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Comparative Study of Lactate Removal in Short Term Massage of Extremities, Active Recovery and a Passive Recovery Period After Supramaximal Exercise Sessions

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This investigation highlights the comparison of blood lactate removal during the period of recovery in which the subjects were required to sit down as a passive rest period, followed by active recovery at 30% $\dot{V}O_2$max and short term body massage, as the three modes of recovery used. Ten male athletes participated in the study. Exercise was performed on a bicycle ergometer with loads at 150% $\dot{V}O_2$max, each session lasting 1 min, interspaced with 15 sec rest periods, until exhaustion. Blood lactate concentration was recorded at recovery periods of 0, 3, 5, 10, 20, 30, and 40 min, while $\dot{V}O_2$, $\dot{V}CO_2$ and heart rate were recorded every 30 sec for 30 min. The highest mean lactate value was found after 3 min of recovery irrespective of the type of modality applied. Significantly lower half life of lactate was observed during active recovery (15.7 ± 2.5 min) period, while short term massage as a means of recovery required 21.8 ± 3.5 min and did not show any significant difference from a passive type of sitting recovery period of 21.5 ± 2.8 min. Analysis of lactate values indicated no remarkable difference between massage and a passive type of sitting recovery period. It was observed that in short term massage recovery, more oxygen was consumed as compared to a passive type of sitting recovery. It is concluded from the study that the short term body massage is ineffective in enhancing the lactate removal and that an active type of recovery is the best modality for enhancing lactate removal after exercise.

Key words: Lactate removal, short term massage recovery, active recovery, half life, supramaximal exercise

Introduction

Lactic acid is produced in any kind of muscular exercise. In strenuous exercise there is a discrepancy betwen the demand and the availability of energy from the aerobic process of exercising, which results in a large production of lactic acid in the muscles subjected to exercise. The accumulation of an excess amount of lactic acid (LA) in muscles under stress is a contributing factor to fatigue. Most of the LA produced during rigorous exercise is removed by direct oxidation (55–70%) while the balance amount is converted to glycogen (<20%), protein constituents (5–10%) and other compounds (<10%) (13). Although these indications and tendencies have been established in experiments with rats and were supported by the investigations on Excess Post exercise Oxygen Consumption (EPOC) (4), it is not clearly understood when applied to human beings (3). In many events, like boxing, wrestling and weightlifting, inter-bout rest periods are short; whereas, in football, hockey and basketball, a longer recovery interval is allowed between the two halves of the game. There is a need to develop a suitable method to enhance the rate of recovery in such disciplines. The removal rate of LA is higher during light aerobic exercise than during a period of resting recovery, following heavy exercise (5,8,17). Information regarding other modes of recovery has been found to be inadequate (10). In recent years, sports massage has gained popularity among amateur as well as professional competitors (19).

Since massage has been advocated for enhancing the recovery and as there is a lack of concrete information regarding the efficiency of massage as a means of lactate removal, the present investigation has been designed to evaluate the possible contribution of short term massage of the extremities to blood lactate removal patterns. Related cardiorespiratory changes in massage in comparison to active recovery and a passive recovery period have also been recorded.

Methods and Materials

The study was conducted on 10 male athletes (5 national walkers, 4 junior middle distance and 1 junior long distance runner). All exercise sessions were performed on a bicycle ergometer (Erich Jaeger, Germany), in an air conditioned laboratory in order to maintain a constant degree of temperature and humidity throughout the experiment. During the period of testing, the athletes in question were undergoing precompetitive season training. However, the level of loading on the day preceding the test was kept to a medium standard and no training was executed on the day of testing.

Table 1 Blood lactate concentration following various modes of recovery.

Modes of recovery	Recovery blood lactate (mMol/l)							
	0 min	3 min	5 min	10 min	20 min	30 min	40 min	Half life (min)
Passive recovery	6.5 ± 0.6	9.5 ± 1.0	9.3 ± 1.4	5.7 ± 0.8	4.9 ± 0.6	3.8 ± 0.5	3.3 ± 0.3	21.5 ± 2.8
Active recovery	6.6 ± 0.5	9.5 ± 0.8	8.9 ± 1.6	4.4 ± 0.6	3.4 ± 0.5	2.9 ± 0.5	2.6 ± 0.3	15.7 ± 2.5
Massage recovery	6.8 ± 0.6	9.6 ± 1.0	8.7 ± 1.4	5.6 ± 0.6	4.4 ± 0.5	3.9 ± 0.4	3.2 ± 0.5	21.8 ± 3.5

Values are mean ± SD.

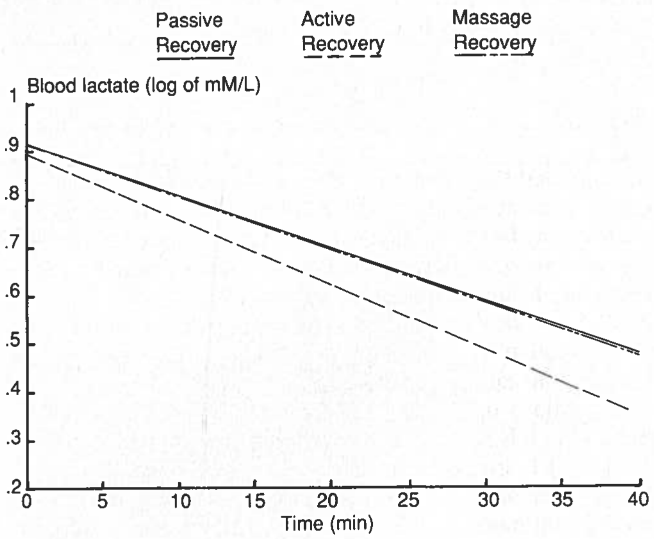

Fig. 1 Relationship between blood lactate concentration and time during recovery in various modes.

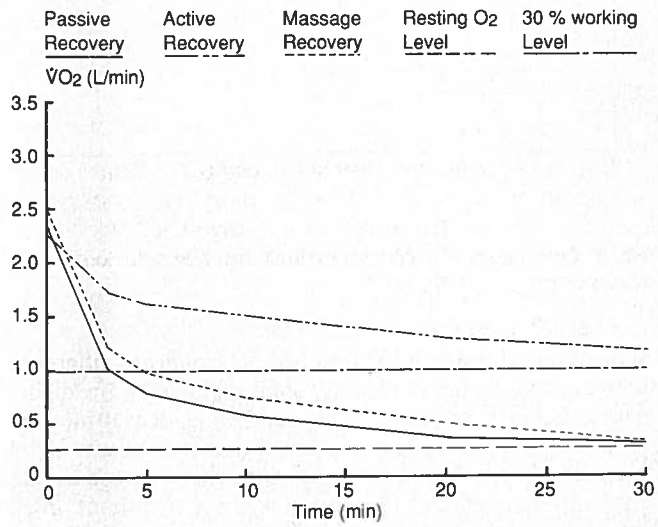

Fig. 2 Changes in oxygen consumption following various modes of recovery.

At first, the volunteers were subjected to a system of graded exercises of the lower limbs on a bicycle ergometer until exhaustion in order to determine the level of $\dot{V}O_2max$. The initial load was adjusted to 1 watt/kg of body weight and increased every 2 min by 0.5 watt/kg of body weight and at 80 rpm of pedalling. Respiratory gas exchange was analyzed continuously and computed every 30 sec during each stage of the exercise session using an Oxygen Analyzer (OM-14, Sensormedics, USA) and Ergopneumotest (Erich Jaeger, FRG). The heart rate (HR) was recorded by a telemetry system (Sport Tester, PE 3000, Polar Electro, Finland).

In the next phase, supramaximal exercise (150% of $\dot{V}O_2max$) was executed by the volunteers in sessions of 1 min of exercise with a pedalling rate of 80 rpm followed by 15 sec recovery periods until exhaustion. On the whole, the volunteers were able to tolerate about 3 to 5 sessions of such exercise. After supramaximal exercise three types of recovery modes were studied on different days with a minimum interval period of 48 hours. The recovery modes were as follows – resting in a relaxed sitting position (passive recovery or PR) for 40 min, pedalling on a bicycle ergometer at 30% of $\dot{V}O_2max$ (active recovery or AR) for 40 min, and the application of massage to the extremities (massage recovery or MR) for 10 min. The massage, consisting of kneading and stroking, was provided by a qualified physiotherapist and only the upper and the lower limbs received massage. The volunteer and the mode of recovery on a particular day was selected by random number generator programme in a computer. During the recovery period blood samples were collected from the pre-warmed fingertips at various intervals – just after the exercise (0 min or peak), 3, 5, 10, 20, 30, and 40 min after the completion of exercise. The procedure of blood sample collection has been mentioned in an earlier study from the same laboratory (14). The samples were analyzed by using an automated lactate analyzer (23L, YSI, U.S.A.). The gas exchange ($\dot{V}O_2$ and $\dot{V}CO_2$) and heart rate (HR) were also recorded every 30 sec until the end of 30 min of recovery. The volunteers were subjected to exercise at 30% of $\dot{V}O_2max$ intensity on bicycle ergometer for 8 min at a later date to record the steady state gas exchanges and HR.

The data of time and lactate, in each mode of recovery, were fitted into a semi log straight line regression model. The time required to remove half the amount of maximum lactate was considered as the 'Half Life' of lactate in the blood. The half lives were estimated using the regression equation between time and lactate. In order to estimate the differences among the mean values, repeated measures of ANOVA were applied with post hoc Newman-Keul test. The significance level was taken at $p < 0.05$.

Results

Mean and SD values of age, height, weight and $\dot{V}O_2max$ of the volunteers were 21.1 ± 4.25 yrs, 171.9 ± 5.27 cm, 58.8 ± 7.1 kg and 61.3 ± 5.4 ml/kg/min, respectively. These volunteers were found to be similar to the Indian male elite middle and long distance runners (15). Peak lactate and 3 min lactate levels after

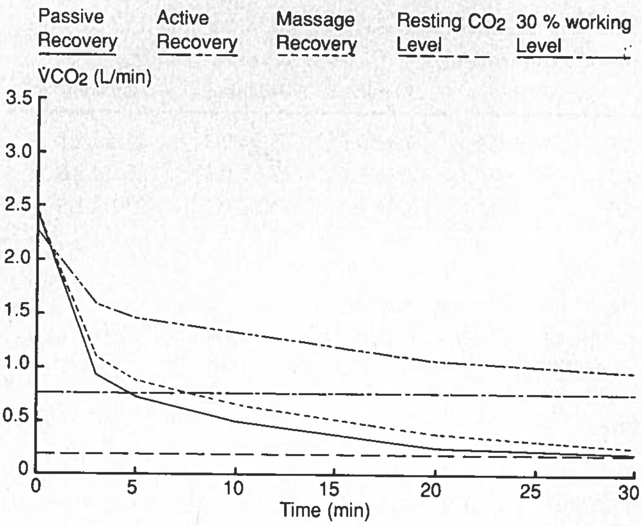

Fig. 3 Changes in carbon dioxide production following various modes of recovery.

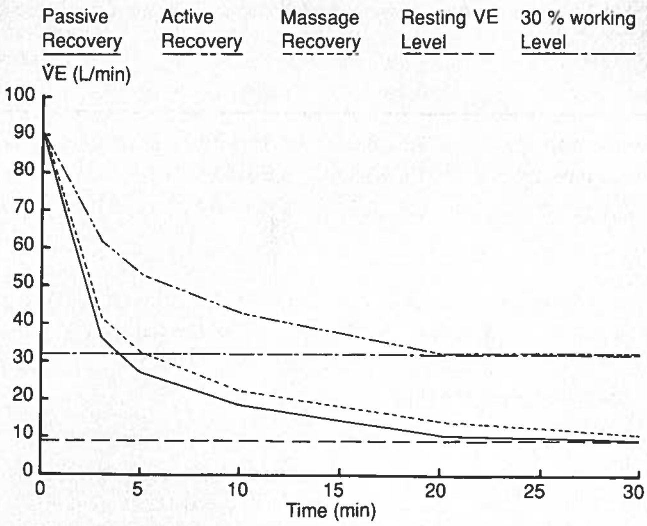

Fig. 4 Changes in pulmonary ventilation following various modes of recovery.

supramaximal exercise sessions had no significant difference in the various modes of recovery applied (Table **1**). The difference in lactate concentration between PR and AR at 10 min and onwards was found to be significant. A similar trend was found between MR and AR, whereas, the difference in blood lactate concentration between PR and MR was not significant. In all the modes of recovery, the highest mean lactate values were obtained in blood samples taken at 3 min after the completion of the exercise. The mean lactate value at 5 min did not show any significant difference as compared to the 3 min value.

The relationship curve for time versus lactate concentration is shown in Fig. **1**. Post exercise lactate removal rates were found to be the fastest in AR, whereas, the lactate removal rate during PR and MR did not show any significant difference in their LA removal rate for a duration of 40 min. AR shows the shortest half life, but MR and PR had no significantly different effects (Table **1**). Fig. **2** illustrates the oxygen consumption following various modes of recovery as well as oxygen consumed during the resting state and at a work intensity of 30% $\dot{V}O_2$max. The differences in $\dot{V}O_2$, compared between all modes of recovery were significant, except at peak lactate levels, and between MR and PR at the 30th min point of time. Interestingly, even up to the 30th min of recovery following sessions of supramaximal exercise, the $\dot{V}O_2$ in AR was much higher than the steady state $\dot{V}O_2$ at a 30% $\dot{V}O_2$max work intensity (1.16 l/min vs 0.99 l/min). Similarly, $\dot{V}O_2$ at the 30th min in PR and MR was significantly higher than the resting level $\dot{V}O_2$. The same was true in the case of CO_2 production in all modes of recovery, except that $\dot{V}CO_2$ in MR has shown no significant difference to the resting level $\dot{V}CO_2$ (0.2 l/min) (Fig. **3**). The response of pulmonary ventilation ($\dot{V}E$) during various modes of recovery has been depicted in Fig. **4**. Ventilation reached resting levels during the PR after the 20th min of recovery, whereas, it was a little delayed in MR and reached resting levels only after the 30th min. In AR the $\dot{V}E$ reached a steady state $\dot{V}E$ level (at 30% $\dot{V}O$max) after 20 min and remained unchanged thereafter.

