance-systems. Glaser and Chao investigated the power output and energy cost of manual wheelchair operation. Waters et al, using free and fast cadence walking on the level, investigated the influence of level of amputation on energy cost in walking of amputees. Mukherjee and Ganguli used
tachographic gait recording technique to detect the presence of abnormality in the gait of those below-knee amputees using PFB prosthesis who were otherwise considered quite close to normal on the basis of other tests. Roy et al. reported an investigation on below-knee amputees by graded load carrying tests most suitable for clinical use to evaluate their performance. Glaser et al. reported that asynchronous hand rim operations were less stressful than the synchronous ones. Wolfe compared the energy cost of wheelchair propulsion on concrete and carpeted surface and concluded that carpeting of the type commonly used in the hospitals impose a burden upon the subjects. Cerny compared the energy demands of walking and wheelchair propulsion in paraplegic patients and reported that wheelchair propulsion is superior to walking for the customary wheelchair users. Hash compared energy cost of wheelchair propulsion and walking in stroke patients. Stallard et al. evaluated orthoses by means of speed and heart rate and established that heart rates could be used for these purposes. Sankarankutty et al. compared walking with axillary, elbow and Canadian crutches to normal walking and concluded that walking with the Canadian crutch was less stressful than walking with axillary or elbow crutches.

In 1980, Glaser et al. evaluated wheelchair design changes which might reduce operational energy cost and stated that asynchronous propulsion with a high drive ratio produces
less wasteful movements and proved better than synchronous ones. To study quantitatively the power output requirements for wheelchair locomotion under different conditions, Glaser et al. devised specialized instruments and techniques in the same year. Ghosh et al. compared walking with axillary crutches to normal walking. It was concluded that optimum walking speed in both the cases was the same but walking with crutches demanded higher energy costs. It was shown in normal subjects, use of crutches cause an average 16% increase in vertical force on the upper limb and this may lead to skeletal abnormalities. Brown et al. designed and evaluated a new parapodium with knee and hip locks which enabled the young lower extremity disabled patients to sit and stand without fear and increased their confidence and skill in other areas. In the same year Gardner et al. designed hand operated tricycle to increase the range of independent activities of disabled children. Cerny et al. reported a study on the energetics of walking and wheelchair propulsion in persons with paraplegia and confirmed that walking is much more energy demanding than wheelchair propulsion. Patterson and Fisher studied cardiovascular stress. The same researchers also determined the energy of ambulation with crutches. Goswami et al. compared the efficiency of different types of tricycles by studying heart rates during propulsion and observed that a cranking system located in middle-front position of the user was more
convenient than cycles with cranking systems located to the left or right side of the user. Nag et al evaluated physiological cost and work performance of the lower extremity disabled persons during hand-cranked tricycle propulsion and noted that mechanical efficiency of cranking was best in two arm cranking performed at heart level.

From the above review of the existing literature it could be noted that though sporadic attempts have been made to study different aspects of locomotion and performance capacity of the disabled, studies regarding evaluation of the aids is still scanty. Most of the studies have been made from the viewpoint of physiological cost of activities with the aids.

1.4. AIM OF THE PRESENT STUDY:

In India, the orthopaedically disabled group constitute the largest among the physically disabled and, the lower extremity disabled either severe (with confining disabilities) or less severe (with ambulation disabilities), is the largest among them. The less severe group is generally prescribed with prostheses and/or orthoses. Those, who are unaware of the availability of prostheses and/or orthoses, such as the lower extremity disabled persons living in rural areas, spend the rest of their lives using the indigenous crude crutches or bamboo or wooden sticks as locomotor aids. The severe group commonly use the wheeled chairs etc., for mobility and locomotion.
The mobility aids which are in use extensively in India for the purpose of locomotion (PTB prostheses, quadrilateral-socket type prostheses with uniaxial hinge joint (QSUHJ) prostheses, calipers, wheelchairs and tricycles and the like) were mostly evolved as a result of transfer of technology from the Western countries. From the review of previous work it is evident that in the Indian situation, these aids have been used for a long time without proper scientific evaluation. It is a fact that physique of the people of the Western world vary widely from that of the Indians. In most cases imported, sophisticated aids (specially wheelchairs and tricycles) are built with the body sizes of the Western people in mind, which are bound to result in difficulties in using these aids. It was also observed that most of the disabled persons do not use the prostheses or orthoses due to poor alignment, poor design, improper matching as to the individual requirements, and the like. These difficulties make the attempts at physical rehabilitation of the disabled a partial one, in India.

It is now established that proper matching of the man-machine and the environment secures a better performance from the system. The matching primarily has to fulfil two conditions; firstly, the aid should be capable of performing the expected function and secondly, the aid should be suitable in terms of the physiological and psychological abilities and the anthropometric characteristics of the user.
Thus to obtain better performance of the man-locomotor aid system, mobility or locomotor aids should be properly matched with the user.

Hence, the present study was undertaken in order to evaluate the man-locomotor aid systems prevailing in India considering the physiological, biomechanical and anthropometric characteristics of the disabled people. The study was performed on the most common man-locomotor aid systems, such as, amputee-prostheses system, amputee/polio affected-crutch system, polio/paraplegia affected tricycle/wheelchair systems.