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THE EFFECTS OF ANTHROPOMETRIC PARAMETERS
ON A STEP ERGOMETER TASK IN CHILDREN

by

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Thesis presented in partial fulfillment of
the requirements for the degree of Master of Science
in Kinanthropology

University of Ottawa

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ABSTRACT

The present study was conducted to determine the effect of leg length relative to stepping height on a standardized bench stepping exercise with respect to relative oxygen consumption, heart rate and minute ventilation. Thirty male subjects aged eight to twelve (mean age 10.1 years) participated in the study.

Alterations in stepping pattern for three successive tasks were produced by varying platform height according to fixed percentages (30,40 and 50 percent) of leg length while maintaining a constant exercise load. Results indicated that there were no significant intraindividual differences in relative oxygen consumption, heart rate and minute ventilation among the three bouts of exercise. As well, the correlations among the physiologic measurements at the three specified stepping conditions reflected a low degree of interrelationship.

Individual differences in anthropometric parameters of knee joint angle, leg length and a leg length to weight index were further assessed for their possible effects on interindividual physiologic responses. To this end, two groups of 10 subjects were formed by comparing the top third and bottom third of the original sample according to the selected anthropometric measurements. No significant differences were revealed between groups except for minute ventilation, which was higher ($p = 0.01$) for the longer legged subjects according to the leg length classification, and for those subjects having a low index in the leg length to weight index classification. Results further indicated that when subjects were classified on the basis of leg length, the shorter legged individuals,

although working at higher rates of stepping compared with their longer legged counterparts, were not at a physiologic disadvantage.

It was concluded that with respect to stepping height, leg length did not appear to influence the physiologic responses of the subjects, at least not at the intensities of effort employed in this study.

Stepping ergometer, leg length, standardized exercise, positive external work

INTRODUCTION

The development of valid and reliable tests of physical fitness for children remains an area of concern for fitness and health specialists. Over the past decade, much emphasis has been devoted to the study, measurement and development of cardiorespiratory fitness (aerobic power) in adults. More recently, a need has been identified by various agencies for valid field tests of aerobic power specifically for young children.

One traditional test that has commanded favorable acceptance has been the step ergometer exercise. The economy, mechanical simplicity and administrative ease of this test has led it to be extensively employed in both submaximal and maximal tests of cardiorespiratory fitness in adults. However, certain criticisms pertaining to the validity and reliability of traditional step ergometer tests have been raised (Miyamura et al., 1975; Cardus, 1978). One contributing factor to this controversy appears related to conflicting evidence linking anthropometric parameters (particularly leg length) to exercise performance and physiologic efficiency in both adults and children.

Miyamura et al. (1975) indicated that anthropometric parameters such as leg length did not influence performance on a step-test. However, the total amount of work for the 13 and 14 year old boys in this study was not held constant as they did not vary stepping rate for different heights of bench. In addition, only pulse recovery scores were utilized as the criterion in their assessment of leg length on performance.

Similarly, Howe and Collis (1973) determined that leg length had no bearing on stepping performance in college-aged males. In this study,

however, no attempt was made by the investigators to vary the height of the bench to accommodate subjects of varying stature and leg length. In addition, gas analysis was not conducted in the above two studies to verify physiologic efficiency, the authors relying only on post-exercise heart rate indices to determine the effect of stepping height to overall leg length.

The one study that determined oxygen consumption (VO_2) patterns to assess intraindividual physiologic differences was that of Shahnawaz (1978). He investigated the oxygen consumptions for 7 modes of stepping at a fixed rate of work expressed in the study as 10 meters/min. It was found that stepping height relative to leg length was a significant factor since intraindividual differences in VO_2 among the modes of stepping were readily detected. The author concluded that for most individuals, optimal working efficiencies would be achieved with subjects stepping at heights of approximately 50% of leg length in any comparable stepping exercise.

Based on these data, Harrison et al. (1980) adapted the step test nomogram of Margaria et al. (1965), modifying the exercise by utilizing a platform height adjusted to fifty percent of their subjects' individual leg lengths. Correlations between the predicted $\text{VO}_{2\text{max}}$ (corrected step height) and the directly measured treadmill $\text{VO}_{2\text{max}}$ in 9 adult males were substantially higher, $r=.91$ than for the fixed height (uncorrected) test, $r=.64$.

From the above findings, it appears that conflicting evidence exists with respect to the influence of leg length on stepping performance. This influence, however, could be potentially greater in children where anthropometric characteristics can vary greatly even

among children of the same chronological age (Kramer et al., 1969; Funakawa, 1973; Tanner, 1981).

Therefore, the purpose of the present study was to determine the importance of leg length in children relative to stepping height in a standardized bench-stepping exercise on selected physiologic variables, ie. relative $\dot{V}O_2$, heart rate and minute ventilation. More specifically, intraindividual physiologic differences were assessed by variations in the pattern of stepping for three successive tasks. This was accomplished by correspondingly adjusting stepping height and stepping frequency, thereby maintaining a constant exercise load in all cases.

A further purpose of the study was to assess the extent to which individual differences in knee joint angle, leg length and a leg length to weight index would influence intersubject responses on the selected physiologic variables.

METHODS AND MATERIALS

Subjects

Thirty boys eight to twelve years of age (mean age 10.1 ± 1.2 years) participated in the study. Their physical characteristics are shown in Table 1. Informed consent was obtained from the children's parents prior to participation in the experiment. The subjects were physically fit athletic individuals being competitive cross-country skiers, hockey players or gymnasts. All subjects were asymptomatic of any illness or injury throughout the phases of the study. They performed the stepping tasks dressed only in a light pair of shorts and socks.

Procedures

Anthropometric measurements

Prior to the stepping exercise, anthropometric measures (height, weight, overall leg length and relative segment lengths of the right leg) were recorded. Overall leg length was measured as the vertical distance between the top of the greater trochanter and the base of the foot. The anatomic landmark employed to identify the upper limit of the lower leg segment was the top portion of the head of the fibula as determined by palpation. The lower limit was the base of the foot. The difference between total leg length and the length of the lower leg segment was taken to represent the length of the upper leg segment.

Calculation of knee joint angle

Upon completion of each experimental session, individual knee joint angles (at adjusted heights of bench) were calculated trigonometrically (for details, see Appendix B). The basic assumption in the mathematical model was that the heel of the subject's foot was placed on the edge of the step; the lower limb creating a 90° angle with the platform.

The angle between the upper and lower leg segments as calculated obviates the possibility of subjective error in physical measurement utilizing a double armed goniometer. However, to verify the accuracy of the model, the calculated angles were compared to goniometer measurements in five subjects at three separate heights of bench. Physical measurements supported the accuracy of the model; being within $\pm 3^\circ$ for all comparative observations.

A limitation inherent in either approach, however, is that they

represent fixed, essentially idealized conditions. Neither technique can fully account or compensate for possible variations in a subject's movement pattern throughout the duration of exercise. Therefore, these values should be regarded merely as approximations of the actual knee angles generated by subjects upon step up.

Experimental protocol

To control for leg length, a stepping task modified from the design of Shahnawaz (1978) was devised. Subjects were matched for stepping height by having them work at heights expressed as fixed percentages of overall leg length. Since the relative energy requirements of a stepping exercise are essentially dependent upon stepping height and stepping frequency and not the absolute workload (Nagle et al., 1965, 1971), the exercise intensity was expressed as (meters/min) rather than (kgm/min) of positive work. The load was calculated as the product of stepping height and rate of ascent. Prior feasibility work indicated that six meters/min provided a desirable aerobic stimulus to the children without unduly taxing them. In other words, with a metabolic requirement calculated to be between 6 and 7 Mets, or about 21 to 24 ml/kg.min based on the equations of Nagle et al. (1965), such an intensity was considered to reflect an essentially aerobic task with non-significant anaerobic energy contribution. The feasibility work also provided the range of heights and cadences that would be practicable for the age range of the children studied. As such, the tests were conducted for stepping heights from thirty to fifty percent of overall leg length. Increments of stepping height were 10% of leg length. The elevations and cadences were correspondingly adjusted to

ensure a constant load of 6 meters/min in each of the three exercise bouts for all subjects. Each test was performed for 5 minutes. This was deemed sufficient time for an apparent steady state to be reached before the end of the fifth minute of work. Rest periods of 6 minutes duration followed each five minute period of stepping. This time interval was found to allow for near complete recovery between exercise bouts as reflected by heart rate and oxygen consumption. Thus, no appreciable fatigue or carry-over effects were present to confound the treatment effects.

Subjects stepped to the sound of an electronic metronome at the counts of "one-two", to a complete erect stance and returned on the "three-four" count to the floor. The subject alternated the lead or lifting leg with a skip every minute on an audible signal from the examiner in order to equalize the lifting work between legs. The subjects were shown how to distribute the load of lifting between the major muscle groups involved in the task.

To verify the accuracy of the VO_2 measurements, ie. to test for variations due to random error or fluctuations in readings caused by instrumental sensitivity, three subjects repeated the experiment, each at one of three heights for three successive trials. In other words, one subject worked three times at the 30% condition, the second three times at 40%, and the last, three times at 50%. All other conditions during the repeat experiment remained the same as during the experiment proper. Within subject differences in VO_2 were quite stable, the 40% and 50% conditions showing a range of 0.5 ml/kg.min while the 30% condition demonstrated a range of 0.8 ml/kg.min among trials.