The HR response in PR and MR was also very similar in nature throughout the recovery period of 30 min (Fig. **5**). In the case

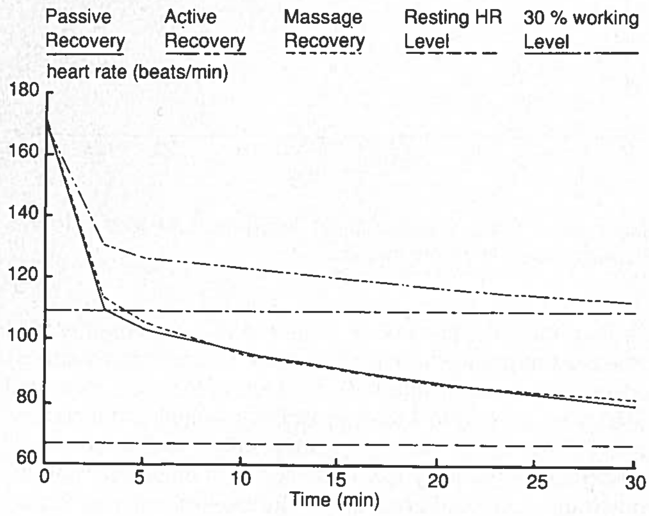

Fig. 5 Changes in heart rate following various modes of recovery.

of MR and PR the HR was considerably decreased at the 30th min of recovery (81±5.3 and 79±9.1 beats/min, respectively). However, the values were still significantly higher than the resting condition (67±5.3 beats/min). The steady state HR at the 30% $\dot{V}O_2$max work load was 109±11 beats/min, and HR during AR at the 30th min was approaching towards this range, while the difference was insignificant.

The excess amount of oxygen consumption and CO_2 production during recovery was also calculated and is shown in Table **2**. The total $\dot{V}O_2$ recorded after 30 min of exercise at 30% $\dot{V}O_2$max work rate was deducted from the $\dot{V}O_2$ consumed during AT, and this value was considered as the excess $\dot{V}O_2$ for AR. The excess $\dot{V}O_2$ for MR and PR was calculated from the sum of $\dot{V}O_2$ during 30 min, following each mode of recovery, minus the resting $\dot{V}O_2$ for the same period. The oxygen consumed in excess during each of the various recovery modes was found to be highest in MR followed by AR and PR, whereas, excess CO_2 production was highest in AR, followed by MR and PR. The differ-

Table 2 Excess oxygen consumption and carbon dioxide production during various modes of recovery for 30 min.

Variable	Passive recovery		Active recovery		Massage recovery	
	Total	Excess	Total	Excess	Total	Excess
VO_2 (l/min)	17.3 ± 2.8	9.5 ± 2.8	41.6 ± 2.9	12.0 ± 4.9	20.6 ± 3.6	12.8 ± 3.6
VCO_2 (l/min)	14.7 ± 2.4	9.0 ± 2.1	37.1 ± 3.0	14.4 ± 3.5	17.8 ± 3.3	12.1 ± 3.2

Values are mean ± SD

ence between MR and PR was significant in the case of VO_2, and for VCO_2, both AR and MR were significantly higher than PR.

Discussion

The physiological responses to massage have been attributed to: 1) an increase in local circulation, 2) an increase in cellular permeability and 3) the soothing effect it has on the central and peripheral nerves (22). Some recent studies indicate that massage results in an earlier recovery than rest alone as it is accompanied by an increase in the total circulating blood volume by shifting plasma (16), RBC (16), haemoglobin (1), while other studies have reported that the use of massage has no such benefits, at least in respect to quicker lactate elimination or raised circulating blood cell volume (6,21). The responses described by Wakim (22) may suggest better removal of lactate from the muscle cells and an increase in transport of lactate in systemic circulation. In such a case, the blood lactate value at 5 min would increase or at least come close to the 3 min value (assuming that massage has been started at 1 min). However, the benefits of massage, in comparison to simple rest, may be marginal because, after heavy exercise, the HR remains above resting levels for some time, thus ensuring good circulation in muscles that were exercised. Also, the increased local muscle temperature helps to maintain a higher rate of circulation (9). In the present experiment the highest lactate value was found at 3 min after the end of exercise in all modes of recovery, and subsequently declined at 5 min, although not significantly. This indicates that massage does not have any extra advantage in enhancing the diffusion of lactate in the different body compartments in the first 5 minute. Previous studies have indicated that blood LA concentration reaches peak at 4 min (2) and 7.65 min (12), after the cessation of short bursts of supramaximal exercise. Whereas, Sjodin et al. (20) have shown blood lactate to reach its peak level between 2 to 4 min of recovery after 4 to 7 min of exhaustive exercise. It has also been stated that a 3 min period of recovery is not sufficient for establishing an equilibrium between the active muscle and the passive areas of lactate space (11). Since no blood sample was taken at 4 min of recovery, the existence of a peak value at 4 min could not be excluded. In view of the present observations, it could be stated that peak lactate may be reached in 3 to 5 min after repeated sessions of supramaximal exercise, and that massage may be considered ineffective for a faster removal of LA from the muscles.

Studies relating to the fate of lactate have indicated that the major portion of the blood LA is oxidized (13), the time phase of this oxidation has not been clearly defined. Since peak lactate appears at 3 to 5 min during AR, it may be assumed that lactate may not be the possible substrate for energy production at this stage. The increase in the speed of lactate formation is maintained for some time even after the completion of exercise due to the already enhanced kinetics of reaction. A few studies have indicated that the half life of LA remained constant for a particular individual, at least for a blood LA concentration of 4 to 20 mM/l, and for a resting recovery pattern (3), but findings regarding changes in the half life, with variation in recovery modes are not available. AR shows the shortest half life and it is obvious that the time required for oxidation of lactate would be smaller than gluconeogenesis. An increased cardiac output, VO_2 and lactate oxidation may be responsible for a shorter life in AR, as compared to MR and PR. The first detectable differences in the removal of lactate found in the case of AR at 10 min is indicative of the utilization of lactate as a substrate for energy production in later stages of recovery.

An increase in the muscle temperature due to friction may enhance oxygen uptake (18), and this may be the reason for a higher excess VO_2 at various stages of recovery in MR as compared to AR and PR. Exercise at 30% of VO_2max may also raise the temperature of the muscles (3,13), hence a similar amount of excess VO_2 for AR and PR supports this view. There was no increase in VE corresponding to the raised VO_2, which indicates a change in the oxygen uptake in the lungs. But, in MR such an increase in VO_2 is unrelated to lactate kinetics, as lactate removal in MR is similar to PR. However, based on these data it is not possible to confirm that an increase in VO_2 during MR is possible. The total quantity of CO_2 produced during the recovery period was lower than the amount of oxygen consumed in all cases as being an absolute fact, since AR has shown higher CO_2 output in a relative sense. This higher CO_2 production may be taken into account if there was also a decrease in the alkali reserve. Massage has not shown any impact on heart rate in the present study. At this point the question regarding the effectiveness of a 10 min massage regime may arise. Since the available literature in this connection is not universal regarding the duration of massage (23), and rest periods in a game situation are usually about 10 min, massage of this particular duration was thought to be sufficient for establishing its effectiveness to induce transient effects. The major consumer of LA in the body includes relatively inactive muscle (7). Considering the proposed role of massage in enhancing the circulation and permeability, the whole body should have received the massage to increase the consumer muscle mass. However, in that case each portion of the body would have received a massage for only 3 min, which may not be sufficient. It was thought better to increase the duration of massage to individual parts of the body rather than the mass. Therefore, the expected beneficial effects of short term massage to enhance the removal of lactate in a game situation as compared to passive recovery modes remains unproved. Among the three recovery modes in question, AR may be considered a much better recovery process than MR and PR, particularly when faster rate of lactate elimination is the main criterion.

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Effect of sampling frequency on EMG power spectral characteristics

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Abstract

During digitization of surface EMG, the signal is converted by an Analog-to-Digital (A/D) convertor at a specific sampling rate. This sampling rate should be selected cautiously because a high rate may include noise signals and a low rate may lead to errors. The present study was undertaken to show the effect of sampling rate on EMG power spectrum. The study was carried out on nine subjects and EMG record was done from deltoid muscle at sampling rates of 4, 6, 8 and 10 KHz during maximal voluntary contraction. Biopotential coupler with a response range of 5 Hz to 2 KHz was used during recording of the EMG signal which was processed later by Fast Fourier Transform software. The study showed a linear relationship between the sampling rate and the mean power frequency (MPF). But there was no distinct effect of sampling rate on mean and root mean square (RMS) of the digitized signal.

Introduction

In recent times there has been a considerable increase of interest in automatic methods of data processing specially in electromyogram (EMG) recordings. Such interest is demonstrated in recent reviews (1, 16). Electrical events related to muscle fibre excitation is recorded with different kinds of electrodes placed on or into the muscle. The analysis of EMG signal varies widely and has made the standardization of the method difficult. The recorded signals are being expressed as IEMG (7), Mean EMG or Average EMG (17), motor unit firing criteria such as Turns, Amplitude-turn ratio, EMG jitter, and the like (2, 3, 5). However, introduction of digital signal processing techniques in the analysis of EMG signals has opened a new vista.

In digital signal processing EMG signal is amplified and converted to a digital form by an Analog-to-Digital (A/D) converter. One important technical point to be considered in such a case is the amount of data to be acquired, stored on low cost rapid access memories and processed in a limited time. The digitization process needs to be done at a specific sampling rate which is selected according to the range of signal frequencies, noise cut-off and various other factors. If a high frequency of sampling is chosen like 50 KHz (9) or 20 KHz (8) the digital representation of the signal is accurate, but it becomes difficult to process such an amount of data quickly and avoiding the inclusion of noise in the measurement. On the other hand, a low sampling frequency 4 KHz (14) or 5 KHz (15) leads to errors in measurement of the shape, amplitude and frequency spectrum of the signals.

In a number of previous studies on EMG, using power spectral measurements, a variety of sampling frequency have been applied which

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have culminated into difficulties of comparison among different studies. The present study is an attempt to investigate the effect of changes in sampling rate on EMG power spectral measures and to indicate suitable sampling rate for surface EMG studies.

Materials and methods

Nine male volunteers of sports schools had participated in the study. Age, height and weight of the volunteers were 17.3 ± 1 yr, 177.7 ± 9.4 cm and 69.7 ± 8.2 kg respectively. The EMG signals from mid-deltoid muscle, during maximal voluntary contraction (MVC), were recorded by Sensormedics Dynograph (model R612) using a coupler which had a response range of 5 Hz to 2 KHz (type 9878 Biopotential coupler). The signal was digitized (on line) using a Multiprogrammer (HP 6954A) at four different sampling rates (4, 6, 8, 10 KHz). The digitization was done by CAT Software and subsequently stored in floppy drive.

For recording, bipolar Ag/AgCl surface electrodes with 8 mm contact diameter were used. The skin was carefully prepared before the electrodes were placed longitudinally on the muscle keeping 4 cm inter-electrode distance. During recording, each subject was placed on a table with legs hanging vertically from knee and gave four MVC isometrically (6). One MVC lasted 5 sec and the subject was allowed to take 5 min rest between two recordings. During each MVC, 3,000 data points were recorded and stored in floppy disk.

The data were processed with Fast Fourier Transform (FFT) software and Hamming window function, 512 data points were analysed at a time to obtain a power spectrum periodgram. Five consecutive periodgrams were averaged and used to calculate mean power frequency (MPF). MPF was calculated as the ratio between the spectral moments of orders one and zero (13), $MPF = M_1/M_0 = \int_0^\infty fP(f)\,df / \int_0^\infty P(f)\,df$, where f is the frequency and $P(f)$ is the myoelectric signal power spectrum. Mean and Root Mean Square (RMS) value of 3,000 data points from each signal were also calculated.

Results

Mean and RMS EMG of the sports persons have been described in table 1. The mean and RMS EMG values indicated high interindividual variability, however, no significant difference could be found in various sampling rates. Spectral characteristics of EMG signals have been shown in table 2. The peak of the power spectrum has been defined as the range of frequency whose power content is maximum. The peak of the power spectrum was almost similar in all the sampling rates (Fig. 1). The frequency after which the spectrum became flat did not vary much with the change in the sampling rate, but the MPF of the spectrum increased with the sampling rate. The relationship between sampling rate and MPF has been shown in figure 2. The correlation coefficient was found as 0.96 ($p < 0.001$).

Table 1. — *Mean and RMS of EMG signal digitized at different sampling rates*

	Sampling rates			
	4 KHz	6 KHz	8 KHz	10 KHz
Mean (micro volt)	158.8 ± 64.5	126.5 ± 46.7	139.1 ± 55.9	149.3 ± 66.1
RMS (micro volt)	200.2 ± 80.9	159.0 ± 58.3	162.5 ± 58.4	186.7 ± 83.9

Table 2. — *Characteristics of the power spectrum at different sampling rates*

	Sampling rates			
	4 KHz	6 KHz	8 KHz	10 KHz
Mean MPF (Hz)	165.2 ± 7.6	238.1 ± 18.6	296.1 ± 28.1	368.8 ± 32.3
Range of MPF (Hz)	153.9 to 178.7	214.6 to 280.9	253.9 to 349.6	317.9 to 433.5

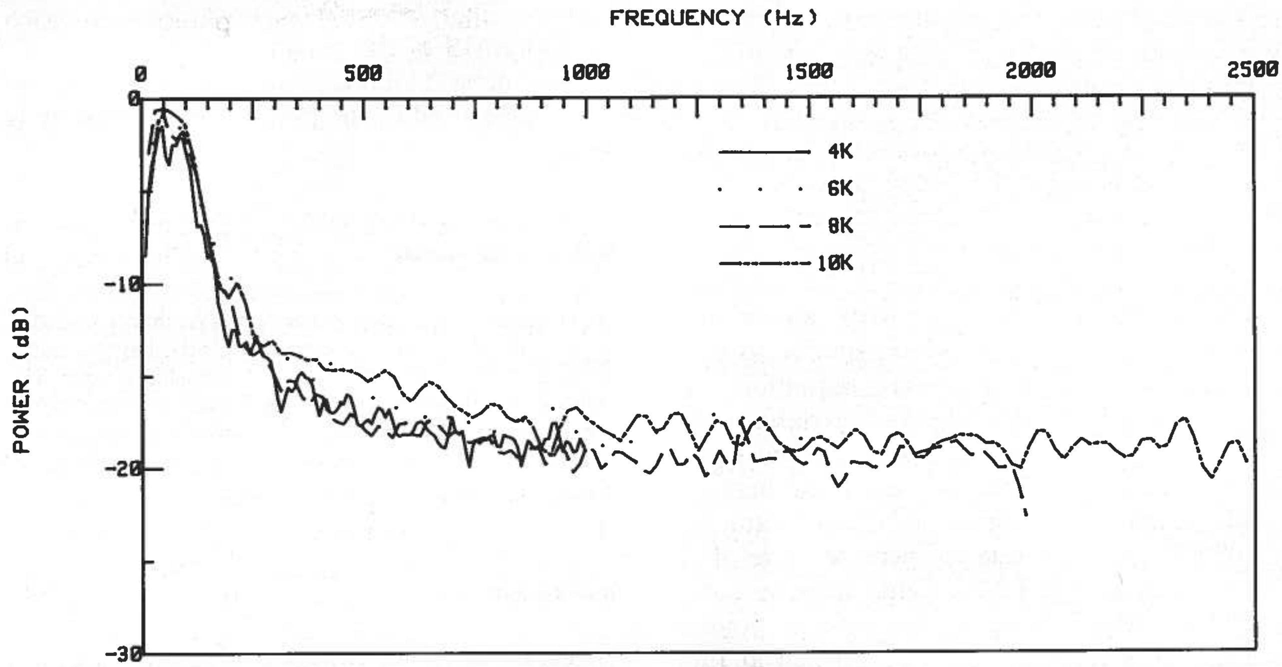

Fig. 1. — Variation of power spectra in different sampling rates.