Apparatus

A stepping device with an adjustable platform was constructed, modified from the design of Nagle et al. (1965). The platform, set in a sturdy steel frame and guided on roller bearings could be elevated or lowered by a steel cable fitted to the back portion (riser) of the platform. The cable was activated by a hand crank. The height of the platform could be varied from between nine and fifty cm. The exact heights could be judged with the aid of a measuring tape fitted to the front vertical aspect of the frame adjacent to the platform. The platform was covered with a thin rubber mat to prevent slipping of the feet when working on the device. For the recording of heart rate throughout the work bouts, the Polar Electro Technology Sport Tester PE 3000 digital heart rate monitor system (Nor AM Patient Care Products, Oakville, Ontario) was affixed to each subject. The heart rate measurement interval was every 5-seconds. The average of the last four 30-second measurements in each 5-minute exercise was accepted as a relative steady state value. For the energy cost requirements of the stepping sequences, the child was fitted with a 2-way breathing valve. Gas analysis was conducted by employing the Roxon Medi-Tech System (Thermax Instrument Division, Pittsburgh, PA. USA) with expired gases collected every 30-seconds starting at the 2.5 minute point of each 5 minute test. The average of four successive 30-second readings beginning at the 3-minute mark was considered to represent a steady state VO_2 level. The gases were directed to and analyzed by Ametek S-3A1 oxygen and Ametek CD-3A carbon-dioxide analyzers.

Statistical analysis

A complete counterbalancing technique was employed in the investigation to control for possible sequencing effects. All possible sequences of the three treatment levels (percentage leg length) were employed. This ensured that ordering effects such as learning and practice were held constant. As well, possible negative carry-over effects such as fatigue were controlled by the introduction of rest intervals between successive trials.

Descriptive statistics, means and standard deviations for the physiologic and anthropometric parameters were computed. To determine the reliability of the anthropometric measurements, test-retest correlations on measures of overall leg length and lower segment lengths were computed on 14 subjects.

To examine the effects of overall leg length relative to stepping height, a one-way Anova with three repeated measures was carried out on the data for oxygen consumption, heart rate and minute ventilation. Pearson product moment correlation coefficients were computed to determine the degree of interrelationship among the three physiologic variables at the three conditions of exercise.

To assess the influence of individual differences in the anthropometric parameters of knee joint angle, leg length and a leg length to weight index on the above physiologic criteria, two groups of 10 subjects were formed by comparing the top third and bottom third of the sample based on the above anthropometric parameters. A two-factor repeated measures Anova was selected to test for significant dependent variable differences between the two groups. All data were analyzed utilizing the Stat View Statistical Analysis

Package (Brainpower Inc. Calabasas. Cal. USA).

RESULTS

The test-retest correlation coefficients computed on 14 subjects for measurements of overall leg length ($r = 0.89$) ($X = 71.5$, $SD_x = 4.68$, $Y = 72.3$, $SD_y = 4.28$), and for lower leg segment length ($r = 0.85$) ($X = 36.7$, $SD_x = 3.5$, $Y = 37.5$, $SD_y = 3.6$) reflected a sufficient degree of reproducibility in measurement technique.

The mean responses of the subjects to the three experimental conditions are presented in Table 2.

The repeated measures analyses of variance carried out on the data indicated that the treatment effects were not statistically significant within subjects. Therefore, each subject could be said to have had similar levels of relative oxygen consumption, heart rate and minute ventilation for the three conditions of stepping.

Pearson product moment correlation coefficients computed among the dependent variables for the three treatment conditions are presented in Table 3.

Statistically significant correlation coefficients were found for all variables except at the 30% conditions. However, the magnitude of the coefficients indicates that the proportion of shared variation between correlated variables was low.

A summary of results for the two factor repeated measures Anova selected to test for significant dependent variable differences according to the high and low grouping classification for knee joint angle, leg length and a leg length to weight index is presented in

Table 4, and illustrated in Figures 1 to 3.

These results indicate that significant differences in dependent variable scores between the high-low grouping classifications for leg length and a leg length/weight index were detected only in minute ventilation. No significant repeated measures (treatment effects) or interaction effects were revealed.

DISCUSSION

The mean relative oxygen consumption (21.2 ml/kg.min), mean heart rate (128.3 beats/min) and mean minute ventilation (20.9 liters/min) for the three modes of stepping taken together were rather low, reflecting a modest intensity of work. These values represent approximately 42 to 46 percent of a theoretical $\dot{V}O_{2\max}$ of 45-50 ml/kg.min (Shephard et al., 1968; Shephard, 1982; Cunningham and Paterson, 1985) and approximately 60 to 65 percent of a theoretical heart rate maximum of 200 beats/min (Massicotte and McNab, 1979; Cunningham et al., 1976; Jetté et al., 1984) for the average Canadian boy in this age category.

However, a basic design requirement of the experiment was that no appreciable fatigue factor or carry-over effect be present between repeat bouts of exercise. Whenever exercise is discontinuous, the extent of recovery between work bouts depends upon the intensity of work, the length of the intervening rest periods as well as the fitness of the subject (Astrand and Rodahl, 1986). During the feasibility phase of the study, when repeat bouts at higher intensities were attempted, an upward drift or cumulative displacement of the steady state heart rate was found to occur in some individuals, irrespective of the stepping sequences specified. This strongly indicated the presence of a negative carry-over effect contaminating the data. Recovery would have required considerably longer rest intervals, with the attendant problem of maintaining subject motivation and interest. In addition, higher working intensities would

have required assessment of the contributions from both aerobic as well as anaerobic processes to the total energy cost. Therefore, a more moderate exercise load which could be undertaken repeatedly was deemed the best possible compromise for examining intraindividual responses in children.

Anova reflected no significant differences in relative oxygen consumption, heart rate or ventilation to the three experimental conditions. This strongly suggests that alterations in the pattern of stepping did not affect the relative efficiencies of effort. Therefore, the relationship of stepping height to overall leg length within any given individual for the exercise load specified was not of critical importance. This is in general agreement with the findings of Howe and Collis (1973) and Miyamura et al. (1975) who concluded that alterations in stepping heights to suit the leg lengths of subjects were not warranted.

The present results do not corroborate the findings of Shahnawaz (1978). It is possible that the workload in the present study could not manifest changes of sufficient magnitude to affect the efficiency of effort within this sample of children. Conceivably, a higher intensity of work as in the study of Shahnawaz (1978) might have elicited such changes. However, the high variability in intersubject $\dot{V}O_2$ responses to the various modes of stepping at the 10 meters/min exercise intensity witnessed in the study of Shahnawaz points to the possibility that some subjects did not attain a steady state $\dot{V}O_2$ level. In addition, the oxygen costs of stepping may not have been a full reflection of metabolic activity since significant anaerobic contribution may have occurred in some subjects at this level of work.

Furthermore, the present study employed three successive tasks and thereby avoided possible daily variations in subject responses as well the possibility of intraindividual measurements being confounded by day to day instrumental fluctuations. Shahnawaz tested each subject only once per day. It is conceivable that the above considerations may have affected his results to some degree.

It is noteworthy that Harrison et al. (1980) modified the step ergometer nomogram technique of Margaria et al. (1965) by utilizing adjusted stepping heights based on the findings of Shahnawaz (1978). Harrison et al. (1980) found that correlations between the test to direct $\text{VO}_{2\text{max}}$ treadmill values ($r=.91$) were significantly greater than the non-adjusted test ($r=.64$). The authors nevertheless acknowledged that with a sample of only 9 subjects, their results may have been spurious.

Certain studies have suggested that the nature of the stepping exercise may create imbalances in the HR- VO_2 response (Nagle et al., 1965; Keren et al., 1980) and particularly over low workloads (Nagle et al., 1971) when compared to similar loadings on the cycle ergometer and treadmill. Accordingly, Pearson product moment correlation coefficients were computed among the dependent variables at the three conditions of thirty, forty and fifty percent of leg length. Statistically significant correlations were detected for all but the thirty percent conditions. However, the overall magnitude of the coefficients suggests that they were not particularly meaningful in physiologic terms. This mode of exercise was characterized by incorporating the lowest stepping height coupled with the fastest cadence. Keren et al. (1980) remarked that while stepping, too rapid a

cadence may affect the efficiency of effort as evidenced by an imbalance in the HR- $\dot{V}O_2$ response. Selective recruitment of more fast twitch or Type II muscle fibers (specialized for anaerobic energy production) at rapid rates of muscular contraction might result in heart rate rising disproportionately relative to oxygen consumption (Shephard, 1982; Stegemann, 1981). Under such conditions, the O_2 cost of exercise would not be representative of overall metabolic activity since anaerobic contribution would be unaccounted for. However, in the study of Keren et al. (1980), an imbalance was found to occur only at extremely rapid rates of ascent, greater than 50 lifts/min. It cannot be stated with certainty that such an imbalance existed relative to the other stepping conditions, noting that the fastest frequencies at 32 lifts/min for the shortest legged boy were quite moderate. In addition, preadolescents are considered to be more limited in anaerobic capability compared with older children and adults (Eriksson, 1972; Macek et al. (1974). It is therefore unlikely that the above factor would account for the findings, considering the modest loads imposed upon the subjects. Rather, the results overall would seem to simply reflect a generally poor interrelationship among these variables at low working intensities.

It has been proposed that the relative oxygen requirement in stepping is primarily dependent upon the stepping height and stepping rate relationship and not the absolute workload (Nagle et al., 1965; Kamon, 1970; Nagle et al., 1971). Therefore, it tends to vary little interindividually (Nagle et al., 1965; McArdle et al., 1973), under the assumption of a uniform working efficiency among individuals.

However, since parameters of leg length (Shahnawaz, 1978), body size, body weight (Astrand and Rodahl, 1986) and knee joint angle (Ariel, 1969) are purported to affect the working efficiency among individuals and thus the relative oxygen requirement, the data were further reanalyzed to assess the extent to which individual differences in knee joint angle, leg length and a leg length to weight index would influence intersubject physiologic responses.

The grouping classification of knee joint angle was chosen to test Ariel's (1969) assertion of how this parameter might affect physiologic efficiency, ie., if a large knee joint angle with its improved mechanical leverage for extension compared to a small knee joint angle would be reflected in dependent variable scores. Since subjects were being matched for stepping height, overall leg length did not in itself define the resulting knee angle. This was determined instead by the relative leg segment ratios among the subjects. Therefore, a measure of control over possible age and size dependent differences in physiologic responses was provided.

Anova did not confirm that any significant differences existed. However, the difference in mean upper segment to lower segment ratios of 1.03 to 0.85 for the high end and low end groups respectively may simply not have been large enough to have elicited any effects on performance. It also must be noted that while the subjects were able to perform the exercise sequences as specified, slight individual variations in movement pattern upon step-up could not be fully controlled. This additional factor may have precluded detecting potentially significant differences between the two groups.