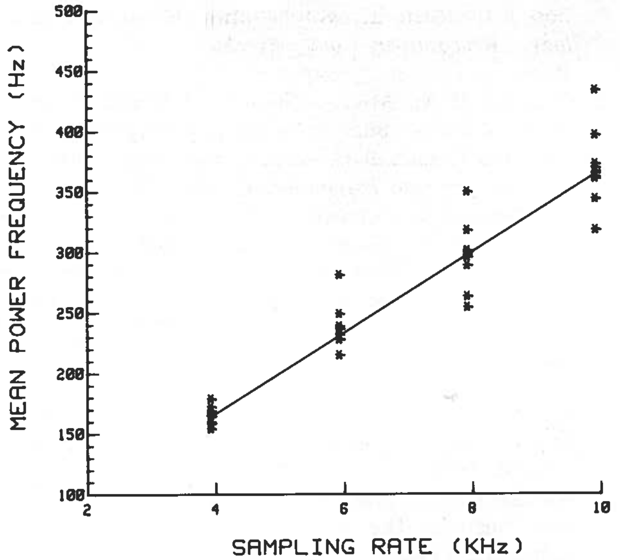

Fig. 2. — Relationship between Mean Power Frequency and sampling rate.

Discussion

The theory of digital signal processing explains three major sources of error, aliasing, leakage and Picket-Fence effect during FFT application (18). To avoid these errors a few restrictions have been laid in the FFT processing. The signal should be bandlimited and the sampling rate must be sufficiently higher to meet the expression $fs \geqq 2fh$, where fs is samling rate and fh is highest frequency present in the signal. A number of previous studies have used sampling rates lower than this specified limit (11). Although higher limit of the sampling rate has not been specified, studies have shown that too high a rate includes noise signals where small turns appear like a series of peaks (4). The frequency resolution is also an important factor, as the major peak of a particular component may lie between two of the discrete transform lines. For a desired frequency resolution the minimum record length is required to be selected according to $tp = 1/F$, where tp is record length and F is frequency resolution. The number of points in the record length is determined by $N \geqq 2fh/F$.

In some earlier studies lower sampling rates were used to record digital signal. MPF value was shown below 100 in biceps brachii muscle at 40% MVC using 1 KHz sampling rate (13). In another study (12) 1024 Hz sampling rate was used to record signal from same muscle and reported MPF during MVC as 137.1 ± 10 and during 50% MVC as 134.6 ± 5.5. In the present study the MPF values were observed higher in all the sampling rates than the above studies. The higher MPF values of the present study were obviously due to the higher sampling rates. Significant correlation between the sampling rate and MPF value confirms this view. Interpolation of the regression equations at 2 KHz sampling rate indicate that in case of deltoid muscle the MPF could be around 99.8 Hz. In one study (10) the MPF was in the range of 65 to 130 Hz which is similar to the predicted value from regression equation. It was also clear that interindividual variability in MPF was lowest in case of 4 KHz and at 6, 8, 10 KHz rates the variability were quite higher. Possibly the higher sampling rates act as amplifier of the spectrum due to increase in resolution frequency. The EMG signal may be considered as a Baseband signal as the power spectrum was found to be concentrated at the lower frequencies. Dominance of EMG power spectrum of eight muscles of arm and leg was reported between 50-200 Hz (19) and in the same experiment EMG activity was not observed above 350 Hz. This study did not mention the sampling rate clearly. Peaks of power spectrum were demonstrated around 50 Hz in biceps brachii and soleus, and activity upto 350 Hz were seen using 1 KHz sampling rate (13). Similar peak values were also observed in the present study. Use of higher sampling rates lengthen the range of power spectrum and as MPF is the frequency value at which the area under the curve is divided in two equal halves, the flat portion of the spectrum becomes the determining factor for the increase in MPF at higher frequencies. Clearly, the possible compromise between the resolution frequency and interindividual variability could be achieved by using a sampling rate of 4 KHz.

The major findings of this study are:

- change in sampling rate does not shift the peak of the power spectrum in case of surface EMG;
- mean power frequency increases linearly with the sampling rate but this is possibly due to the effect of widening of the spectrum;
- sampling rate has no distinct effect on mean and RMS of the signal;
- the most suitable sampling rate for the coupler used in the present study possibly is 4 KHz.

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Ergonomic analysis of wheelchair designs

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Summary

Four types of wheelchair available in India were evaluated from physiological, anthropometric and biomechanical points of view. None of the wheelchairs had a seat designed to provide comfort to the majority of disabled users. The diameter of the castor wheels in one type of wheelchair was found to be more suitable for overcoming the more common obstacles in buildings and net oxygen cost of this type was found to be much lower than the others. Propulsion of all the wheelchairs consumed more than 50% of the $VO_{2\,max}$ of the disabled persons. The space allowed between the hand rim and the wheel was not adequate in any of the designs for comfortable and efficient propulsion. From the present evaluation it was concluded that although one type of wheelchair was preferable amongst the four examined, it still needed several modifications.

Relevance

The physiological and anatomical limitations of wheelchair occupants place special demands on 'chair design. Ergonomic analysis provides design information of value in reducing the musculo-skeletal loads on the user.

Key words: Ergonomics, Wheelchairs, Musculo-skeletal, Physiology, Biomechanics

Introduction

Wheelchairs provide a wide field of mobility to disabled persons with confining disabilities. So far, the existence of four types of wheelchair (indoor, outdoor, combined indoor-outdoor and special chairs) has been reported. In India the use of wheelchairs is restricted to indoor purposes: outdoor and combined indoor-outdoor chairs are totally absent. Special chairs or wheeled ordinary chairs are rarely used. Numerous attempts have been made to evaluate and improve wheelchair designs in Western and European countries[1–9]. Most of the studies describe either physiological costs involved in driving the wheelchair or engineering improvements and mechanisation in the design, but do not consider the physical and anatomical limitations of the users. The present study describes the analysis of wheelchairs available in India, considering the physiological and physical limitations of the disabled persons.

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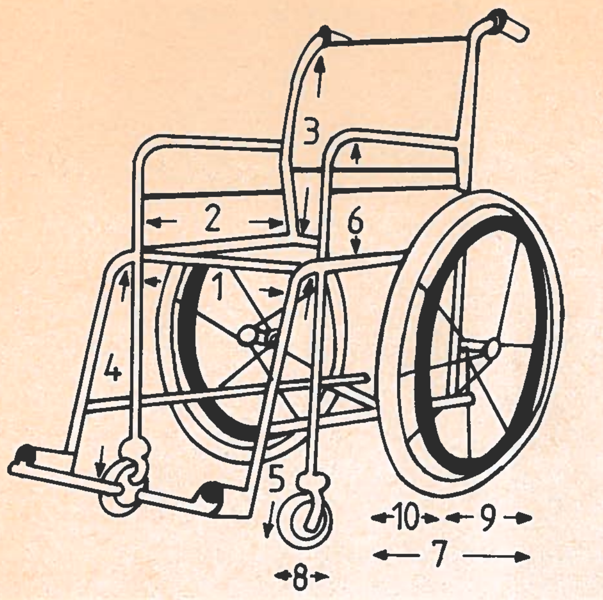
Materials and methods

Indian wheelchairs

Wheelchairs that are available in India vary little in their design but have measurable differences in their dimensions due to manufacturers' specifications. In total, four types of wheelchair were selected for evaluation from different states of India; among them three were of a non-folding type (A, B and C) and one was a folding type (D). Figure 1 describes their dimensions with a general diagram.

The volunteers

The volunteers cooperating in the present investigation comprised nine and six disabled persons for A and B type wheelchairs, respectively, and six disabled persons for the evaluation of both C and D type wheelchairs. Of the 21, 15 were paraplegics due to trauma and six were post-polio patients with both lower limbs severely affected. Since the use of different models of wheelchair is restricted to areas around the centres of their manufacturers, it was not possible to evaluate the models with the same group of volunteers since large geographical distances separate the centres. Mean and standard deviation (s.d.) of age, height and weight of the disabled volunteers are described in Table 1.



Key	Wheelchair type A	B	C	D
1. Seat width	42·0	41·0	44·0	44·0
2. Seat depth	42·0	37·5	49·0	41·5
3. Back rest ht.	40·0	28·0	38·5	40·5
4. Seat to foot rest ht.	38·0	50·0	39·0	32·5
5. Seat to ground ht.	51·5	56·0	53·0	47·0
6. Seat to arm rest ht.	30·5	15·0	15·0	13·0
7. Diameter of back wheel	62·0	64·0	58·0	58·0
8. Diameter of front wheel	18·0	9·5	10·0	10·0
9. Diameter of hand rim	56·0	54·0	44·0	44·0
10. Clearance between rim and wheel	3·0	2·5	8·0	7·5
11. Weight of wheelchair	23·0	25·0	26·0	25·0

Weight in kg, others in cm

Figure 1. A general diagram of a wheelchair and various dimensions of four types of wheelchairs.

Investigation methods

Evaluation of the wheelchairs was made in situations simulating actual usage, and the variables selected for measurement were peak heart rate, oxygen uptake, net oxygen cost and speed of propulsion. The oxygen consumptions of the activities studied were predicted from the heart rate–oxygen consumption relationship established in a previous study[10].

The volunteers were asked to propel the wheelchairs on a smooth concrete surface for a period of three minutes at their accustomed speeds. The period of observation was restricted to three minutes, as it was found that most were obliged to rest after continuously propelling wheelchairs for about this length of time. The speed was measured by the time taken to cover a distance of five metres marked on the floor. During the days of these experiments the recorded environmental temperatures showed no significant variations.

Selective anthropometric measurements of the disabled persons related to wheelchair design were taken according to standard methods[11] and are given in Table 2.

Table 1. Personal data of the volunteers

Wheelchair type	*Age (yrs)*	*Height (cm)*	*Weight (kg)*
Type A	23·8	152·9	49·7
	±4·2	±11·2	±2·4
Type B	28·8	159·4	50·0
	±4.2	±5.0	±10·9
Type C & D	27·8	158·6	45·1
	±1·7	±8·3	±6·5

Table 2. Anthropometric measurements related to wheelchair design (N=61)

Parameters	*Mean*	*s.d.*	*Percentile values* 5th	50th	95th
Popliteal height	38·4	3·4	34·3	37·7	46·5
Buttock popliteal length	39·9	2·8	35·7	39·9	44·7
Elbow rest height	18·1	2·3	13·6	18·3	21·3
Hip breadth	28·4	2·2	24·4	28·4	33·4
Hand thickness at 3rd metacarpal	2·6	0·1	2·2	2·5	2·9

(measurements in centimetres)

Results

Anthropometric analysis of seat

In addition to the mobility provided to the disabled persons, wheelchairs also serve the purpose of resting chairs for long term sitting. Improvement of the wheelchair seat is therefore of importance. The seats were analysed with regard to the recommendations for better seat designs evolved from various studies in this area[11–15].

Sitting height is determined by the popliteal height of the population. Seat to foot rest heights of three types of wheelchair (A, B and C) were greater than the 5th percentile value of the popliteal height of the disabled persons. Wheelchair B had a value exceeding the 95th percentile of the disabled group.

Seat width should be such as to accommodate the person and also to allow sufficient space for alteration of posture. Seat widths were nearly the same in all four types and were significantly greater than the 95th percentile value of the hip breadth of the disabled group.

Depth of the seat should allow sufficient space between the front edge of the seat and back of the knee joint and this is determined by buttock-popliteal length. Wheelchair B had a similar depth to the 5th percentile value but the rest of the wheelchairs had greater seat depths.

Back rests had a space of 5–10 cm between the seat surface and the lower edge of the back rest, and no inclination of seats or back rests was observed to be present in any of the types.

Table 3. Speed of wheelchair propulsion—comparison between previous reports and the present study

	Speed on hard surface Mean (m/min)	±s.d.
Wolfe[9] (Paraplegic using hard tyred wheelchairs)	82·7	19·0
Wolfe[9] (Paraplegic using pneumatic tyred wheelchair)	79·8	18·6
Cerny[1]	75·0	22·8
Hash[4]	37·0	9·6
Gordon[16]	32·0	—
Peizer[7]	81·8	8·33
Present study		
Wheelchair Type A	84·9	10·3
Wheelchair Type B	59·1	9·7
Wheelchair Type C	51·2	3·4
Wheelchair Type D	47·5	6·1

Wheel size

It was observed that the diameter of the back wheel was largest in type B, followed by those of types A, C and D in decreasing order, whereas the diameter of the front wheels was largest in type A, followed by types C, D and B respectively.

Space between hand-rim and the wheel

It was observed that clearance between rim and wheel is minimum in type B followed by types A, D and C. Comparison of this value with the hand thickness of the disabled persons indicated that type B and A wheelchairs had insufficient clearance to allow the hand, in a large proportion of the disabled, to grip the rim comfortably whereas, in types D and C the clearance was too large, requiring abduction of the arms to an excessive degree.

Variation in speed of propulsion

Table 3 describes the speeds of wheelchair propulsion measured by different authors, compared with the present study. This review reveals various propulsion speeds. Gordon[16] reported an average velocity of 32 m/min by tuberculosis patients. Wolfe[9] reported higher average speeds of propulsion on concrete surfaces adopted by paraplegic subjects using a hard tyred wheelchair. Pneumatic tyred wheelchairs resulted in decreased velocity on both surfaces. Cerny[1] reported a similar velocity by habitual wheelchair users. In another study on hemiplegic patients, Hash[4] reported a slower velocity of wheelchair propulsion.

In the present study, four different speeds were observed to be adopted by the users of the four types of wheelchair, though in all instances the surfaces on which they were driven were of hard concrete and all the subjects were paraplegics and habitual wheelchair users. The highest speed of propulsion was observed during the use of type A wheelchairs.

Table 4. Comparison of physiological costs of wheelchair propulsion

	Heart rate beats/min	*VO_2 ml/kg/min*	*Net O_2 cost ml/kg/m*	*Relative VO_2 (% of $VO_{2\ max}$)*
Wolfe[9] (paraplegic using hard tyred wheelchair)	126 ±17	15·5 ±5·3	0·191 ±0·037	
Wolfe[9] (Paraplegic using pneumatic tyred wheelchair)	127 ±18	15·7 ±3·8	0·201 ±0·037	
Cerny[1]	109 ±16	13·28 ±4·07	0·18 ±0·04	
Hash[4]	107 ±13	10·04 ±1·47	0·272 ±0·092	
Present study				
Type A wheelchair	127 ±12	17·8 ±2·5	0·21 ±0·02	65·6
Type B wheelchair	129 ±8	18·3 ±1·7	0·313 ±0·03	68·5
Type C wheelchair	114 ±8	15·2 ±2·0	0·304 ±0·03	56·6
Type D wheelchair	124 ±11	17·3 ±2·6	0·36 ±0·01	64·6

Physiological cost of wheelchair propulsion

Table 4 summarizes the mean and standard deviations of the physiological variables during active propulsion of wheelchairs by the subjects and the values reported by other authors.

A comparison of peak heart rates during propulsion of the four types of wheelchair shows that heart rates were minimum while using the type C and maximum with the type B wheelchairs. The difference in the mean value of peak heart rates in the use of these two types of wheelchairs was significant (by unpaired *t* test, $P<0{\cdot}05$). No significant differences in peak heart rates were observed when comparisons were made between the values during the use of the other types. A similar trend was observed when oxygen uptakes per unit body weight were compared.

Since there was a variation in the self-selected speeds of propulsion of different types of wheelchairs, the effect of the variations was nullified by expressing the oxygen uptake per unit distance travelled. This parameter has been termed as the net oxygen cost in the literature[17]. Net oxygen costs of propelling the four types of wheelchair were compared and these had a pattern different from those observed in comparisons of peak heart rates. Propulsion of type A wheelchairs required minimum net oxygen costs, whereas the type D'chairs imposed maximum costs. No significant difference was observed when the values of this parameter

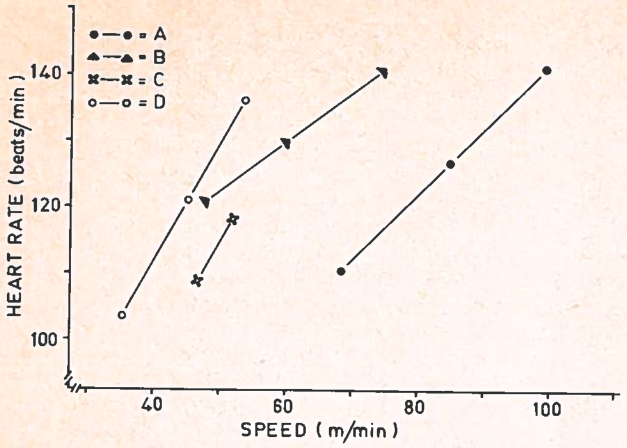


Figure 2. Relationship between speed and heart rate during driving different wheelchairs.

during the use of type B and type C were compared. Comparisons of net oxygen costs entailed in the uses of all the other types of wheelchair elicited significant differences.

It has been mentioned in earlier studies that the variables speed of travel and heart rate bear a close relationship, and over a wide range of speeds the relationship was curvilinear[18]. The heart rates and speeds of propulsion were observed to be highly correlated with the use of all types of wheelchair, except type C. The best correlation was obtained with type D, followed by types B and A. Slope of the relationship line was greatest for type C followed by types D, B and A (Figure 2). Only the values of speed, heart rate, oxygen consumption and net oxygen cost of propelling type A wheelchair conformed closely to those obtained by Wolfe[9], but were considerably higher than those obtained by Cerny[1].

It has been established by earlier researchers that any muscular exertion could be prolonged for up to one hour, provided the oxygen consumption did not exceed 50% of the maximum oxygen uptake of the subjects[19]. It was observed that propulsion of all four wheelchairs required a higher percentage of oxygen over this recommended value.

Discussion

Analysis of the wheelchair seats indicates that only the seat height of type D wheelchairs was suitable for 95% of the disabled population, whereas type A could accommodate 50% and type B only 5% of the disabled group. The seat width of all four types could comfortably accommodate all of the disabled population. The seat depth of type B chairs could accommodate more than 50% of the disabled population. Thus, in 50% of cases for this type of wheelchair the back rest becomes

Table 5. Comparison of the status of wheelchairs from physiological, anthropometric and biomechanical point of view, using an arbitrary scoring system

Aspects	Wheelchair type A	B	C	D
Speed of driving	1	2	3	4
Physiological cost	1	3	2	4
Seat height	2	4	3	1
Seat width	2	1	3	4
Seat depth	3	1	4	2
Back rest	0	0	0	0
Arm rest	0	0	0	0
Wheel size	1	4	2	3
Space between rim and wheel	1	4	3	2
Weight	1	2	3	2
Total weighting	12	21	23	22

(1='best' chair for that feature, so low overall score is preferable)

useless or, if used, would alter the natural spinal curvature. All other types provide a worse situation. The back rests of types A, B and C were fixed and made of metal sheets. The back rest of type D wheelchairs was also fixed and made of foam plastic material. None of the back rests could provide adequate lumbar support and would force the disabled persons to sit in an undesirable posture. Hence, none of the wheelchairs fulfilled the criteria of an ideal rest chair or an ideal work chair.

In general, the front wheels of a wheelchair are small (castor wheels), whereas the back wheels are large with a rim for propulsion by hand. Regarding the diameter of the wheels, there have been no studies to specify optimum diameter. Large wheels may shift the centre of gravity of the wheelchairs upwards and reduce their stability. The small castor wheels at the front are not suitable for negotiating architectural barriers like kerbs, bumps, etc. In the present study, the diameters of the front wheels of the type A wheelchair were preferable for overcoming low architectural barriers on the floor.

The space between the hand rim and the wheel is a critical dimension which may determine the relative difficulty of wheelchair propulsion. The space should allow the thumb or fingers to be introduced comfortably through it and an adequate force to be applied to the rim. However, too large a space between these two would require a higher degree of abduction of the arms and may make the exertion of force difficult. It has been reported that abduction of the arm increases the resting muscular activity[20]. This could reduce the force to be applied and impose early fatigue in the muscles involved. None of the wheelchairs was found suitable in this respect.

Analysis of the physiological cost of wheelchair propulsion indicates that, though oxygen uptake for propulsion of type A wheelchairs was higher than those for

types C and D, the net oxygen cost in its use was lower than those for all the others. Speed of propulsion of the type A wheelchair was much higher than all the others. If the other wheelchairs were propelled with speeds at which type A wheelchairs are customarily propelled it could safely be assumed that oxygen uptakes and heart rates during propulsion of these other types might attain higher values than those observed with the use of type A chairs. Hence, from considerations of the physiological stresses of propulsion, the type A wheelchair seems to be much better than types B, C and D.

To make the comparison easier, the method of arbitrary scoring was applied. The wheelchairs were categorised according to the goodness of fit from the physiological, anthropometric and biomechanical point of view. The best among the four was numbered as 1 and the others were numbered in increasing order (Table 5). It can be observed that the type A wheelchair is comparatively better than types B, C and D. Types B and D seem more or less equivalent according to the attempted categorization. There are certain disadvantages to the type A wheelchair and it is expected that with suitable modifications in the design of its seat, wheel size, space between the rim and wheel, etc., greater optimization of the physiological cost, ease of operation and comfort of the user disabled persons may be achieved.

Recommendations

The following recommendations for modifications of the different types of commonly used wheelchairs for the lower limb disabled emerge from this study.

1. The seat width of the wheelchair seat should be 2–4 cm greater than the 95th percentile value of the disabled individuals.
2. Seat depth should be 2–5 cm less than the 5th percentile value of the buttock-popliteal length of the disabled group.
3. A good support for the back should be provided and be available for the whole of the upper back, including the head, because patients often have a problem of balancing their head in the vertical plane. It may be better to allow a space of 10–15 cm between the seat surface and lower edge of the back rest.
4. The gap between the wheel and the hand rim should be greater than the 95th percentile value of the hand thickness at the third metacarpal of normal persons.

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Anthropometric characteristics of disabled and normal Indian men

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Keywords: Anthropometric characteristics; Disabled men; Indian men; Normal men.

This paper describes a preliminary study of the anthropometric characteristics of disabled Indian men, undertaken in order to facilitate the design of mobility aids. Fourteen anthropometric measurements were made in 61 men with disabilities of the lower extremities caused by poliomyelitis or spinal cord injury, and in 140 normal men. The study reports reduced growth of the affected parts and also some acquired deformity in the upper limbs. Inter-correlations between the body dimensions were different in the disabled and normal groups.

1. Introduction

The design of mobility aids for people suffering from disabilities of the lower limbs requires data concerning their physical and physiological limitations. A number of studies have described the latter (Asmussen and Molbech 1954, Gordon 1958, Erdman *et al.* 1960, Asmussen 1968, Ganguli *et al.* 1973, James and Nordgren 1973, Ganguli *et al.* 1976, Ghosh *et al.* 1980, Glaser *et al.* 1980, Nag *et al.* 1982, Goswami *et al.* 1984) but data about the physical dimensions of disabled people are scanty. This is probably because of the wide variety of disabilities encountered and the frequent need for personalized design of aids. Most studies have been performed in Europe and North America (Floyd *et al.* 1966, US Department of Health, Education and Welfare 1968, Kenward 1971, Goldsmith 1976, Institute for Consumer Ergonomics 1981), but few data have been reported for disabled people in India (Goswami *et al.* 1986). This preliminary study has been undertaken to establish the anthropometric characteristics of Indian disabled men to facilitate the design of mobility aids.

2. Materials and methods

The subjects of the present study, who were all volunteers, consisted of 61 males suffering from lower limb disabilities and 140 normal males. Since the purpose was to provide anthropometric data for the design of mobility aids, all the disabled subjects were wheelchair or tricycle users affected by poliomyelitis or spinal cord injuries. Anthropometric dimensions were measured with the Martin anthropometer, spreading caliper, slide caliper or steel tape, using the method of Damon *et al.* (1971). For subjects unable to stand erect unaided, stature was measured with the subject supported against a wall and precautions were taken against the bending of the trunk and knees.

3. Results

Table 1 shows the mean and distributions (standard deviation, s.d.) of the anthropometric measurements in the disabled and normal subjects. Mean values of all

Table 1. Anthropometric measurements of disabled (DI, $n=61$) and normal (NI, $n=140$) subjects.

Measurements	Mean		s.d.		5th percentile		50th percentile		95th percentile	
	DI	NI	DI	NI	DI	NI	DI	NI	DI	NI
(1) Age (yrs)	24·4	23·7	3·8	2·8	—	—	—	—	—	—
(2) Weight (kg)	41·4	54·3	5·4	6·1	31·8	45·0	41·6	53·3	50·0	66·6
(3) Stature (cm)	139·2	165·2	17·5	4·8	110·0	154·0	141·0	164·8	163·3	175·0
(4) Acromial height (sitting) (cm)	47·3	56·6	6·8	2·6	33·0	50·4	48·1	56·8	56·4	62·4
(5) Elbow rest height (right) (cm)	18·1	21·2	2·3	2·2	13·6	17·6	18·3	20·9	21·2	26·4
(6) Popliteal height (right) (cm)	38·4	42·7	3·4	2·2	34·3	38·9	37·7	42·4	46·5	47·4
(7) Buttock–knee length (cm)	48·4	54·7	2·6	2·1	45·4	51·3	48·2	54·5	54·0	58·4
(8) Buttock popliteal length (cm)	39·9	45·1	2·8	5·2	35·6	41·4	39·9	44·8	44·7	48·7
(9) Arm grasp (Max.) (cm)	67·9	70·8	5·7	5·2	57·4	61·2	67·2	70·7	76·2	79·8
(10) Arm reach from wall (cm)	79·9	81·9	4·9	4·3	69·4	74·5	77·9	82·1	87·4	89·0
(11) Elbow-to-elbow breadth (cm)	38·2	37·6	2·7	3·7	33·4	30·7	38·2	37·9	43·4	44·0
(12) Hip breadth (cm)	28·3	30·8	2·2	2·1	24·4	25·4	28·4	30·4	33·4	34·7
(13) Hand breadth at thumb (cm)	9·3	9·5	1·4	0·3	7·0	8·4	9·3	9·5	11·7	10·3
(14) Hand thickness at metacarpal III (cm)	2·6	2·4	0·1	0·1	2·2	2·0	2·5	2·3	2·9	2·6

these dimensions, except for the elbow-to-elbow breadth and hand breadth at the thumb, were significantly lower in the disabled group than in the normal group. The disabled group displayed a greater variability. The ninety-fifth percentile values for body weight, stature, acromial height, buttock–knee and buttock popliteal length in the disabled group were lower than the respective fiftieth percentile values for the normal subjects. The fiftieth percentile values for elbow rest height and popliteal height in normal men were between the fiftieth percentile and the ninety-fifth percentile values of the disabled group. The ninety-fifth percentile values of maximum arm grasp and arm reach from the wall in the disabled men was a little higher than the fiftieth percentile measures in the normal men. Elbow-to-elbow breadth did not follow this overall trend. The fifth and fiftieth percentile values of this dimension were a little higher in the disabled group than in the normal group, but the ninety-fifth percentile

Table 2. Correlation matrix of the body dimensions of normal individuals.