During the feasibility phase of the study, it was found that

to standardize the exercise load for all subjects, shorter legged boys were required to compensate with a higher rate of stepping next to their longer-legged counterparts. Nagle et al. (1965) and Kamon (1970) have proposed that stepping frequency was of greater importance to the oxygen requirements of the task than was stepping height at any given work rate. Therefore, shorter legged boys should have been at a physiologic disadvantage relative to longer legged boys. On the other hand, an analysis of the natural frequency of oscillation of the lower limb (Stegemann, 1981) has revealed that subjects tend to intuitively select stride frequencies which are particularly economic (ie. their choice of stride frequency was correlated with the natural frequency of the leg). Since the frequency of oscillation for the leg varies as $\sqrt{LL}^{-1}$ (Shephard, 1982), shorter legged individuals tend to work more economically at higher rates of stepping compared to longer legged individuals. So, while the investigation employed overall leg length as a grouping criterion, in effect, the parameter being examined was relative stepping frequency and its possible effects on physiologic responses.

Anova revealed that no significant differences were present between the two groups with regard to either oxygen consumption or heart rate. Only minute ventilation ($p = 0.01$) was significant. This can be explained by the fact that since absolute ventilation is largely size dependent, the longer legged (and in most cases heavier) boys had to ventilate more. It appears, therefore, that at the level of work employed, the two groups were effectively matched for cadence and working at a relative pace which was energetically favorable. The present findings, therefore, do not concur with the results of Nagle

et al. (1965). In addition, the lack of any intraindividual differences for oxygen consumption are in disagreement with the findings of Nagle et al. (1965, 1971).

Both body weight and leg length have been identified as factors affecting working efficiency and the relative oxygen costs in both adults and children (Davies, 1980; Astrand, 1952; Astrand and Rodahl, 1986). Cooke and Holt (1974) employed a LL/Wt index as a classification tool to test the physical fitness of subjects. The present study employed such an index as another grouping criterion. It was considered a more appropriate method for classifying subjects than body weight alone. In this way, body weight as it relates to leg length irrespective of overall body size parameters could theoretically avoid purely age and size dependant characteristics confounding the results. Anova indicated that a statistically significant F ratio was present only for minute ventilation. Close inspection revealed, however, that the grouping method employed was not entirely satisfactory in avoiding a clustering tendency. With so few subjects which could be grouped, it was found that for the most part, heavier children clustered in the low index group and most of the lighter children in the high index group. Therefore, ventilation being size dependant was clearly greater for the low index subjects. The relative oxygen costs and heart rates, however, were quite uniform between the two groups. This confirms that for such a homogeneous sample of children, the relative oxygen costs and associated heart rate responses were not dependent upon the absolute workload but rather upon the stepping height and stepping rate components of the task.

In summary, no significant intraindividual differences were revealed in the dependent variable physiologic measurements. Therefore, alterations in the pattern of stepping did not elicit changes in physiologic economy within subjects.

Pearson product moment correlation coefficients computed among the dependent variable scores indicated a poor degree of interrelationship at the exercise load specified in the study.

No significant intergroup physiologic differences were revealed except for minute ventilation by comparing the top third and bottom third of the sample according to knee joint angle, leg length and a leg length to weight index.

It was concluded that for the working intensities and stepping patterns employed in the investigation, the relationship between platform height and leg length did not significantly influence either intraindividual or interindividual physiologic responses in subjects.

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Table 1. Means and standard deviations (SD)
for anthropometric characteristics of subjects (N=30)

<u>Parameter</u>	<u>Mean</u>	<u>SD</u>
Age (yrs)	10.1	1.2
Height (cm)	142.6	7.8
Weight (kg)	33.6	7.6
Leg length (cm)	72.0	4.7
Leg length/weight ratio (cm/kg)	2.1	0.3
Upper leg (cm)	34.3	2.6
Lower leg (cm)	36.7	3.2
Upper leg/lower leg ratio	0.9	0.1
Knee angle ° (30%)	112	1.7
Knee angle ° (40%)	100	2.3
Knee angle ° (50%)	88	2.8

Table 2. Means and standard deviations for the
 physiologic parameters of the subjects (N = 30)
 at the three experimental conditions

<u>Conditions</u>	<u>N</u>	<u>Mean VO_2</u>	<u>SD</u>	<u>Mean HR</u>	<u>SD</u>	<u>Mean MV</u>	<u>SD</u>
A 30%	30	21.0	2.6	127.7	9.7	21.3	3.4
leg length							
B 40%	30	20.9	2.8	128.2	11.0	20.8	3.7
leg length							
C 50%	30	21.5	2.7	129.0	10.1	20.6	3.9
leg length							

VO_2 = ml/kg.min

HR = beats/minute

MV = liters/minute

Table 3. Pearson product moment correlation coefficients relating VO_2 , HR and MV at the three experimental conditions (N = 30).

VO_2 at 30%	-----	HR at 30%	$r = .16$	non-significant
VO_2 at 40%	-----	HR at 40%	$r = .46$	$p > .01$
VO_2 at 50%	-----	HR at 50%	$r = .43$	$p > .025$
HR at 30%	-----	MV at 30%	$r = .04$	non-significant
HR at 40%	-----	MV at 40%	$r = .36$	$p > .05$
HR at 50%	-----	MV at 50%	$r = .40$	$p > .025$
VO_2 at 30%	-----	MV at 30%	$r = .27$	non-significant
VO_2 at 40%	-----	MV at 40%	$r = .57$	$p > .005$
VO_2 at 50%	-----	MV at 50%	$r = .52$	$p > .005$

$\text{VO}_2 = \text{ml/kg.min}$

HR = beats/minute

MV = liters/minute

30%, 40% and 50% refer to the

percentages of overall leg length (ie. the experimental conditions of exercise).

Table 4. Summary table for two factor three repeated measures Anova on physiologic variable according to grouping classifications of knee joint angle, leg length and a leg length to weight index.

<u>Classification</u>	<u>Variable</u>	<u>Groups</u>	<u>Treatments</u>	<u>Interaction</u>
		<u>F-ratio</u>	<u>F-ratio</u>	<u>F-ratio</u>
Knee joint angle	VO ₂	.84 (NS)	1.56 (NS)	3.05 (NS)
	HR	.72 (NS)	.72 (NS)	.68 (NS)
	MV	.57 (NS)	1.41 (NS)	.26 (NS)
Leg length	VO ₂	3.22 (NS)	1.32 (NS)	.17 (NS)
	HR	.01 (NS)	.50 (NS)	1.03 (NS)
	MV	8.24 (.01)*	1.99 (NS)	.92 (NS)
Leg length/ weight	VO ₂	.84 (NS)	.93 (NS)	1.05 (NS)
	HR	.04 (NS)	.20 (NS)	.38 (NS)
	MV	8.05 (.01)**	.91 (NS)	.55 (NS)

NS = Non significant

* Longer legged group sig >

** Low index group sig >

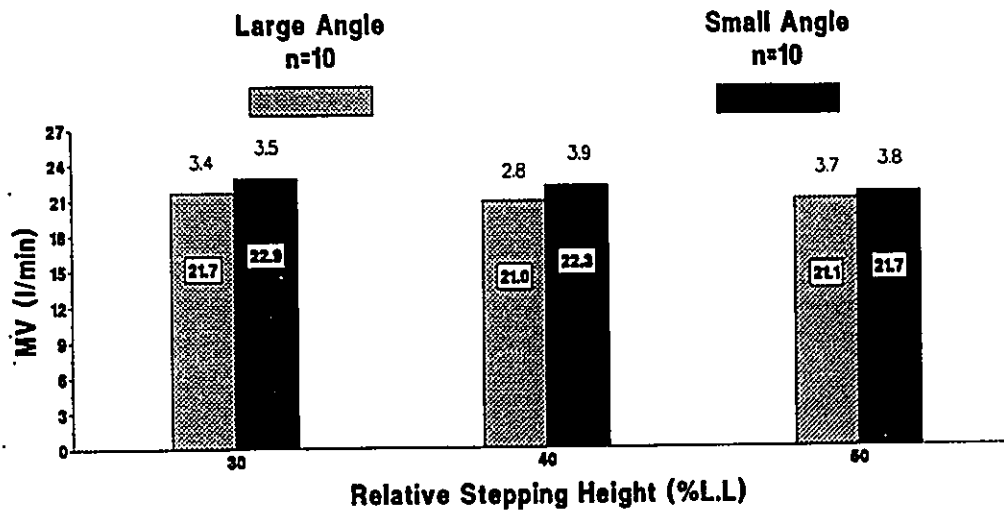
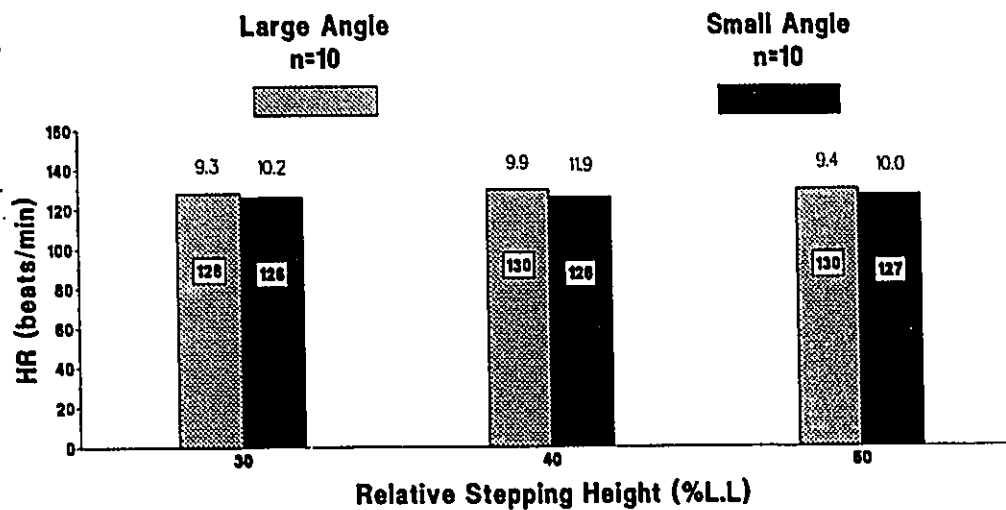
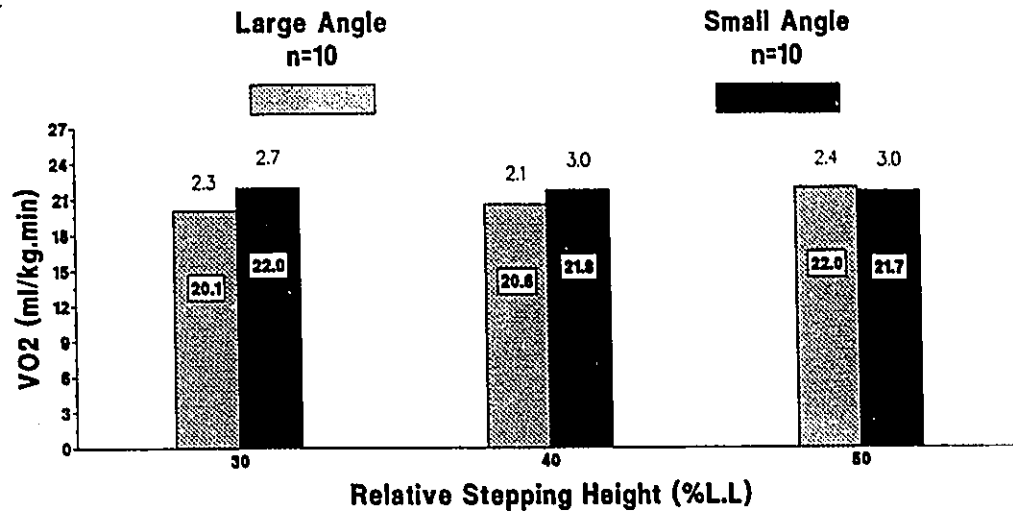
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(Fig. 1)