	(1)*	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1)*		0·54	0·18	−0·04	0·29	0·15	0·23	−0·02	0·07	0·09	0·48	0·21	−0·29	−0·15
(2)			0·46	0·11	0·35	0·26	0·58	0·32	0·16	0·1	0·52	0·42	0·17	0·17
(3)				0·28	0·41	0·55	0·52	0·7	0·3	0·24	0·03	0·24	0·23	0·26
(4)					0·38	0·32	0·08	0·22	0·18	0·09	−0·2	−0·24	0·06	0·16
(5)						0·1	0·06	−0·06	−0·13	−0·1	−0·04	−0·07	−0·09	−0·09
(6)							0·37	0·57	0·33	0·21	0·17	0·33	−0·11	0·12
(7)								0·65	0·42	0·44	0·51	0·43	0·05	0·09
(8)									0·42	0·4	0·12	0·23	0·16	0·25
(9)										0·86	0·27	0·22	0·03	0·11
(10)											0·27	0·21	−0·05	−0·11
(11)												0·57	−0·01	−0·05
(12)													0·17	−0·01
(13)														0·38

*The serial number of the dimensions corresponding to those in table 1.

Table 3. Correlation matrix of the body dimensions of disabled individuals.

	(1)*	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1)		0·08	−0·04	−0·22	0·0	0·27	−0·01	−0·22	−0·13	−0·3	−0·06	−0·2	−0·32	−0·001
(2)			0·83	0·17	0·27	0·07	0·42	0·13	−0·23	0·02	0·1	0·24	−0·19	−0·42
(3)				0·25	0·37	0·04	0·39	0·06	−0·05	0·11	0·08	0·23	−0·16	−0·13
(4)					0·61	0·0	0·08	0·16	0·2	0·26	0·18	0·22	−0·03	−0·01
(5)						−0·26	0·39	0·06	−0·07	−0·07	0·002	0·22	−0·11	0·04
(6)							0·07	−0·08	0·08	0·17	0·28	0·02	−0·01	0·37
(7)								0·5	−0·09	−0·21	0·07	0·29	−0·06	−0·28
(8)									−0·08	0·15	−0·18	0·22	−0·12	−0·55
(9)										0·75	0·1	0·08	0·21	0·4
(10)											0·1	0·17	0·19	0·07
(11)												0·36	0·44	0·5
(12)													0·17	−0·08
(13)														0·3

*The serial number of the dimensions corresponding to that of Table 1.

Table 4. Anthropometric measurements among normal Indian (NI), US civilian (USC) and British car drivers (BCD).

Measurements	5th percentile			50th percentile			95th percentile		
	NI	BCD	USC	NI	BCD	USC	NI	BCD	USC
(1) Body weight (kg)	45·0	58·0	58·0	53·3	73·3	75·0	66·6	94·1	98·0
(2) Stature (cm)	154·0	162·6	162·0	164·8	173·7	173·0	175·0	185·1	185·0
(3) Acromial height (sitting) (cm)	50·4	57·3	—	56·8	62·1	—	62·4	66·8	—
(4) Elbow rest height (cm)	17·6	—	19·0	20·9	—	24·0	26·4	—	30·0
(5) Popliteal height (cm)	38·9	—	39·0	42·4	—	44·0	47·4	—	49·0
(6) Buttock–knee length (cm)	51·3	56·3	54·0	54·5	61·1	59·0	58·4	65·9	64·0
(7) Buttock popliteal length (cm)	35·7	—	44·0	39·9	—	50·0	44·7	—	55·0
(8) Arm reach from wall (cm)	74·5	—	—	82·1	—	—	89·0	—	—
(9) Elbow-to-elbow breadth (cm)	30·7	—	35·0	37·9	—	42·0	44·0	—	51·0
(10) Hip breadth (cm)	25·4	33·6	31·0	30·5	37·3	36·0	34·7	42·1	40·0

value was lower. For the hip breadth dimension the fifth, fiftieth and ninety-fifth percentile values were lower in the disabled group. The fifth and fiftieth percentile values of hand breadth at thumb were found to be lower among the disabled persons, whereas the ninety-fifth percentile value was higher in this group. All the percentiles of hand thickness at metacarpal III were higher among the disabled persons. Correlation matrices for the dimensions of the normal and disabled groups are given in tables 2 and 3, respectively. The pattern of inter-correlations among the measurements was found to be different in the normal and disabled groups. Among 91 inter-correlations 38 were statistically significant in the normal group, whereas only 17 were significant in the disabled group. The highest correlation was observed between maximum arm grasp and arm reach for the normal group, but was between weight and stature for the disabled group. Also, the correlation between hand breadth at thumb and hand thickness at metacarpal III was lower in the disabled group than in the normal group. Significant correlation was observed between stature and maximum arm grasp of the normal group, but that of the disabled group was low and negative.

The data of the normal group obtained from the present study were also compared to those of British car drivers (BCD) (Haslegrave 1979, 1980) and the US civilian population (USC) (McCormick 1976); all the data are presented in table 4. Most of the values for the fifth, fiftieth and ninety-fifth percentiles of the normal group were found to be lower than those of the comparable measurements of the BCD and USC populations. The ninety-fifth percentile weight, buttock–knee length and hip breadth of the normal individuals were even lower than the fiftieth percentile BCD and USC population values.

4. Discussion

The results of this survey suggest that the growth of the lower extremities of the disabled subjects had been reduced as a result of their medical conditions, but the dimensions of the elbow-to-elbow breadth and hand breadth at thumb indicated a near

A disabled person with acquired deformity at the left elbow.

normal development of the upper extremities. This interpretation was contradicted to a certain extent by a significantly lower value of arm reach and maximum arm grasp and also a lower correlation value between these two dimensions in the disabled group. This contradiction could only be explained by the presence of concurrent deformity in the upper limb. In fact, most of the disabled men studied had acquired some deformity in the elbow and wrist joints (figure 1). Differences in the pattern of inter-correlation of the dimensions between the normal and disabled group indicates a distortion of bodily proportions.

5. Conclusions

The present study shows that the design of aids for disabled persons should be based on their anthropometric characteristics, which are different from those of the normal population. More detailed studies on the anthropometric characteristics of disabled persons are needed.

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Cet article rapporte une étude pilote consacrée aux caractéristiques anthropométriques des handicapés physiques en Inde et dont l'objectif est de faciliter la conception d'aides de déplacement. On a relevé 14 mensurations anthropométriques chez, d'une part, 61 hommes présentant des infirmités des membres inférieurs provoquées par la polyomyélite ou par des lésions de la moelle épinière et, d'autre part, chez 140 hommes normaux. L'étude rapporte une croissance amoindrie des membres atteints et également quelques déformations acquises dans les membres supérieurs. Les inter-corrélations entre les dimensions corporelles diffèrent entre le groupe des handicapés et le groupe des normaux.

In dieser Veröffentlichung wird eine Vorstudie zur anthropometrischen Charakteristik von Behinderten in Indien vorgestellt. Diese Studie erfolgte mit der Zielsetzung der Verbesserung der Gestaltung von Bewegungshilfen. Bei 61 Personen mit Behinderungen der oberen Extremitäten aufgrund von Kinderlähmund und Wirbelsäulenbeschwerden sowie bei 140 Nichtbehinderten, wurden jeweils 14 anthropometrische Werte gemessen. Die Studie zeigt eine Reduzierung der Größe der betroffenen Körperteile sowie eine Deformation der oberen Gliedmaße. Bei den Behinderten und Nichtbehinderten waren die Interkorrelationen zwischen den Körpermaßen differierend.

本論文は移動補助装置の設計を容易にするために実施されたインド人男性身体障害者の身体計測特徴の予備研究を述べる。ポリオまたは脊髄損傷による下肢の傷害を持つ61名の男性と14名の健常な男性に対して14の身体計測を行った。該当部の成長の停滞と上肢の後天的変形も見られた。身体計測値の相関は障害者と健常者では異なっていた。

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Evaluation of a sports specific training programme in badminton players

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We studied the effect of a short three week programme, dominated by specific training, on the aerobic capacity (VO_2 max) and ventilatory anaerobic threshold (VanT) of badminton players and also to evaluate the intensity of the specific training on the basis of heart rate and blood lactate concentration. The study was conducted on five women badminton players (age 13-14 yr; height 160-165 cm and weight 47.0-51.5 kg) who were semifinalists in the 1988 subjunior or junior national championships. The VO_2 max and VanT were determined at the commencement and at the cessation of the training. The VO_2 max was evaluated on an automatic analyser during a graded running protocol on a treadmill and VanT was determined by the gas exchange method from the VE-VO_2 relationship. The three week programme was dominated by specific training, apart from other conditioning programme. The mean VO_2 max was found to improve from 2.11 l/min (43.8 ml/kg/min) to 2.24 l/min (46.4 ml/kg/min), while the VO_2 at VanT improved from 1.48 l/min (30.8 ml/kg/min) to 1.68 l/min (33.7 ml/kg/min). The improvement in both was statistically significant. The mean heart rate and blood lactate concentration during the specific training were 161 b/min and 3.9 m*M*/l respectively while training with the shuttlecock and 185 b/min and 6.2 m*M*/l respectively during shadow practice. The findings indicated that the intensity of specific training was quite high, varying from aerobic-anaerobic transition level to aerobic overload region and was able to alter the VO_2 max and VanT of the players, even with a short precompetition training.

Elite badminton players adapt a high aerobic capacity (VO_2 max) through training (Mikkelsen, 1978, Int. Cong. Sp. Sc. Abstract, Alberta). Physical training which improves the cardio-respiratory fitness indicated by aerobic capacity (VO_2 max), has been reviewed extensively[1]. Scientists have used cycling, running or other aerobic type[1], interval type of training programmes[1-4] to observe the adaptation in the cardiorespiratory fitness. Recently, the anaerobic threshold component has gained importance, especially in continuous events, due to its correlation with endurance performance[5-7]. The importance of anaerobic threshold in nonconti-nuous intermittent games has been discussed elsewhere[8-10]. The anaerobic threshold is generally determined from blood lactate concentration where it increases steeply after a certain intensity of workload known as lactate threshold[11] or by the gas exchange method known as 'ventilatory threshold' estimated from the deviation point of VE-VO_2 linearity[12, 13]. It has also been reported[12-13] that ventilatory anaerobic threshold (VanT) is directly related and also caused by blood lactate threshold. While improvement in lactate threshold through physical training is evident[7], there are contradictory reports[14, 15] on the improvement in VanT for every sport there is a specific training to

Present address: Sports Authority of India, J.N. Stadium, New Delhi 111003 build up fitness of the players for that sport. Similarly, in badminton, there is a sports specific specialized training to improve the specific activity required for the game. In a short precompetition training camp, the sports specific training programme, dominates the physical conditioning programmes.

Hence, the main objectives of this study were to (*i*) investigate the effect of such a short (3 wk) training schedule, dominated by sports specific training, on the physiological variables, like VO_2 max and VanT level of a group of female badminton players in the age range of 13-14 yr; and (*ii*) quantify the intensity of the sports specific training, studying the heart rate, the blood lactate response and to observe the results in the adaptative process of the cardiorespiratory parameters in pubescent female badminton players.

Material & Methods

The study was conducted on five selected female badminton players (age 13-14 yr; height 160-165 cm; weight 47.0-51.5 kg) who were at least semifinalists in the subjunior or junior national championship in 1988. The study was conducted during a training camp held at Netaji Subhas National Institute of Sports, Patiala. The VO_2 max and VanT of each player were measured at the commencement of the training and immediately after the cessation of training. The VO_2 max was evaluated by analysing the expired air continuously on an automatic analyser (Erich Jaeger, FRG) during a graded running protocol on a treadmill. The initial speed of the treadmill was 6 km/h (1.66 m/sec), this was increased at the rate of 2 km/h (0.55 m/sec) every 2 min till exhaustion. The VanT was determined by gas exchange method from the VE-VO_2 linearity[10, 12, 13, 16].

The three week training schedule contained basic speed work (2 sessions/wk), basic endurance (1 session/wk), specific training on the court (6 session/wk) and singles game with technical corrections (6 sessions/wk). There were 3 sessions (morning, forenoon and evening). The morning session was for basic speed work, endurance work and specific training on the court (3 days in the morning session was devoted to singles game). The forenoon session (3 days) on three days contained teaching skill, technique and tactics. Each of these activities was preceded by a basic warm up of bending and stretching exercises. The endurance run contained 2.4 km slow run, the duration of which was 12-13 min. Basic speed work contained 60 m all out sprint, repeated 10 times with 1 min rest between each run and 3 sets were performed by each player. In between each set, 5 min rest was given. The evening game contained competitive practice with technical corrections.

Specific training on the court was a simulated activity of the game where a player had to run to strike the shuttle at different corners of the court starting from the middle and after striking, return quickly to midcourt (the starting zone). Each player had to perform three sets of 10 repetitions where the ratio of work and rest pause was 1 : 1 (1 min short burst of activity was followed by 1 min of rest). In between the sets, 5 min rest was allowed. Specific training on the court was divided into two parts, training with and without the shuttle cock (shadow practice), on alternative days. Intensity of the training schedule was evaluated by measuring the heart rate and blood lactate concentration, during training sessions. The heart rate was measured in all the training sessions with the help of sport tester PE 3000 computerized system (Polar Electro, Finland). The blood lactate was measured only during specific training on the court since the training programme was dominated by specific training schedule and our main objective was to evaluate the intensity of such sports specific training. The blood samples were collected from the finger tip within 2 to 2.5 min of the training activities. These were analysed in a standardised automatic lactate analyser (YSI, USA). Special care was taken to prevent contamination with sweat[17-19].

Statistical analysis is of the differences in the physiological variables, before and after training was done by using the paired 't' test.

Results

The pre and post training VO_2 max of the players are shown in Table I. The differences were found to be statistically significant ($P<0.05$). The improvement in the relative VO_2 max was, on an average, 6 per cent above the pretraining value. Of the 5 girls the VO_2 max had improved from 2 to 11 per cent in 4, while it remained unchanged in one girl. The VO_2 of each player at VanT before and after training are illustrated in Table II and the difference is significant ($P<0.05$). However, the improvement in VanT was from 7 to 12 per cent in all 5 girls. Even subject S3 whose VO_2 max remained unchanged as a result of training, had shown an improvement of 6.5 per cent in VanT.

Table I. Pre-and post-training values of VO_2 max in subjects undergoing sports specific training

Subjects	Pretraining VO_2 max		Post-training VO_2 max	
	l/min	ml//kg/min	l/min	ml/kg/min
S1	2.06	43.8	2.10	44.7
S2	2.04	42.5	2.23	46.4
S3	2.68	52.0	2.67	51.8
S4	2.06	43.8	2.29	48.7
S5	1.75	37.2	1.91	40.6
Mean	2.11	43.8	2.24*	46.4*
±SD	0.34	5.3	0.28	4.2

*$P<0.05$

Table II. Pre and post-training values of VO_2 at ventilatory anaerobic threshold in subjects undergoing sports specific training

Subjects	Pretraining VO_2 max		Post-training VO_2 max	
	l/min	ml/kg/min	l/min	ml/kg/min
S1	1.50	31.9	1.68	35.7
S2	1.24	25.8	1.37	28.5
S3	1.73	33.5	1.84	35.7
S4	1.55	32.9	1.68	35.7
S5	1.40	29.8	1.55	32.9
Mean	1.48	30.8	1.68*	33.7*
±SD	0.18	3.1	0.17	2.2

*$P<0.05$

The mean heart rate response of the players in each training programme and the blood lactate response in specific training programmes are shown in Table III. The heart rate and blood lactate responses during specific training without a shuttlecock (shadow practice) were higher ($P<0.05$) than during training with a shuttle.

Discussion

Physical training improves the VO_2 max[20]. The intensity of physical exercise is the most important factor in developing VO_2 max. A significant

Table III. Mean heart rate and mean blood lactate response of badminton players during each training item (Data are mean ± SD)

Training item	S1	S2	S3	S4	S5	Total
Warm up	124±10	104±13	136±14	129±16	138±16	126±17
Endurance run	181±12	161±7	191±9	180±21	203±12	183±12
Speed work	162±1	169±5	172±2	174±2	204±2	176±2
Specific training						
(a) With shuttle	153±5	153±11	160±4	165±10	177±5	161±7
Blood lactate (m*M*/l)	3.2±0.7	3.5±0.5	3.9±0.6	4.1±0.8	5.0±0.9	3.9±0.7
Rest pause	138±6	140±7	149±10	145±12	166±16	147±10
(b) Without shuttle	176±5	175±5	193±10	187±6	193±7	185±7*
Blood lactate (m*M*/l)	4.6±1.0	5.1±0.8	6.8±0.4	7.0±0.5	7.5±0.5	6.2±0.6*
Rest pause	157±9	156±11	174±14	165±12	182±8	167±10
Game practice	170±2	156±7	174±13	165±4	177±15	168±8

*$P<0.05$ as compared to training with the shuttle

improvement is observed at training intensities of 90-100 per cent of the maximum aerobic capacity[1] and of 80-95 per cent of the maximum aerobic capacity, when the training session is for a long duration (30-40 min)[2, 21]. The training schedule in this study was dominated by specific training on the court, where the intensities were 78 and 90 per cent of the maximum heart rate, with and without a shuttle cork, respectively. The movements became a little slow during specific training with the shuttle than without shuttle. This is evident from the significantly higher heart rate and blood lactate responses during training with and without a shuttle. Endurance training constituting continuous type of exercise can improve the VO_2 max in young adults[3]. But most effective is the intermittent type of exercise session[20]. Intermittent training results in higher increase in VO_2 max and maximal exercise capacity whereas continuous training improves the muscle oxidative capacity and delays the accummulation of blood lactate during maximum exercise[22, 23].

The specific training of badminton is intermittent in nature and the total duration for each subject was for 40 min. Three weeks of specific training, the intensity of which was 78-90 per cent of the maximum capacity (maximum heart rate) had improved the VO_2 max of 13-14 yr old female badminton players by 6 per cent.

Gaeser and Poole[15] did not observe any change in VanT of untrained persons as a result of 3 wk endurance training of continuous type at 70-80 per cent of the VO_2 max, whereas Poole and Gaeser[24] found significant change in VanT as a result of interval/intermittent training. Our results also indicate that intermittent/interval training can improve the VanT to a greater extent than the VO_2 max.

Quantification of training schedule is essential to assess the effect of a training programme on physiological variables. The objective assessment or quantification of training in sports can be done by studying the physiological variables[25], especially the heart rate and blood lactate[7, 10, 19]. The mean blood lactate levels during specific training were 3.9 mMol/l and 6.2 mMol/l, during training with and without shuttlecork, respectively. Blood lactate concentration of 3.9 mMol/l can be considered as lactate threshold level or anaerobic threshold level or aerobic to anaerobic transition level[7]. This level has also been identified as onset of blood lactate accumulation, (4 mMol/l; OBLA)[26]. Even the mean heart rate during this training (161b/min) corresponds to the anaerobic threshold heart rate of the badminton playing girls[10]. On the other hand, 6.2 m*M*/l blood lactate level during specific training without the shuttle-cork reveals aerobic overload region[27, 28]. Endurance training/interval training which elicits blood lactate concentration of 4-6 m*M*/l are considered as optimal level of training and the degree of improvement in such cases are observed to be more in the aerobic to anaerobic transition level than in VO_2 max[7]. In this study, the degree of improvement in the VanT level of the players was more than that of the mean VO_2 max with three weeks of a specific training programme. Our observation also support the observations of previous workers.

Our study shows that (*i*) the intensity of sport specific training in badminton is 78-90 per cent of the maximum heart rate of players. This elicits blood lactate response of 3.9-6.2 m*M*/l which corresponds to variation from anaerobic threshold level to aerobic overload region; (*ii*) the three week training schedule dominated by specific training in badminton is able to alter the VO_2 max as well as the Vant level of the players. The degree of improvement in the VanT level is more than in the VO_2 max; and (*iii*) in a precompetition training camp, coaches and sports scientists may depend on sports specific training to develop not only the skill but also the physiological variables. There may be no need for a separate conditioning programme to develop the latter.

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Aerobic-anaerobic transition level of Indian middle & long distance runners

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A study was carried out on 23 elite Indian runners (12 middle distance and 11 long distance runners) to assess the aerobic-anaerobic threshold level and also to compare them with international counterparts to enable the coaches and sports medicine specialists in using the anaerobic threshold (AT) concept more efficiently as a training tool in endurance events. The cardiorespiratory variables at maximum effort were determined during a graded protocol of running on treadmill, starting from 10 km/h and increasing every 2 min at the rate of 2 km/h till exhaustion. The AT was considered from the ventilatory threshold (VT) measured by non-invasive gas exchange method. The maximum aerobic capacity of Indian middle and long distance runners found to be 62.0 and 68.1 ml /kg/min, respectively, were significantly lower than those of their international counterparts. The mean VO_2 of the Indian middle distance runners at AT level was 49.9 ml/kg/min as compared to 58.0 ml/kg/min of the world class runners. The long distance runners also exhibited a lower VO_2 at AT level as compared to international runners. It is concluded that, as the AT level is a well established determinant in distance running performance and a significant improvement of maximum aerobic capacity (VO_2 max) may not be possible if the runners reach a plateau, more emphasis should be given to improve the AT level of Indian distance runners.

The maximum aerobic capacity (VO_2 max) is a determining factor in endurance events[1] and as a result of endurance training, distance runners acquire a high relative VO_2 max[2]. The aerobic-anaerobic transition level (the anaerobic threshold level) is considered an important parameter in sports and clinical medicine[3]. A high aerobic-anaerobic transition level reflects the high fractional utilization of oxygen for a long duration activity without building up of a significant amount of anaerobic metabolites. The regression coefficient between distance running performance and the anaerobic threshold variables are higher than the regression coefficient between VO_2 max and distance running performance[4-7], irrespective of whether the anaerobic threshold was determined from lactate threshold point[5] or was considered from ventilatory threshold point measured by non-invasive gas exchange method[8]. It has been reported[8,9] that ventilatory threshold may be coincident with and also caused by blood lactate threshold. Hence, studies on aerobic-anaerobic threshold variables together with VO_2 max would be of significance in endurance athletes.

This study makes an attempt to assess the aerobic-anaerobic threshold level of Indian elite middle and long distance runners and also to compare them with their international counterparts to enable coaches and sports medicine specialists to use the anaerobic threshold concept more efficiently as a training tool in endurance events.

Material & Methods

The study was conducted on 23 Indian runners (12 middle and 11 long distance) who were undergoing training at the Netaji Subhas National Institute of Sports, Patiala, prior to their participation in international championships. The runners were administered a graded running protocol on a motor driven treadmill. The initial speed was 10 km/h and this was increased after every 2 min at the rate of 2 km/h till exhaustion. The physiological variables, *viz.*, heart rate (HR), ventilation (VE), O_2 consumption (VO_2) and CO_2 production (VCO_2) were monitored on a computerized ergopneumotest (FRG) at 30 sec intervals. The maximal values of the physiological variables were considered from the following criteria: (*i*) the VO_2 had reached a plateau, *i.e.*, it did not increase more than 100 ml/min with a change in work load; (*ii*) heart rate reached a maximum of more than 180 beat min; and/or (*iii*) volitional intolerance of the work load[10,11]. VE (l/min, BTPS) of each runner were plotted against VO_2 (l/min, STPD) and the anaerobic threshold level of each runner was determined from the deviation point of VE-VO_2 linearity[8,9,11] (as has been shown in the Fig.). Statistical significance was tested by applying unpaired Student's 't' test.

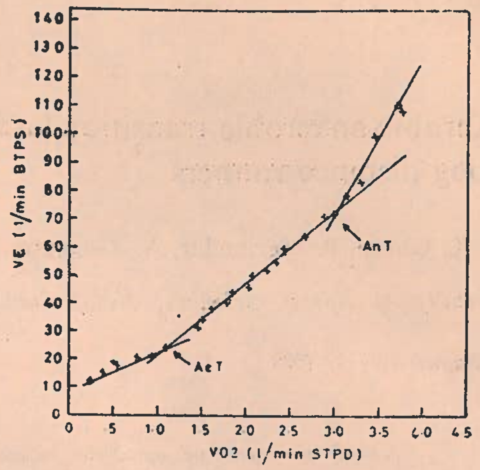

Fig. Determination of aerobic (AeT) and anaerobic (AnT) threshold from the deviation of ventilation (VE)-oxygen consumption (VO_2) linearity.

Results

The mean relative VO_2 max of the long distance runners (68.1 ml/kg/min) was significantly higher ($P<0.05$) than that of the middle distance runners (62.0 ml/kg/min). The long distance runners were comparatively shorter and younger ($P<0.05$) than their middle distance counterparts (Table I). When compared to the world class runners (Table I), both the middle and long distance runners in the present study exhibited significantly lower VO_2 max ($P<0.01$) than that of the runners studied abroad[12,13].

No significant differences existed in any of the physiological variables at anaerobic threshold (AT) level in middle and long distance runners, though the long distance runners revealed a higher relative VO_2 at AT than the middle distance runners (Table II). The physiological variables of the Indian

Table I. Comparative assessment of physical and physiological variables of runners at maximum effort (Data are mean±SD)

Subject	Ref. no.	n	Age (yr)	Height (cm)	Weight (kg)	VO_2 max (l/min)	VO_2 max (ml/kg/min)
Middle distance runners	Present study	12	25.3 ±3.0	176.2 4.7	63.1 4.3	3.89 0.44	62.0 6.1
Czechoslovakia	12	8	23.8 ±3.1	180.3 2.9	66.4 3.9	4.71** 0.33	70.9†
USA	13	5	22.0* ±1.5	—	71.9** 1.0	5.20†	72.4** 1.2
UK	11	10	18.0** ±1.1	176.3 4.2	63.0 5.2	4.78†	75.9** 3.0
Long distance runners	Present study	11	22.9 ±1.7	171.2 2.1	60.2 3.8	4.16 0.39	68.1 3.0
Czechoslovakia	12	7	24.1 ±3.2	176.0 2.7	62.0 3.4	4.64 0.40	74.8†
USA	13	8	21.4 ±1.0	—	64.5* 2.4	—	74.4** 1.3

P, * <0.05; ** <0.01; †SD not cited in original reference

Table II. Physiological variables of Indian and world class runners at anaerobic threshold level

Subject	Ref.	n	VO_2 (l/min)	VO_2 (ml/kg/min)	% VO_2 max	Heart rate (beats/min)
Middle distance runners	Present study	12	3.15±0.48	49.9±6.9	80.0±7.6	168.8±5.5
Czechoslovakia	12	8	3.90±0.20**	58.7†	82.8±3.9	178.1±6.0
USA	13	5		58.0±2.1**		
UK	11	10		62.2±3.8**	81.9±5.9	
Long distance runners	Present study	11	3.21±0.22	53.4±2.4	79.1±4.7	170.0±5.7
Czechoslovakia	12	7	3.96±0.27**	63.8†	85.3±5.1*	172.1±6.7
USA	13	8		62.2±2.1**		

P, * <0.05; ** <0.01; †SD not available middle and long distance runners at AT, when compared with those of their international counterparts[11–13], showed that the VO_2 of Indian runners at AT level were lower than those of the international runners (Table II).

Discussion

The long distance runners exhibited higher relative VO_2 max than middle distance runners, as in long distance running, a major source of energy is supplied through oxidative process[14,15]. This difference in VO_2 max between long and middle distance runners has also been reported earlier[12]. The middle distance runners in the present study revealed a relative VO_2 max of 62.0 ml/kg/min whereas 70-75 ml/kg/min has been reported in other studies abroad[10,12]. The relative VO_2 max of Indian long distance runners (68.1 ml/kg/min) is also much lower than that of elite international counterparts (74.4 and 74.8 ml/kg/min)[12,13]. Since VO_2 max is a test for assessing the running endurance, the distance runners who acquire a high VO_2 max will obviously be at an advantage. That VO_2 max improves with training but reaches a plateau at a certain time, whereas, distance running performance continues to improve has been observed[16–19]. A higher correlation between the AT and distance running performance indicates that a runner who is able to run with a high percentage of VO_2 max (closer to his maximum capacity), without building up a significant amount of anaerobic metabolites will certainly perform better[20]. This indicates that the VO_2 as well as the per cent VO_2 max at AT level is of much significance in distance running performance. The VO_2 of the Indian middle and long distance runners at AT level were 3.15 and 3.21 1/min (corresponding to 80.8 and 79.1% of the VO_2 max, respectively), while the world level middle distance runners' AT level is at 3.9 1/min (82.8% of VO_2 max). This signifies that the world class runners run the middle distance with a comparatively higher intensity utilizing a higher fraction of oxygen where the aerobic supply of energy is dominant over the anaerobic sources[15]. Though the per cent VO_2 max at AT level of the Indian middle distance runners is comparable to their international counterparts, the VO_2 at AT level of world class middle distance runners is significantly higher than that of the Indian runners. The fractional utilization of VO_2 max at aerobic to anaerobic transition point by the Indian long distance runners is also significantly lower than their international counterparts. The world class long distance runners utilize 85 per cent of the VO_2 max, whereas the Indian runners utilize only 79.1 per cent. The elite marathoners who utilize 86 per cent of VO_2 max, can complete a marathon within 2 h 15 min and those who utilize 75 to 80 per cent at marathon pace race, could complete the same within 2 h 30 min to 3 h[21].