Means and SD's for Physiologic Variables According to Group Classifications of

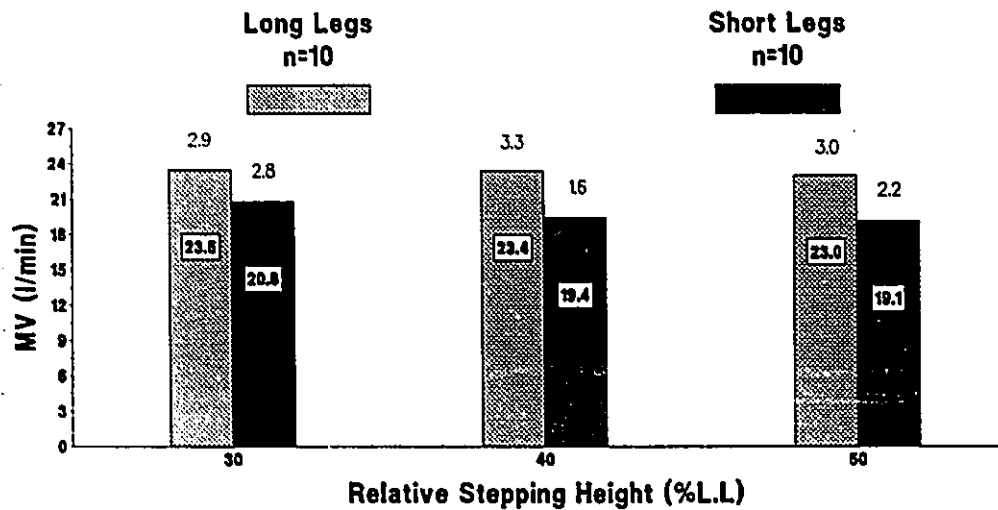
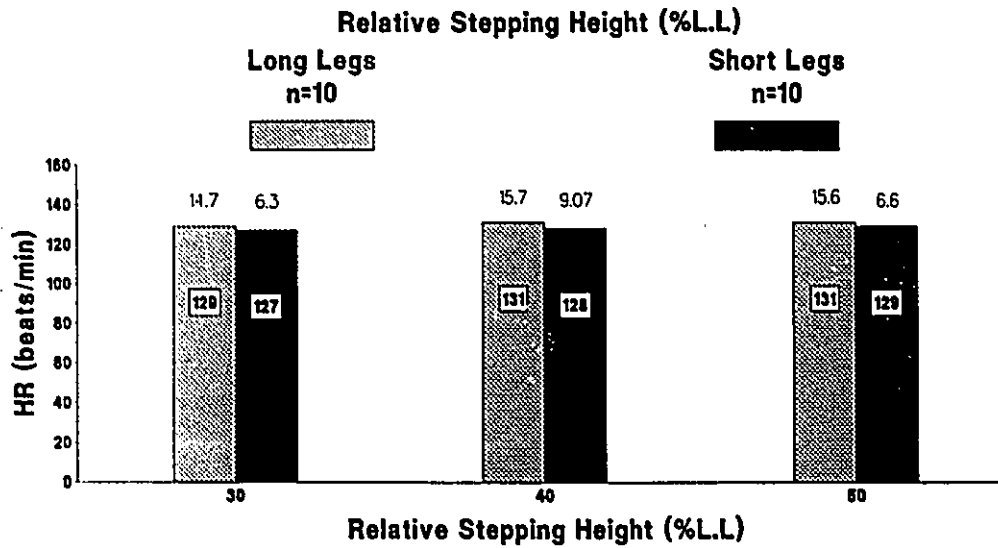
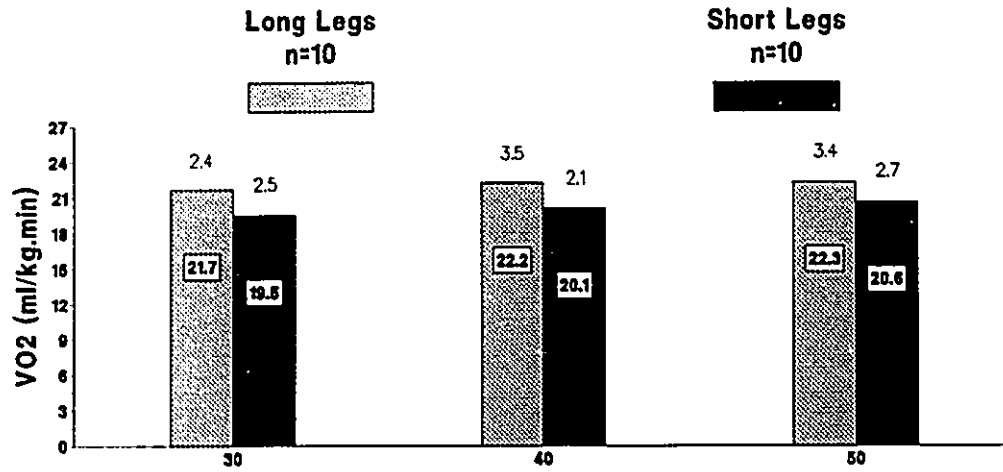
Knee Joint Angle



(Fig. 2)

Means and SD's for Physiologic Variables According to Group Classifications of

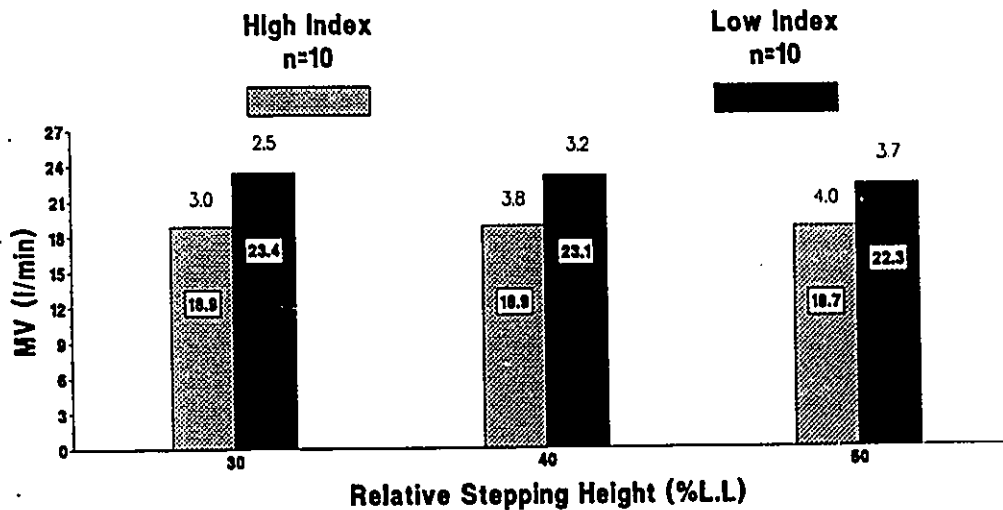
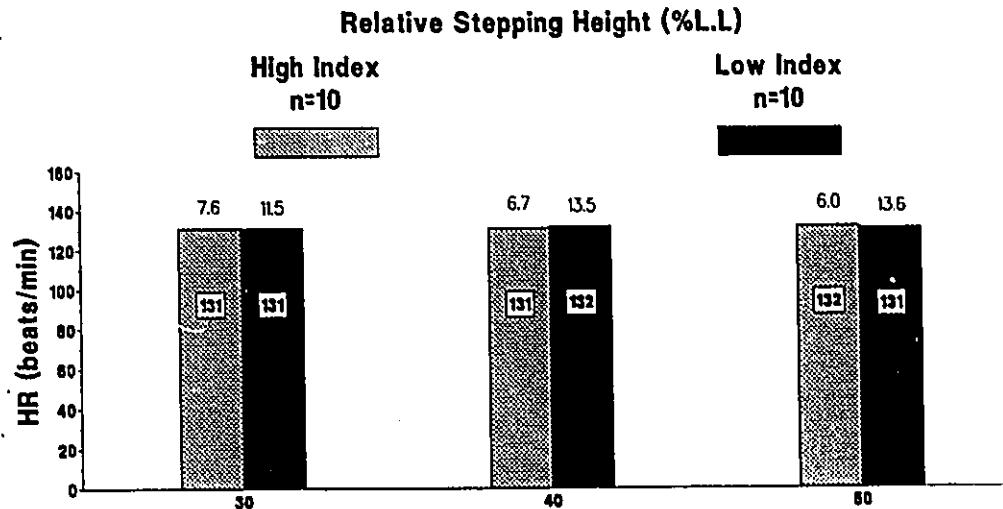
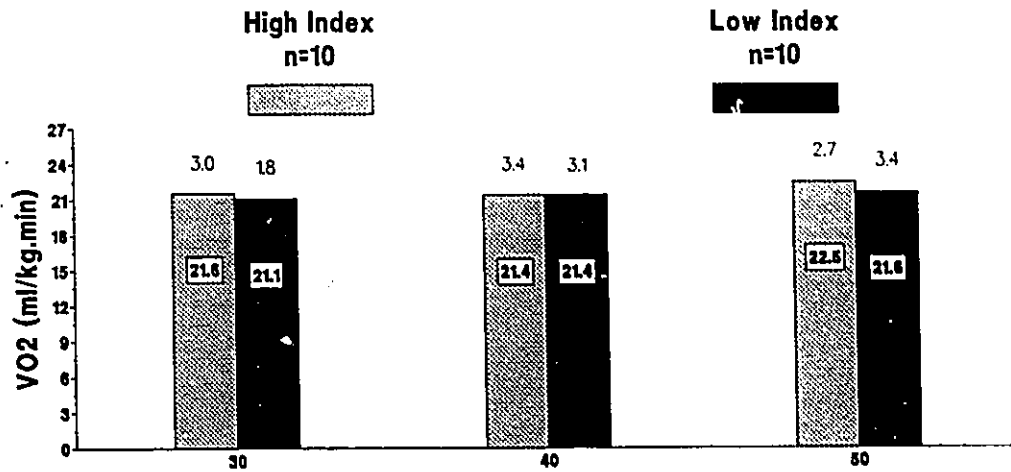
Leg Length



(Fig. 3)

Means and SD's for Physiologic Variables According to Group Classifications of

Leg Length to Weight Index



Appendix A

Review of literature

Review of literature

INTRODUCTION

The purpose of this section is to review the relevant scientific literature with regard to the concept of aerobic power and its assessment in children. The review is submitted in three parts:

Part 1 Factors affecting aerobic power

Part one will deal with the definitions and determinants of aerobic power in children. The standardization of physiological data and the effects of physical activity, growth and trainability.

Part 2 Techniques and procedures to evaluate aerobic power in children

A review of the various techniques and procedures for direct and indirect tests and the criteria employed to indicate adequate physiological effort for the evaluation of aerobic power.

Part 3 Mode of ergometric testing

Ergometric testing in both laboratory and field situations

is reviewed. The physical factors affecting performance in the major ergometric tasks is discussed. Previous investigations into the various factors affecting performance in a stepping task, with reference to young children are considered. As well, the physical movements employed and the physiological responses produced by such activity are compared to work on other devices.

Part 1 FACTORS AFFECTING AEROBIC POWER

Sources of energy for activity

For muscle contraction to occur, energy must be liberated and transferred. This energy is derived from three energy systems which operate concurrently, the amount of energy derived from each system being dependent on the intensity and duration of the activity.

1. The immediate source of energy is derived from the splitting of the high energy phosphate, (adenosine triphosphate)(ATP), stored in limited quantities at the contractile site of the muscle. Another energy-rich phosphate found in muscle is creatine phosphate (CP). CP cannot be used directly by muscle for energy. Rather, the energy released from its breakdown is used to regenerate the ATP broken down during muscular contraction. The high energy phosphates, ATP

and CP, have been referred to as alactic anaerobic energy sources. This emphasizes that O_2 is not used directly (anaerobic) and lactic acid is not formed (alactic)(Howald et al., 1978).

2. ATP and CP stores in muscle are limited. In order for muscle contraction to proceed beyond a few seconds, the ATP and CP must be continually resynthesized. Anaerobic glycolysis (the degradation of glycogen and glucose to pyruvic and lactic acid) is a second pathway by which this resynthesis occurs. Since O_2 is not involved and since lactic acid is formed, this pathway is often referred to as the anaerobic lactic pathway. Fairly large amounts of ATP can be rapidly regenerated from this pathway per unit of time. However, the amount of glucose and glycogen in the body is limited, as is the body's ability to tolerate high concentrations of lactic acid. Therefore, the contribution of anaerobic glycolysis to energy production is limited to only a few minutes of effort.

3. The main source of energy production for activities which continue beyond a few minutes is derived from the aerobic process. The production of ATP by this process involves the combustion of nutrients, especially fats and CHO (and under certain conditions, proteins) in the presence of oxygen. The nutrients are provided from sources within the muscle (free fatty acids, glycogen) or from sources outside the muscle (free fatty acids from adipose tissue, glucose from the

liver). In order to generate ATP through the aerobic process, O_2 must be supplied in appropriate amounts to the mitochondria. The oxygen supplied is derived from the atmosphere. The body's respiratory and cardiovascular systems are responsible for taking up and delivering the oxygen to active tissue. The principal by-products of aerobic metabolism are H_2O , CO_2 and heat. The water is partially retained in the body, assisting homeostasis, and the CO_2 and heat are eliminated to the atmosphere.

The rate at which aerobic metabolism occurs is therefore dependent upon two processes: a) the ability of tissues to utilize the available oxygen, and b) the ability of the pulmonary, cardiac and vascular mechanisms to transport O_2 to the mitochondria in the active tissue (Thoden et al., 1982). As such, the maximal rate of aerobic metabolism otherwise known as maximal aerobic power (MAP or VO_2 max) has been defined as the maximum rate at which energy can be released from the oxidative processes (Kaijser, 1970). Alternatively, Astrand and Rodahl (1986) have defined it as the highest oxygen intake an individual can attain during physical work while breathing air at sea level (work time 2-6 minutes depending on workload).

Nature of aerobic power

Aerobic power has traditionally been accepted as a valid indicator of the status and change in cardiorespiratory fitness (Shephard and al., 1968). This is because it reflects

not only a major pathway of metabolic energy production but also the functional and structural interrelationships of the heart, blood, lungs and muscles.

Recently, this classical concept has been challenged by researchers who claim that MAP is primarily a measurement of the capacity of the muscles to extract O_2 and is not limited by the ability of the cardiorespiratory system to deliver the required O_2 (Kaijser, 1970; Saltin, 1973; Holloszy, 1973, 75, 77; Booth, 1975; Howald, 1975; Howald et al., 1978). Their arguments are based on a) the close correlations which exist among skeletal muscle fibre types, tissue enzyme levels and MAP, and b) an increase of key rate limiting enzymes with training. As such, a causal link has been identified between gains in MAP and increases of enzyme activity.

A number of researchers have argued convincingly against this peripheral limitation theory (Clausen, 1976, Kawashiro et al., 1978, Keul, 1973, Rowell, 1974, Shephard, 1977, 1982, Simmons and Shephard, 1971). These authors adhere to the traditional view that the central component (ie. the cardiorespiratory system) provides the key limitation to MAP.

The cardiorespiratory determinants of VO_2 max have been divided into two groups: a) dimensional factors and b) functional capacities (Holmgren, 1967)

Dimensional factors include the size of the lungs, the diffusing surface area, the pulmonary capillary bed, the vascular system, the heart and maximal heart rate and concentration of hemoglobin in circulating blood. Each

component of the O_2 transport system in addition has a functional transport capacity. The functional capacity of the ventilatory system can be described by the maximal voluntary ventilation (MVV). The transport capacity of the alveolo-capillary diffusing system is described by the diffusing capacity of the lungs for carbon monoxide (DL, CO). The functional capacity of the cardiovascular system can be described by the maximal cardiac output and the stroke volume (SV) that can be maintained during maximal work.

A large oxygen transport capacity requires an optimal combination of both the dimensional factors and functional capacities. The question arises as to which link in the oxygen-transport system limits the delivery of oxygen to the exercising muscles.

Studies during exhausting work have indicated that both ventilation or "saturation" of intracellular oxidative reactions (an inability of the muscle cells to use more oxygen) seldom limit oxygen transport in healthy individuals. This leaves the cardiovascular system, ie. the ability to sustain a large stroke volume and adequately distributed cardiac output to working tissue as the major limiting factor.

The ability to work for prolonged periods using a large muscle mass is normally limited by a decreasing circulatory capacity (Shephard, 1983). A decrease in venous return and hence cardiac output may be compounded by an excessive cardiac workload or diminished myocardial contractility due to increasingly inadequate coronary perfusion (Grote, 1983). In

vigorous activities involving a limited muscle mass, performance may be hindered by a reduction in blood flow through the active musculature (Lind & McNichol, 1967). High intensity muscle contraction can also limit the flow of blood to active muscle via mechanical compression of the muscle vasculature, with a resulting impaired oxygen delivery. Anaerobic glycolysis then gradually leads to a build-up of acid metabolites until effort is finally limited by local muscle fatigue.

Physiological and biochemical determinants of aerobic power: children

The ability of the circulatory pump to supply oxygen to the active musculature with increasing metabolic demands has been suggested to be a crucial limiting factor in adults. (Holmgren, 1967; Saltin and Rowell, 1980). Available evidence indicates that this may also occur in children (Bar-Or et al., 1971; Eriksson, 1973, 1978). In addition, it should be recognized that distinct child/adult differences exist with respect to the components of the oxygen transport chain which may complicate the measurement of aerobic power in children.