The study reveals that the Indian middle and long distance runners exhibit a lower VO_2 max and anaerobic threshold level than the world class runners. Several studies have shown that even when the VO_2 max is not much increased significant improvement in AT level is possible, provided the training schedule is administered at AT[22]. Training below and above this level may not be adequate to improve upon the same AT. Significant improvement in VO_2 max may not be possible when the runner reaches a plateau. It is, therefore, suggested that more emphasis should be given to improve the AT level of Indian distance runners for betterment of their performance, as it is well established that AT level can be improved by training.

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Heart Rate and Blood Lactate Response in Competitive Badminton

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Summary: Ten junior national level (13–14 years of age) female badminton players having 3–6 years of training were studied to investigate the demands of the game on heart rate and blood lactate during competition. The mean $\dot{V}_{O_2max}$ and the anaerobic threshold level were 48.3 ml/kg/min and 66.3% of the $\dot{V}_{O_2max}$. Game analysis revealed that heart rates were higher in the second and third games than in the first game, whereas no difference was found in blood lactate concentration. Anaerobic threshold, heart rate, and total duration of the game indicated an anaerobic–aerobic time domain ratio of 3:1. We conclude that junior national level female badminton players attained optimum aerobic capacity and anaerobic threshold levels that could be improved later through further training, and dissimilar strain on the cardiovascular and anaerobic metabolic systems is possible due to the intermittent nature of the game. **Key Words:** Badminton—Heart rate—Blood lactate.

The demand or intensity of a game is generally studied either from the time–motion characteristics (1,2) or from physiological responses, e.g., heart rate, blood lactate, glycogen depletion and hormonal responses (3–5). Such studies on badminton are scanty and sporadic in the world literature. Coad et al. (6) reported that the oxygen consumption during recreational badminton was 2.52 L/min. In elite players, the blood lactate concentration during badminton never exceeded 5.7 mmol/L (7). The heart rate of players during a badminton singles game reached a near maximal value (8). All of the above studies concluded that badminton is a high intensity intermittent game. Moreover, for competitive situations, there are only a few such studies (7).

Presently, the anaerobic threshold concept is gaining more importance in continuous events, since this is well correlated with endurance performance (9–11). However, the interpretation of the anaerobic threshold concept in intermittent games is infrequent and only estimated (12,13). In the present study, the anaerobic threshold heart rate (AT_{hr}) and blood lactate responses have been used to investigate the demand or intensity of the game involving junior national level players in a competitive situation during a selection trial, prior to an international competition. The study should guide trainers in monitoring a long-term training program, emphasizing the workload required during training sessions.

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MATERIALS AND METHODS

Ten Indian female badminton players (14–16 years age) who had been involved in junior national level competition and had experience of 3–6 years extensive training participated in the present study. The study was conducted in a precompetition training camp held at Netaji Subhas National Institute of Sports, Patiala, India, in two phases.

In phase 1, the maximum aerobic capacity ($\dot{V}_{O_2max}$) of the players was determined in the laboratory, using a graded running protocol on a treadmill until exhaustion. The initial speed of the treadmill was 1.66 m/s (6 km/h) and was increased at the rate of 0.55 m/s (2 km/h) every 2 min. The heart rate (HR), oxygen consumption ($\dot{V}_{O_2}$), carbon dioxide production ($\dot{V}_{CO_2}$), and ventilation ($\dot{V}_E$) were monitored continuously on a standardized automatic analyzer (Erich Jaeger, Wuerzburg, Germany) at 30 s intervals. The anaerobic threshold is generally determined from the blood lactate concentration when it is increasing steeply after a certain intensity of workload (14) or by the gas exchange method from the deviation point of $\dot{V}_E$–$\dot{V}_{O_2}$ linearity (15,16). In the present study, the anaerobic threshold level of each player was determined from the gas exchange method. An example from an experimental subject included in this study is shown in Fig. 1. The HR at this level was considered to be anaerobic threshold heart rate (AT_{hr}). Previous studies have supported that the ventilatory anaerobic threshold coincides with and is caused by the blood lactate threshold (14,15,17).

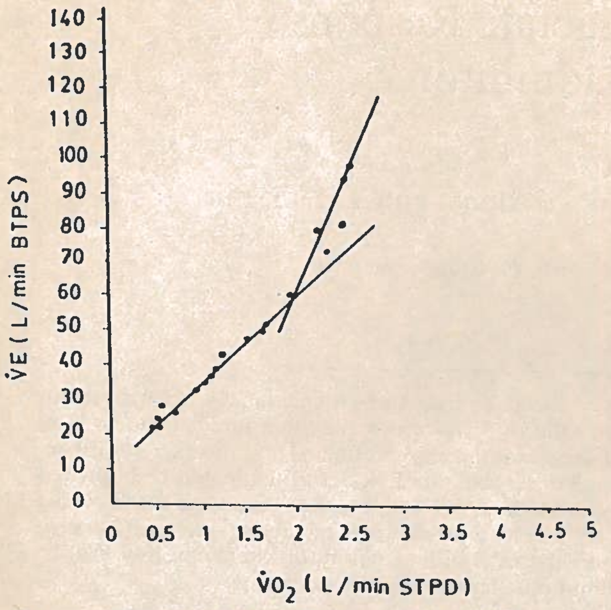

FIG. 1. Determination of anaerobic threshold by the gas exchange method.

In the second phase of the investigation, the HR of each player was measured continuously at 5-s intervals during a singles game in the selection trial by a telemetric device, Sport Tester PE 3000 system (Polar Electro, Kempele, Finland), which included a microcomputer for further analysis.

After each game, a blood sample was collected from the finger tip and blood lactate was analyzed in a standardized automatic lactate analyser (YSI, Ohio, U.S.A.). Special care was taken to prevent contamination from sweat and to encourage rapid circulation to the finger prior to sampling. A similar technique was followed by previous researchers (18–20).

A total of 25 matches were analyzed, of which 14 ended in two games, while the remaining 11 matches were extended to three games. In total, 61 games were analyzed. The percentage dominancy of both the aerobic and anaerobic component in a game were determined from the duration for which the HR was below and above the AT_{hr}, from the heart rate at 5-s intervals derived by the microcomputer. A graphical example of the response of the HR in an experimental subject is shown in Fig. 2.

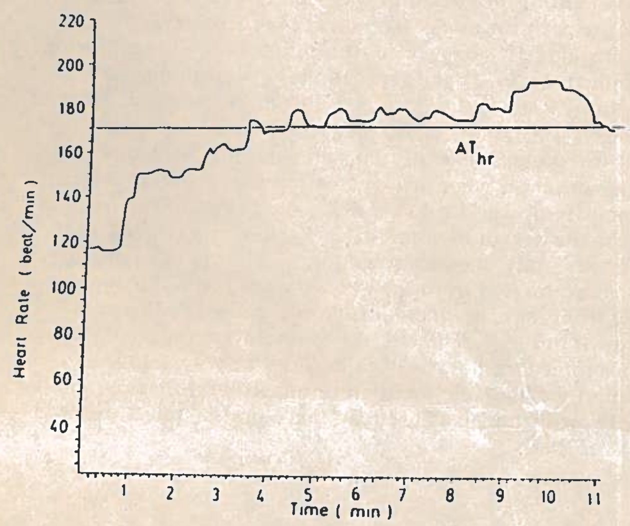

FIG. 2. Response of heart rate during playing singles badminton. AT_{hr} denotes the anaerobic threshold heart rate.

TABLE 1. *Physical characteristics of female badminton players*

Variables	Present study	Indian seniors (13)	World class (7)
n	10	4	9
Age (years)	15.2 ± 0.9	22.8	—
Height (cm)	163.0 ± 5.1	159.8	—
Weight (kg)	48.6 ± 5.4	51.4	—
$\dot{V}_{O_2max}$			
L/min	2.32 ± 0.82	2.64 ± 0.32	3.00
ml/kg/min	48.3 ± 5.5	51.4 ± 6.7	52.9

RESULTS

The mean and standard deviation values of physical characteristics of Indian badminton players are shown in Table 1. The mean $\dot{V}_{O_2max}$ of the present players was 2.32 L/min (48.3 ml/kg/min) and was comparable to that of the highly experienced Indian female players (2.64 L/min; 51.4 ml/kg/min) (13). The reported value of top Swedish female players was higher (3.0 L/min; 52.9 ml/kg/min), as reported by Mikkelsen (7). In Table 2, the physiological variables, like $\dot{V}_{O_2}$ and HR, of the present players at the anaerobic threshold level have been illustrated and compared to those of the highly trained senior female players (13). No statistically significant difference existed between them.

The mean HR, blood lactate concentration, and mean duration of the games along with the analysis of HR in aerobic and anaerobic dominant regions (below and above the AT_{hr}) are shown in Table 3. The duration of the first, second, and third games were 10.8, 9.3, and 10.2 min, respectively (11 point game). The heart rate in the first, second, and third games were in the anaerobic dominant region to the extent of 71.1%, 78.8% ($p < 0.05$) and 79.2% ($p < 0.05$) of

TABLE 2. *Physiological variables of female badminton players at AT*

Variables	Present study	Indian seniors (13)
n	10	4
$\dot{V}_{O_2}$ at AT		
L/min	1.56 ± 0.22	1.64 ± 0.19
ml/kg/min	31.8 ± 4.9	32.1 ± 4.1
% $\dot{V}_{O_2max}$	66.3 ± 6.6	62.3
HR (beats/min)	164.6 ± 5.6	159.3 ± 9.4

AT, anaerobic threshold; HR, heart rate.

TABLE 3. *Heart rate, blood lactate, and time domain in aerobic–anaerobic component in singles badminton with duration of game*

Variables	Game 1	Game 2	Game 3	Total
n	25	25	11	61
Heart rate (beats/min)	159.5 ± 11.3	170.6 ± 8.7*	179.4 ± 8.2*	169.8 ± 9.7
Blood lactate (mmol/L)	4.37 ± 0.61	4.00 ± 0.80	4.18 ± 0.56	4.18 ± 0.67
Total duration (min)	10.8 ± 4.3	9.3 ± 3.5	10.2 ± 3.5	10.2 ± 3.7
Aerobic component (%)	28.9 ± 8.9	21.2 ± 12.9*	20.8 ± 8.8*	24.6 ± 11.0
Anaerobic component (%)	71.1 ± 8.9	78.8 ± 12.9*	79.2 ± 8.8*	75.4 ± 11.0

* Game 1 vs. game 2 and game 1 vs. game 3, $p < 0.05$ (Student's t test).

total duration, respectively. The mean heart rates in the second and third games were significantly higher ($p < 0.05$) than the first game. However, no significant difference was observed in blood lactate concentration in the three games. The mean heart rate and blood lactate of the total three games were 169.8 beats/min and 4.18 mmol/L, respectively.

DISCUSSION

The relative aerobic capacity ($\dot{V}_{O_2max}$) of the present Indian junior female players was comparable to the senior players, but lower than the world class athletes (Table 1). Even the mean $\dot{V}_{O_2max}$ of outstanding junior tennis players (mean age = 15.8 years) was 48.0 ml/kg/min (21), which was almost the same as that of the present junior female badminton players. This indicates that the present junior players, with 3 to 6 years of training experience, have attained an optimum level of aerobic capacity that can be improved later through additional training.

The ventilatory anaerobic threshold in normal untrained subjects was seen at 50–60% of the $\dot{V}_{O_2max}$ (22), whereas in athletes involved in continuous events, it appeared at more than 70–80% of the $\dot{V}_{O_2max}$ (23). In sportsmen involved in intermittent games like table tennis, ice hockey, and football, the AT was at 59.4, and 56.1, and 66.2% of the $\dot{V}_{O_2max}$, respectively (23). In the present study, the AT in female junior badminton players was observed at 66.3% of the $\dot{V}_{O_2max}$, which is comparable to other players in intermittent games.

Analysis of the heart rate in all of the games ($n = 61$) revealed that in 75% of the total duration of the game, heart rate remained above the AT level but the blood lactate concentration did not show a very high value, i.e., 4.18 mmol/L (Table 3). Mikkelsen (7) also observed a blood lactate value of not more than 5.7 mmol/L in elite Swedish badminton players. This may be due to the intermittent nature of the game, where during pauses between rallies some amount of lactate clearance is possible. Even in the present study, no significant variation in the lactate value in subsequent games were observed although the mean heart rates were significantly higher in the subsequent second and third games (Table 3), which indicated a dissimilar response of the cardiovascular system and anaerobic metabolic system. A higher heart rate in the subsequent second and third games may be one of the reasons for fatigue, while mean lactate values of 4.0 and 4.18 mmol/L in the second and third games, respectively, cannot be considered to be an indication of fatigue. Previous study of Astrand et al. (24) also indicated that in vigorous intermittent types of activity on a bicycle ergometer, with an activity and rest ratio of 1:2, the blood lactate concentration was 7 mmol/L at 10 min but decreased at 20 min and varied little thereafter. In the present study, the activity and rest pause duration was not evaluated. However, Coad et al. (6) observed a 1:2 ratio between activity and rest during recreational badminton.

In intermittent types of activity, the blood lactate level may not increase subsequently, if the intensity remains the same. In soccer, Ekblom (3) reported that in the first half, the mean blood lactate value was approximately 9.7 mmol/L and in the second half it was 9.0 mmol/L, although the heart rate in the second half remained very frequently in the maximum region. Heller et al. (25) observed that in six repetitions of a 15 s rest, the blood lactate concentration was 8 ± 2 mmol/L and the half-time of lactic acid decrease (LA $t_{1/2}$) was 14 to 20 min. If LA $t_{1/2}$ takes 14–20 min, then we think that in badminton the LA_{max} never reaches a very high level. Frequent movements for a prolonged duration with rest pauses in between may not exert much stress on the anaerobic metabolic system, but may affect the heart rate. During short bursts of movement, although the heart rate reaches a high level depending on the intensity of the movement, in rest pauses or between the rallies it decreases. Again, in the later part of the game, when movements become more frequent, the heart rate response becomes near maximal (Fig. 2) and the recovery of the heart rate is also not very fast. Similarly, during short bursts of movement in badminton, the blood lactate increases, but between the rallies, shuttling of the lactate from blood to the muscle is possible rather than a recovery of lactate. It also should be noted here that the duration of female badminton is less than male badminton as well as other intermittent games like soccer. The concentration of blood lactate during intermittent activity may also depend on the duration apart from the intensity. Moreover, the mean heart rate of the players in the present study during a total of three games (169.8 beats/min) was almost similar to the mean anaerobic threshold heart rate (164.6 beats/min). Hence, a mean blood lactate concentration of 4.18 mmol/L in the present investigation was obvious in junior level female players.