During both submaximal and maximal effort, children have a higher ventilation per unit of oxygen intake and a lower ventilatory efficiency than adults (Astrand, 1952). On the other hand, alveolar ventilation accounts for a somewhat larger percentage of total external ventilation in children (Shephard, 1971, 1977). The number of red blood cells and the

concentration of hemoglobin are less when compared to adults which means that the oxygen binding capacity of the blood in children is somewhat lower (Astrand and Rodahl, 1977; Shephard, 1977). However, the diffusing capacity of the child's lungs whether related to body size or oxygen intake is at least as great as that of adults (Shephard et al., 1969; Shephard, 1971).

Bar-Or et al. (1971) indicated that children have higher heart rates and smaller stroke volumes than adults when exercising at the same oxygen intake. Moreover, for the same oxygen intake, total cardiac output is lower by one to two liters/minute, reflecting a hypokinetic circulation (Holmgren, 1967). This lower cardiac output in young children may reflect: 1) small viscera and thus a low blood flow requirement for tissues other than muscle, 2) less subcutaneous fat and thus a reduced need for skin blood flow compared to adults, and 3) increased aerobic enzyme activity, along with a more complete extraction of oxygen, in the working muscles (Rode et al., 1973; Mocellin and Sebenius, 1974).

Godfrey et al. (1971) and Kramer et al. (1969) noted that with children working on a cycle ergometer, cardiac output was linearly related to oxygen consumption. Nevertheless, the heart rate response to submaximal workloads was largely size dependent, with the shorter, lighter child having a higher heart rate response for a given oxygen consumption and workload. These children also tended to have higher maximal

heart rates than larger children. As for heart rate, stroke volume was largely size dependent. However, when corrected for height, the stroke volume values were similar to adults (Astrand, 1976; Eriksson, 1972, 1973, 1978).

Eriksson (1972, 1973) determined that the concentration of muscle glycogen was lower in children than in adults, suggesting an earlier depletion of glycogen reserves in children during sustained effort. Low muscle lactate concentrations have also been observed in children subsequent to both submaximum and maximum exercise (Macek et al., 1974; Shephard, 1977). This may reflect an inability of the child to produce high levels of lactic acid or alternatively, a faster aerobic adaptation to exercise in the child and subsequently, less reliance on anaerobic pathways. These findings are supported by a smaller oxygen deficit reported in children (Eriksson, 1972; Shephard, 1977) and by a lower concentration of the key glycolytic rate-limiting enzyme phosphofructokinase (PFK) (Eriksson, 1973).

The amount of active muscle in an individual is a major determinant of maximal oxygen consumption (Astrand & Rodahl, 1977;). Whenever the rate of work increases, the rate of energy production rises and the individual muscle cells require more oxygen. During heavy exercise, the oxygen consumption of the skeletal musculature can increase by more than 20-to-50-fold. It follows that the muscle mass (or lean body mass) bears a close relationship with the ability of the organism to take up oxygen.

Human skeletal muscle is not, however, a homogeneous tissue. While a thorough discussion of muscle fiber differentiation and its relevance to exercise performance and aerobic capacity is beyond the scope of this review, it is important to at least mention some of the discoveries which have been elucidated in recent years.

The total number of fibers in a muscle group and the fiber types within appear to be established by the fourth or fifth month of intrauterine life (Brown et al., 1975), with their respective kinetic properties apparently being genetically predetermined (Saltin and Gollnick, 1983). Two main types of muscle fibers, each with different contractile, morphological and histochemical properties have been identified. Fast twitch or Type II, and slow twitch or Type I. It can be generalized and said that type I fibers are specialized for aerobic energy production and are rather resistant to fatigue, while type II fibers possess biochemical machinery developed more for anaerobic processes and are therefore more fatiguable . Subgroups, however, exist in the type II family with type IIa fibers more closely linked to type I fibers in their metabolic potential; type IIb fibers, which are less equipped for aerobic metabolism, and type IIc fibers, perhaps being a transformational stage between type I and II fibers. There is a wide spectrum of physiological properties and an ability to adapt to different physiological demands in all fibers (Saltin and Gollnick, 1983). However, there is a paucity of information regarding the physiologic adaptability of skeletal

muscle fiber types in children. In view of the distinct child/adult differences that exist in response to sustained exercise, it remains to be fully established what role muscle fiber composition plays to exercise stress in the childhood years.

A number of investigations relating muscle mass (particularly of the lower limbs) to aerobic power have been conducted utilizing the cycle ergometer. Cotes et al., 1969, Cotes and Davies (1969), Hamley and Watson, 1976, Davies et al., 1972, Cotes et al., 1973 found that size, width and volume of the lower limbs contributed significantly to the observed aerobic power. Up to 80% of the variance in $\text{VO}_2 \text{ max}$ in children was determined by leg volume (Davies et al., 1972). These authors suggested that the functional aerobic power of children was more closely matched to their body size than in adults, and in particular to the dimensions of their lower limbs.

The early work of Buskirk and Taylor (1954) reported that $\text{VO}_2 \text{ max}$ in adults correlated 0.63 with body weight, 0.85 with fat free weight and 0.91 with lean body mass. When oxygen intake was expressed relative to the mass of the individual (ie. in ml/kg.min), the amount of body fat had a significant negative influence on $\text{VO}_2 \text{ max}$. The authors suggested that while fat did not have an effect on the absolute ability of the tissues to extract oxygen, it did have a significant effect on the relative circulatory capacity of the individual.

Goldman and Dill (1977), more recently, found that body

fatness had a significant negative relationship with VO_2 max. Using multiple regression analysis, these authors reported that the correlation coefficient of fat with VO_2 max was -0.561 for adults, but only -0.18 for boys. In a group of 11-12 year old girls of variable body fat, Gutin et al. (1978) found a correlation of 0.87 between percent body fat and 1-km run times (indicating that children with a greater percentage of body fat needed a longer time to complete the event). In a more homogeneous group of 10-14 year olds, Palgi et al. (1984) reported a correlation of 0.55 between body fat and 2-km run times. Both body weight and body fat have been identified as primary factors associated with VO_2 max of young children (Cunningham et al., 1981; Jetté et al., 1984); children with the largest body weights and lowest subcutaneous fat fold measures had the highest levels of aerobic power. In studies involving more homogeneous groups of children with respect to weight and body fat, other measures, such as height, can take precedence (Goldman and Dill, 1977).

Standardization of the measurement of aerobic power

The measurement of maximal oxygen uptake has provided a definitive and objective standard for the assessment of cardiorespiratory efficiency. However, it is not quite so well established as to how the actual values should be expressed, particularly in children.

The simplest and most widely utilized method of standardizing aerobic power is to express values per unit of

body mass, since most physical activity involves displacement of the body. Thus, VO_2 max values have usually been expressed as oxygen consumed per kg of body mass (or weight) each minute ($\text{ml/kg}\cdot\text{min}$). This assumes that aerobic power is directly proportional to mass or weight. However, as suggested by Bailey et al. (1978), evidence to indicate that this is the case has not been completely substantiated.

For both theoretical and practical reasons, the question of how MAP relates to body mass and size is significant. In training studies involving growing children, one must determine whether gains in MAP are a result of training, growth or both factors. In addition, in view of the changes in the relative proportions of fat and lean tissue as a child grows older, objections have been raised to the more traditional method of standardization (Von Döbeln and Eriksson, 1973).

In an attempt to control for the effect of growth, dimensional analysis has been employed as an alternative method of standardizing physiological data. According to the "general" dimensional theory, body stature or height (H) can be used as a marker since it is assumed that parts of the body and their functional capacities grow at similar rates. As such, a number of exponents of (H) have been proposed, each with a certain degree of theoretical backing. Asmussen et al. (1971) proposed a height exponent of $H^{3.0}$ whereas Von Döbeln and Eriksson utilized an exponent of $H^{2.0}$. Earlier, Kleiber (1961) theorized that $H^{2.25}$ would be ideal. More

recently, Bailey et al. (1978) determined $H^{2.46}$ as the exponent best describing a sample of Canadian children.

Thus, significant differences exist between proposed exponents, leaving the question open as to which procedure provides us with the ideal theoretical representation for aerobic power in growing children. Therefore, until greater agreement is found between experimental evidence and theory, it could be argued that the simple measurement of body mass (or weight) should be used to standardize aerobic power, despite its possible limitations.

Physical activity, growth and trainability

Several authors (Astrand et al., 1963, 1971; Seliger et al., 1971; Parizkova, 1972; Rutenfranz et al., 1974; Bailey, 1972, 1976; Siegal and Manfredi, 1984) have found significant correlations between habitual daily activity levels and physical working capacity of children. Astrand et al. (1971) compared youngsters involved in athletics and swimming with non-trained children. Children who were more active demonstrated both morphological and functional differences (including a 10% greater VO_2 max). A second study compared the functional dimensions and physiological fitness of athletically trained youngsters to less active children (Seliger et al. (1971)). At age twelve, athletically trained boys and girls did not differ physiologically from the reference population, but by age fifteen, they had a superior level of fitness as indicated by a higher VO_2 max and lower

resting heart rates.

The longitudinal investigations of Parizkova (1972) also indicated that improvements in aerobic power occurred with participation in physical activity. When children were grouped according to their level of participation in activities, it was found that values of aerobic power for normally very active children were significantly higher than those for the least active boys, but only beginning at age thirteen.

Bailey (1972, 1976) followed the growth and development of Saskatchewan children from age seven to fourteen. The MAP of boys classified as very active was superior to values of sedentary boys at all ages. One important difference seen in the Saskatchewan study in contrast to the observations of Seliger (1971) and Parizkova (1972) was a greater increase of aerobic power in active subjects relative to inactive subjects occurring well before the onset of puberty. Unfortunately, none of these studies provide a definite answer to the question: are children physically fit because they are active, or are they active because they are fit?

It has been argued that training is most effective at the time of the pubertal growth spurt, when the hormonal environment is conducive to protein synthesis (Andrews et al., 1972; Ekblom, 1969; Eriksson, 1972, 73, 78; Dietrich et al., 1974; Kobayashi et al., 1978). Others have maintained that since the average child already possesses a high level of voluntary physical activity, there is little scope for augmenting aerobic fitness through conditioning (Cumming et

al., 1967, 69; Daniels and Oldridge 1971, 78; Koch, 1977, 78; Weber et al., 1976; Cunningham et al., 1981).

The early study of Cumming et al (1967) is often cited as evidence that training has little effect on the aerobic power of young children. This report found no changes in aerobic power following additional physical activity. However, all subjects in this study had previously undergone conditioning and possessed high initial aerobic power.

Daniels and Oldridge (1971) followed fourteen boys, aged 10-15 years, for 22 months. All the boys trained for track competition. Little improvement of aerobic power per unit of body mass was seen during the period of observation. The small improvement in performance was due to an increased efficiency in running. A subsequent investigation by Daniels et al. (1978) concluded that $\text{VO}_{2\text{max}}$ increased proportionally with increases of body weight in active growing boys. Both age and training, however, contributed to a decrease in submaximal values of oxygen intake which accounted for most of the improvements in middle-distance race performance.

Similarly, Koch (1977) did not find increases in either aerobic power or muscle blood flow, other than that attributable to growth. The subjects used in this study were physically fit boys with initial values of $\text{VO}_{2\text{max}}$ averaging 60 ml/kg.min.

In contrast, Brown et al (1972) demonstrated a substantial training response in 8 to 13 year old girls who undertook a season of cross-country running. However, no control group was

employed. As Klissouras and Weber (1972) have indicated, changes in aerobic power can often be observed in both control subjects and training subjects. Nevertheless, Brown and co-workers' results suggest that increases in aerobic power can be achieved, particularly if initial values are low.

Kobayashi et al. (1978) measured the aerobic power of fifty Japanese schoolboys (aged 9 to 13 years) over 5 to 6 consecutive years. In addition, 6 superior runners were followed for 2-3 years, beginning at age 14 years. Seven of the fifty boys trained for 1.5 hours, 4 to 5 times per week. In these boys, an increase in aerobic power of 10% was found, relative to the other less active students. Increased physical activity had little effect on aerobic power until the year previous to peak growth (peak height velocity (PHV)=13.13 years). From this point on, however, training produced marked effects, above the normal increases due to growth. The lack of a training response before the age of 12 suggested that training at prepubescent ages will not appreciably improve aerobic power.

Eklom (1969, 71) randomly allocated 13 eleven year old boys to exercise and control groups. During 32 months of observation, body mass increased 45% in the active group and 28% in controls. Maximal aerobic power increased by 60% and 38% in the two groups respectively. In both cases, values substantially exceeded predictions based on dimensional theory. Eklom suggested that at puberty, increased activity favored the development of static dimensions needed for

aerobic metabolism with a consequent advantage to aerobic power.

Hamilton and Andrew (1976) found that exercise stroke volume was similar in both trained and untrained prepubescent boys, suggesting this to be a limitation to improvement in aerobic power prior to puberty.

Lussier and Buskirk (1977) had 16 boys and girls, aged 8 to 12 years, participate in a distance running program. After 12 weeks, the trained group showed a 7% larger $\dot{V}O_2$ max than in untrained groups, but differences in submaximum values of cardiac output, stroke volume and arterio-venous O_2 difference were not significant between groups.

Eriksson et al. (1975, 1978), in contrast, showed increases in both submaximal and maximal stroke volume and aerobic power with training above and beyond that attributable to growth. The entire increase in MAP was attributed to an increase in maximal stroke volume with little or no difference in maximal arterio-venous O_2 difference. In addition, it was noted that submaximal values of cardiac output at a given O_2 increased with training, a finding that differs from what is typically observed as a result of training in adults.

Significant increases in aerobic power were also reported by Massicotte and McNab (1974). They found that in order to elicit an improvement in aerobic power, preadolescents should exercise at a heart rate above 170 beats/minute. This training threshold represented about 75% of the difference between resting and maximum heart rates.

Cunningham et al. (1981) identified body weight and percentage body fat as the primary factors associated with the aerobic power of 12 year old boys. Daily energy expenditure, expenditure above a critical training threshold, or habitual activity did not contribute significantly to the variation of aerobic power. However, the selected training threshold was only 60% of maximal heart rate. This intensity may not have been adequate as put forth in the study of Massicotte and McNab (1974).

A study by Siegal and Manfredi (1984) suggested that running 1,500 to 3,000 meters, at a moderate intensity (160 beats/minute), three days a week, significantly lowers exercise heart rates. However, perhaps most of the acquired benefit was the result of an improved mechanical efficiency, rather than a physiological adaptation.

In summary, children who train at an adequate intensity obtain similar improvements in aerobic power as adults undergoing equivalent training. The lack of a training response in some children may be attributed to high initial levels of habitual activity and to a limited improvement potential in the prepubescent years. Alternatively, a poor training response may be due to an inadequate intensity of work, (ie. combination of exercise frequency, intensity and duration) relative to normal daily activity. The precise combination of these variables required to achieve optimal gains in MAP is as yet unknown, although the intensity of required effort in children is probably higher than for

adults.

Part 2

TECHNIQUES AND PROCEDURES TO EVALUATE AEROBIC POWER IN CHILDREN

Justification for the evaluation of aerobic power in children

Reports cited by Siegal & Manfredi (1984) have identified a significant number of the current generation of American children with low physical work capacity. There is evidence to suggest that the aerobic power of the average Canadian child may begin to deteriorate as early as ten years of age (Bailey, 1973, 74). A reduction in the spontaneous activity of children early in life may contribute not only to low levels of fitness but also to increased adiposity. With the adoption of a generally sedentary lifestyle during the growing years, there is a greater likelihood of developing overfatness, as well as cardiovascular and other medical disorders later in life. In fact, many regard coronary heart disease (C.H.D.) as being of pediatric origin (Friedman, 1972; Kannel & Dauber, 1972; Wilmore & McNamara, 1974; Gilliam et al., 1977, 82).

Recent studies suggest that the aerobic power (MacDougall et al., 1983) and physical work capacity (Gauthier et al., 1983) of current Canadian children have improved over the last decade; however, most evidence points to a rather low standard (Andrew et al., 1972; Cumming, 1967, Bailey, 1973, 74).

The fitness of children has traditionally been assessed in terms of performance, i.e. skills requiring speed, agility,

coordination, muscular strength and endurance (CAHPER, C.F.A.), rather than measurement of aerobic power. This may not be without some justification, however, since in the view of some investigators (Macek et al., 1976), aerobic activity may be somewhat atypical of the more instinctive and spontaneous bodily movements of children.

Nevertheless, aerobic training, beginning at an early age, may be important in improving the efficiency of the oxygen transport system. In addition, aerobic activity may be beneficial in modifying the primary risk factors of cardiovascular disease and in fostering a healthier lifestyle in adulthood (Siegal and Manfredi, 1984).

Criteria to establish maximal effort in children

Maximal aerobic power, when measured under rigorously controlled conditions, is highly reproducible and has become a widely accepted standard of cardiorespiratory fitness (Astrand and Rodhal, 1977; Shephard, 1982).

The early study of Taylor et al. (1955) showed that as working intensity rose, the oxygen intake increased in a proportional manner; eventually, a plateau in oxygen consumption was attained. These findings were subsequently confirmed by others (Hermanson & Saltin, 1967; Kamon & Pandolf, 1972; Kasch et al., 1976). Typically, a change in oxygen intake of less than 100 ml/min (Thoden et al., 1982) (or in some reports, 2 ml/kg.min) with an increase in work load has been employed as the criterion value demonstrating a

plateau in O₂ consumption.

There is evidence that not all children are capable of consistently achieving a plateau in V_{O2} max. This has been noted for treadmill (Shephard et al., 1969; Cunningham et al., 1977; Paterson et al., 1981), cycle ergometer work (Astrand, 1952; Cumming and Friesen, 1967) and step ergometer work (Funakawa et al., 1973). In order to confirm the measured values, it has therefore been proposed that tests be repeated, or alternatively have a greater degree of emphasis placed on assessment of secondary physiological criteria at maximal output, such as:

1. age-related maximal heart rate,
2. peak respiratory gas exchange ratio (R.),
3. high blood lactate concentration.

However, values for these alternate indicators of maximal effort are somewhat controversial. Maximal blood lactates of approximately 9 mM/L (Macek et al., 1974; Cunningham et al., 1977) are less than found in most adults; as indicated earlier, this may reflect an inability of the child to produce lactate or a difficulty in motivating children to a "true" maximal effort. In addition, it has been reported that anxious children may attain near maximal heart rates when exercising at no more than 80 percent of V_{O2} max (Shephard et al., 1974). Wide differences have also been reported for maximum heart rate. In the classical study of Astrand (1952), maximal heart rates of 210-215 beats/min. were reported. Most other laboratories, however, have found maximal cardiac

frequencies of only 190-200 beats/min. (Massicotte & McNab, 1974; Cunningham et al, 1976; Shephard, 1978; Jette et al., 1984).

These discrepancies indicate the difficulty of objectively defining what constitutes a true maximum test in children, and hence, how valid and reliable the resultant evaluation becomes.

Procedures and protocols utilized in maximal direct measurement tests

Regardless of the ergometer employed, the direct measurement of MAP employs certain patterns or protocols (Thoden et al., 1982). These include:

1. continuous progressive loading,
2. discontinuous progressive loading.
3. one step or constant loading.

Continuous and discontinuous progressive load tests differ principally in the method of increasing working intensity. Discontinuous protocols incorporate specific rest periods between each exercise stage. Each successive stage or load becomes progressively more difficult until the subject is exhausted. As such, these tests are rather time consuming, particularly when rest intervals are prolonged. Nevertheless, they are the method of choice when investigations require information as to how, for example, $\dot{V}O_2$, heart rate and ventilation are altered during specific steady state conditions (McArdle et al., 1973; Stamford, 1975). Steady

state conditions are difficult to achieve in most continuous protocols, unless the work time at each grade is extended to at least 3 minutes. Most progressive, continuous tests employ a protocol in which the load is increased stepwise. Such a protocol not only consumes less time but also reliably reveals the subject's MAP (McArdle et al., 1973). The CASS MAP protocol which has been devised for the testing of elite athletes (Thoden et al., 1982) incorporates this among other design features and has since met with favorable acceptance.