The present study highlights the following: (a) The Indian junior national level female players of 14–16 years of age and having 3–6 years of training experience have attained an optimum level of aerobic capacity and can improve that later through training. (b) The anaerobic threshold level of junior female badminton players was observed at 66.3% of $\dot{V}_{O_2max}$ and this anaerobic threshold concept can be used in investigating the intensity of the game for scheduling the training process. (c) In badminton, dissimilar strains on cardiovascular and anaerobic metabolic systems are possible due to the intermittent nature of the game. Higher HR responses in the subsequent games may be one of the reasons for the resulting fatigue in badminton.

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Anthropometric analysis of tricycle designs

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A comparison of the designs of two types of tricycles available in India for the use of persons with severe both-lower-limb disability was made from the viewpoint of the anthropometric characteristics of the users. It was noted that neither design was compatible with the disabled persons' anthropometric dimensions in a number of ways. The seats did not provide for comfortable sitting. Although the hand crank was relatively well positioned in one, the distance of the crank from the back rest obliged the users to bend forward while driving their tricycles. The study concluded that suitable modifications in the dimensions of the tricycles are required to provide greater comfort, safety and ease of operation.

Keywords: Anthropometric characteristics, invalid carriages, disabled people

Introduction

People with severe handicaps of both lower limbs that preclude standing and walking may use hand-cranked tricycles for outdoor locomotion, especially in the developing countries, like India, where economic considerations restrict the use of motorised wheelchairs. Although tricycles are used by a large proportion of such handicapped people in India, their scientific evaluation leading to further cost efficient developments is scanty. The following is an attempt to explore the compatibility of tricycles with users from the viewpoint of anthropometry.

Materials and methods

Investigated materials

Variations in the design of the tricycles available for the use of the handicapped were observed in the different States of India. Of the two main varieties, one has the arm crank assembly in the middle front position of the user (Type A, Fig. 1), while the other type has one crank either on the right or the left of the user (Type B, Fig. 2). In the Type A tricycle, steering is achieved by turning the crank assembly itself, which is fixed to the shaft attached to the front wheel; in Type B this is done by a separate steering rod or wheel. The Type A tricycle only is commonly available in the State of West Bengal while Type B tricycles are commonly available in the States of Maharastra, Gujarat and Delhi. The present study considered both types for evaluation.

Subjects investigated

Selective anthropometric measurements were made on 61 male lower-extremity disabled subjects habitually using tricycles for locomotion. As the users of the tricycles are mostly paraplegics who had been affected with poliomyelitis or spinal injury, all the subjects in the disabled group were chosen from young adult persons with such disabilities only.

Investigation methods

Standard anthropometric measurements were taken with Martin's anthropometer, spreading calipers and steel tape. Measurements were taken following the definitions in Damon *et al* (1966). Stature was measured with the subjects standing

Fig. 1 Type A tricycle

Fig. 2 Type B tricycle

against a wall. The elbow-to-elbow breadth and hip breadth were taken with the subjects sitting in a relaxed comfortable posture. The various dimensions of the tricycles were measured with callipers and tape.

Discussions

Means and standard deviations of different dimensions of the two types of tricycles have been given in Table 1. Means and standard deviations of the ages and of the anthropometric measurements of the disabled persons have been tabulated in Table 2. In addition, the 5th, 50th and 95th percentile values of the anthropometric measurements also have been given.

Analysis of the tricycle seat

Seats and sitting have been extensively investigated in ergonomics. A number of studies have been made to define the anatomical and physiological principles of seat design (Floyd and Roberts, 1958; Damon *et al*, 1966; Grandjean *et al*, 1973). The following analysis of the tricycle seats was made according to the principles of seat design enunciated through such studies.

Seat height

It has been indicated that undue pressure underneath the thighs hampers circulation in the legs and causes discomfort. To avoid such problems it is better to select the seat height approximately 2·5 cm less than the popliteal height. As much as 95% of the population can be covered by selecting the 5th percentile value of popliteal height; but such a seat height can cause some difficulty for taller people. To compensate for this difficulty, researchers have favoured adjustable seat heights (McCormick, 1976).

In the present study the means of the seat heights in Types A and B tricycles were 27·6 and 35·3 cm respectively. The 5th and 95th percentile popliteal heights of the disabled group were 34·3 and 46·5 cm respectively. The seat height of the Type B tricycle was 2·4 cm less than the 50th percentile popliteal height of the disabled group. So a Type B tricycle could comfortably accommodate 50% of the disabled population, whereas Type A had a seat height much too low, even for the 5th percentile disabled persons.

Seat width

This dimension is determined from hip breadth. The recommendation states that the seat width should be sufficiently greater than hip breadth to allow for some lateral movements. The 95th percentile value should be considered to accommodate the greater proportion of the population. Taking into account the possibility of rest pauses in between the driving spells, and the use of the seat for resting, 95th percentile of hip breadth in a comfortable sitting posture was considered. Mean seat widths of the Types A and B tricycles were found as 42·4 and 41·1 cm

Table 1: Dimensions of tricycles used for evaluation (cm except for last column)

Type of tricycle	Seat width	Seat depth	Back rest height	Seat to foot rest height	Foot rest to ground	Crank centre to back rest	Vertical height of crank centre from seat	Length of the crank arm	Length of the crank handle	Weight of the tricycle (kg)
Type A										
Mean	42·4	33·3	34·9	27·6	32·9	60·5	21·0	13·2	10·5	65·0
± SD	4·3	4·2	8·0	4·4	8·2	4·4	2·1	2·5	0·9	10·8
Type B										
Mean	41·1	41·1	40·3	35·3	18·3	56·4	44·5	17·7	12·2	52·0
± SD	6·5	6·5	1·5	5·0	5·0	9·4	1·2	0·7	1·2	8·5

Table 2: Anthropometric measurements of disabled subjects relevant to tricycle design

Dimension		Mean	SD	Percentiles 5th	50th	95th
1. Age (yr)	:	24·4	3·8	–	–	–
2. Weight (kg)	:	41·4	5·4	–	–	–
3. Stature	:	139·2	17·5	110·0	141·0	163·3
4. Acromion height sitting	:	47·4	6·9	33·0	48·1	56·4
5. Elbow rest height	:	18·1	2·3	13·6	18·3	21·3
6. Popliteal height	:	38·4	3·4	34·3	37·7	46·5
7. Buttock-knee length	:	48·4	2·7	45·4	48·2	54·0
8. Buttock-popliteal length	:	39·9	2·8	35·7	39·9	44·7
9. Maximum arm grasp	:	67·9	5·7	57·4	67·3	76·2
10. Arm reach from wall	:	79·9	5·0	69·4	77·9	87·4
11. Elbow-to-elbow breadth	:	38·3	2·7	33·4	38·2	43·4
12. Elbow-to-elbow breadth (comfortable)	:	47·2	4·4	39·9	46·9	55·8
13. Hip breadth	:	28·4	2·2	24·4	28·4	33·4
14. Hip breadth (comfortable)	:	28·8	2·4	25·4	28·2	33·4
15. Hand breadth at thumb	:	9·4	1·4	7·0	9·3	11·7
16. Hand thickness at metacarpale III	:	2·4	0·1	2·2	2·5	2·9

All the measurements are expressed in centimetres, except age and weight

respectively. These widths were sufficiently larger than the 95th percentile reference hip breadths of the disabled users to allow adequate lateral movements and were therefore satisfactory.

Seat depth

It has been stated that adequate clearance should be kept between the back of the calf and the front of the seat to avoid discomfort due to pressure behind the knee by the edge of the seat. Therefore, buttock-popliteal length becomes the determining dimension of seat depth. It has been stated that the clearance should be between 9 and 19 cm behind the knee joint. To accommodate a larger proportion of the population it is better to consider the 5th percentile value of buttock-popliteal length.

Means of the seat depths of the Types A and B tricycles were found to be 33·3 and 41·1 cm respectively, whereas the 5th percentile of the buttock-popliteal length of the disabled group was 35·7 cm. The 95th percentile of this dimension was found to be 44·7 cm. If, according to the recommendations, a clearance of 9 cm between the front edge of the seat and the popliteal space is taken, the seat depth of Type A tricycle is compatible with less than 50% of the population and that of the Type B becomes incompatible for about 100% of the population.

Back rest

It has been suggested that the back rest should be rigid, gently rounded and spring loaded to support the trunk weight. It has been recommended that the support is most effective if the rest is positioned between 7 and 20 cm above the seat surface. It has been found that most people prefer a seat inclination of 25–26° and the back rest inclination of 105–108° with the horizontal plane, while resting.

Back rest heights of the tricycles were 34·9 and 40·3 cm for Types A and B cycles respectively. There were no spaces in between the seat surface and back rest on both models, not allowing any ventilation in the back, making prolonged sitting uncomfortable. In the case of the Type A tricycle, neither the seat nor the back rest were inclined to the horizontal and vertical planes respectively as required for comfortable sitting. In the Type B tricycle, although the seat was horizontal, an inclination of the back rest was present.

Arm rest

It has been suggested that arm rests should be at such a level as to make the arms hang freely and for the elbows to rest in a natural position. The determining dimension of the arm rest is elbow height. However, the arm rests do not have to interfere with the cranking action.

In both models no arm rests were provided.

Analysis of the position of the crank

It has been stated by earlier researchers that the efficiency of cranking is highest when the axis of the crank assembly is at about the heart level and when both arms could be used simultaneously (Nag *et al*, 1982; Schnauber & Muller, 1970). The heart level is generally considered as a height approximately 10–12 cm below the acromion process. It was observed that the mean acromion height of the disabled people was 47·4 cm. The position of the crank centre should therefore be between 35·0–37·0 cm above the seat surface. From Table 2 it is evident that in Type A tricycles the crank centre is situated at 21·0 cm above the seat surface, whereas in the Type B tricycles the crank centre is situated at 44·5 cm above the seat surface. Hence it is seen that while the position of the crank of the Type A tricycle was much lower with respect to the heart level, that of Type B was much higher. Since arm position at much higher than heart level is more fatiguing than otherwise, Type A tricycles afford an arm position which was more advantageous than that in Type B cycles.

Analysis of the distance of the crank from the back rest

Regarding the pushing and pulling forces of the upper extremities, data are not available for the Indian population. Damon *et al* (1966) have suggested that, while sitting higher, pushing and pulling forces be exerted horizontally at a distance of 59 cm in front of the back rest, by the 5th percentile of average persons. It has also been stated that pushing force is maximum at 180° elbow angle, while the pulling force is maximum at 150° elbow angle (Damon *et al,* 1966). During cranking, the position of the crank should be such that angles between 180° and 150° at the elbow joint can be sustained, so as to obtain maximum pushing and pulling force respectively (Fig. 3). However, to get an elbow angle of 180°, the superior extremity should be completely extended. It was observed that the maximum arm grasp of the disabled people was 57·4 cm and the distance of the crank handle at a position furthest removed from the user was 73·7 and 74·1 cm for Types A and B tricycles respectively. Due to the positioning of the crank so far in front, the users of both tricycles are unable to use the back rest while driving and are obliged to bend forward while cranking. Not only is this fatiguing but long years of use of these aids, which obliges the user to adopt such an abnormal posture, may even lead to secondary deformities of the back.

Conclusions

From the above discussions it may be concluded that neither of these two commonly available models of tricycles is suitable for comfortable and efficient use by disabled people, though a few of the dimensions of the cycles were found compatible with the users' anthropometric measurements. The study proposes the following modifications to the present designs to suit the disabled people better:

1. The arm crank should be provided in the middle front position of the users, as in the Type A tricycle.

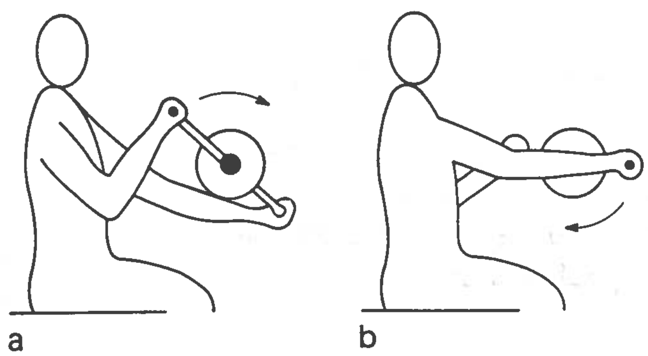

Fig. 3 Ideal position of the crank assembly and position of the two limbs at maximum flexion (a) and complete extension (b) shown diagrammatically

2. The distance of the crank centre from the back rest should be adjustable. The range of adjustment should be between the 5th to 95th percentile value of maximum arm grasp of the population minus the length of the crank arm so that each user may fix it firmly in a position which allows the full extension of his elbow when the crank arm is furthest away from his body, and the use of the back rest to assist in counteracting cranking thrust.
3. The seat width of the tricycle seat should be 5–10 cm greater than the 95th percentile value of hip breadth of the disabled in individuals.
4. The seat depth should be adjustable in the range of the 5th to 95th percentile value of buttock-popliteal length of the population. This adjustment can be done by making the depth equal to the 95th percentile value of the buttock-popliteal length minus 9 cm, or from our measurements about 38 cm. A strip of seat 9 cm wide at the front edge may be hinged in such a way that it could be folded up and kept bolted below the seat to accommodate people with measurement in the 5th percentile range.
5. Instead of making the seat height adjustable, it would be better to provide a foot rest whose height may be adjustable in the range between the 5th and 95th percentile values of the disabled group. It will be preferable to fix the foot rest about 5–10 cm in front of the vertical plane from the front edge of the seat.
6. A good support for the back should be provided. The support should be available for the whole of the upper back including the head as disabled people sometimes have problems of balancing the body and the head in the vertical plane. It may be better to allow an opening of 10–15 cm between the seat surface and lower edge of the back rest for ventilation and for accommodating the buttocks. Holes in the back rest surface may be drilled also to allow ventilation to the back.
7. Suitable arm rests should be provided. It would be preferable to make the arm rests so that they may be adjusted between the 5th and 95th percentile values of the elbow height of disabled people.
8. Height of the foot rest from the ground should be as low as practicable to allow easy mounting and getting down.
9. For safety purposes a hand brake should be provided. The position of the hand brake as fitted in Type A tricycles would be better.
10. The total weight of the tricycles should be reduced as far as practicable to reduce the strength required to drive the tricycle.

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