Both protocols normally begin with a warm-up at a submaximal load. The warm-up at a moderate intensity can minimize the risks of electrocardiographic anomalies (Barnard et al., 1973) and musculoskeletal injuries while helping to maximize oxygen uptake readings (de Vries, 1980).

One step or constant loading tests involve the selection of a workload (based on prior prediction of maximum exercise tolerance) which will exhaust the subject within 3 to 6 minutes (Thoden et al., 1982). While such tests are brief, they are generally inappropriate for a wide range of subjects who vary in age, fitness, cardiac condition and sex (Cardus, 1978).

In adult populations, VO_2 max values vary minimally with variations in protocols such as rate of approach to maximum, increase of treadmill slope versus speed, running versus walking or the use of continuous versus discontinuous tests (Fardy and Hellerstein, 1978; Gibson et al., 1979; McArdle et al., 1973; Stamford, 1975). In children, however, the

situation may be different. Paterson and Cunningham (1978) found that lower maximal heart rates, poorer reliability and lower VO_2 max values were attained with walking tests than running tests. Zauner and Benson (1981) observed values of $\text{VO}_{2\text{max}}$ in children that averaged 6 percent higher when employing an intermittent treadmill run compared to a continuous treadmill walk.

Indirect assessment of maximal aerobic power (MAP) (general)

Although direct measurement of MAP is the preferred method for assessment of an individual's cardiorespiratory fitness status, it requires rather sophisticated equipment, trained personnel, and is time consuming. Also, considerable motivation on the part of the subject is required. As indicated earlier, this can be particularly difficult with young children.

Therefore, for practical purposes, a wide variety of indirect tests using maximal or sub-maximal exercise such as walking, stepping, running or cycling have been developed. With submaximal test protocols, subjects need not be stressed to the point of exhaustion; thus, these tests are safer for the general population. Test duration is normally shorter than in direct measurement protocols obviating the problem of extended motivation. Moreover, the majority of indirect tests require a minimum of equipment thus reducing both instrumentation costs and the need for specially trained personnel. Finally, certain indirect protocols provide for group testing.

The anaerobic or ventilatory threshold as a measure of cardio-respiratory fitness in children

During progressive exercise a point is eventually reached at which a significant accumulation of blood lactate occurs. This exercise intensity has been designated as the "anaerobic threshold". It has been termed as the point at which

peripheral oxygen demand begins to outstrip the oxygen supplied, so that the organism is forced to rely increasingly upon anaerobic mechanisms for energy production. A high anaerobic threshold suggests that the organism can function at a higher rate of work before being forced into anaerobic metabolism. As such, this measure has been suggested as a useful indicator of aerobic performance capacity (Wasserman et al., 1973; Davis et al., 1976). A specific level of lactate accumulation ($>4.0 \text{ mMl}^{-1}$) has provided an objective and valid criterion for assessment of the AT, although requiring blood sampling during effort (Kindermann et al., 1979; Skinner & McLellan, 1980).

Non-invasive methods to estimate AT from certain respiratory gas exchange parameters have been demonstrated (Wasserman et al., 1973; Davis et al., 1976). A ventilatory threshold (VT) has been identified as the starting point of the non-linear changes in ventilation with increasing oxygen consumption. In adult populations, this VT has been shown to correlate highly with MAP (Weltman et al., 1978; Davis et al., 1979; Regbrouck et al., 1982). In children, this relationship has only recently been examined. Children, ranging in age from five to fourteen years, demonstrated a non-linear increase in ventilation with increasing oxygen consumption (Gaisl and Buchberger, 1980; Reybrook et al., 1982; Palgi et al., 1984); this deviation occurred at a somewhat higher percentage of $\text{VO}_2 \text{ max}$ than in adults. To establish the validity of the VT as an indicator of cardio-respiratory

fitness, correlations between the VT and other measures of cardio-respiratory fitness (the PWC 170 and the directly measured $\text{VO}_{2\text{max}}$) were computed. In fifteen children (aged five to six years) the correlation between the directly measured VT and PWC 170 was 0.75 (Reybrook et al., 1982). The correlation between VT and $\text{VO}_{2\text{max}}$ was 0.87 (Palgi et al., 1984).

Both studies suggested that the ventilatory threshold was an objective and valid indicator of cardio-respiratory fitness. Furthermore, such a procedure is valuable since the child is not required to exercise maximally, thereby reducing the influence of motivation on the measurement of fitness.

However, one problem with this method of determination is deciding which breakpoint in ventilation should be used for estimating the VT. Also, the results appear to be somewhat more variable in children than in adults. The higher percentage of $\text{VO}_{2\text{max}}$ at which non-linear increases in ventilation starts in young children has been in part attributed to the low capacity of young children to perform anaerobically (Reybrook et al., 1982). Non-linear changes in ventilatory parameters may also be coincidental to lactate accumulation and not necessarily a cause-effect relationship (Hagberg et al., 1981). It has been suggested that factors other than $\dot{V}_E$ can contribute to the non-linear increase in pulmonary ventilation with increasing VO_2 s. Local hypoxia in the peripheral chemoreceptor area during heavier exercise may cause an increase in ventilation yet have nothing to do with

blood lactate levels (Astrand and Rodhal, 1986).

Although there appears to be some controversy surrounding the concept of the anaerobic (ventilatory) threshold, in children this can partly be attributed to a lack of adequate data. Preliminary findings appear to be at least promising and further study will no doubt help clarify the issue.

Interpolated measurements

Interpolated measurements such as the PWC 170 (physical working capacity at a heart rate of 170 beats per min) have also been presented as an alternative basis of measurement. However, one drawback of interpolated submaximal tests including the PWC 170 in young children is that they do not take into account the degree to which circulatory response is size and age dependent (Kramer et al., 1969; Godfrey et al., 1971). Compared to older, larger children, the smaller child will have a higher heart rate response for a given oxygen uptake and workload, despite the fact that cardiac index is linearly related to oxygen consumption regardless of age or size. A further drawback is the manner in which workload is increased. Substantially higher PWC 170 values can be obtained from a continually increasing task (as used by some German and Dutch laboratories) than from a step-wise increment of work (as utilized by CAHPER researchers (CAHPER, 1968-1983)).

One interesting alternative to the usual submaximal and maximal test for the estimation of MAP has been to plot an

oxygen consumption recovery curve, extrapolating this backwards and upwards to conditions during maximum effort (Leger et al., 1980). Results in adults indicated a correlation of 0.92 with directly measured values without systematic error. This procedure has more recently been validated with two groups of children on the cycle ergometer (boys and girls, eight to eleven years old, and boys thirteen years old) with correlations of direct measured values of 0.93 (Mercier et al., 1983). Thus, backward extrapolation of the O_2 consumption recovery curve may be a valid alternative to direct measurement procedures. The procedure does not require the individual to breathe into a respiratory valve while exercising, thereby reducing artificiality found in the standard procedures. However, the test requires a maximal effort on the part of the child, and despite suggestions otherwise, such a procedure may be too unwieldy for generalized use in the field.

Extrapolation and nomogram techniques

In general, submaximal tests of aerobic power are based upon the linear relationship between exercise heart rate and oxygen consumption. Several authors have shown that in most cases, the relationship between VO_2 and heart rate is linear between 50 and 90 percent of aerobic power (Astrand & Ryhming, 1954; Maritz et al., 1961; Margaria et al., 1965).

Three prediction techniques have been commonly used:

1. extrapolation of the oxygen consumption-heart rate

line to a theoretical age-related maximum heart rate (Maritz et al., 1961),

2. a nomogram based on the observed heart rate at two fixed work rates (Margaria et al., 1965)
3. a nomogram based on the measured steady state heart rate at a single oxygen consumption or equivalent work load (Astrand and Ryhming, 1954).

This linear relationship between heart rate and oxygen consumption presupposes a constant or steadily increasing stroke volume and arteriovenous oxygen difference as workload increases (Cardus, 1978). In healthy adults, departures from linearity are small and generally insignificant (Cumming and Borysk, 1972; Davies, 1968; Wyndham, 1959). However, certain investigators have indicated that young children experience greater difficulty in sustaining stroke volume at high exercise intensities, leading to a disproportionate rise in heart rate at high rates of work (Bar-Or et al., 1971; Godfrey et al., 1971). Furthermore, since greater uncertainty surrounds the maximum attainable heart rate in the growing child predictive techniques based on submaximal data may yield underestimated values (Hermanson and Oseid, 1971; Shephard, 1978; Metz & Alexander, 1971).

Field and performance tests to estimate aerobic power in children

Until recently, many fitness specialists and physical educators assessed fitness simply by means of "performance

tests". One such test, the CAHPER Fitness Performance Test (CAHPER, 1966) consisted of a battery of 6 test items including both fitness related and performance related exercises.

Test items included a 1 minute speed sit-up, flexed arm hang, standing long jump, 50 yard run, shuttle run, and the 300 yard run.

A very similar test was devised by American researchers (AAHPER, 1965). However, they employed a 600 yard distance run, in place of the 300 yard run.

These test batteries, while quite useful in evaluating athletic abilities, are regarded as inadequate for assessment of a child's specific level of aerobic fitness (Cumming & Keynes, 1967; Metz and Alexander, 1970; Docherty and Collis, 1976).

Cumming and Keynes (1967) correlated VO2 max and PWC 170 with scores for the CAHPER test in young people, six to eighteen years of age. Non-significant correlations led them to conclude that the original CAHPER test did not measure any factor related to aerobic fitness. Rather, these tests were highly dependent on speed, balance, agility and motor skills, as well as motivational factors.

As a result of these findings, a need was identified by professionals and various agencies and organizations for the development of a simple field test that could adequately assess a child's aerobic fitness status and yet require little equipment or specialized training.

During 1979, the Canada Fitness Award (based on the CANPER Fitness Performance Test) was revised in order to change the scores to metric units and to replace the 300 yard run with a test that would be a better indicator of aerobic fitness. Additionally, norms were to be updated and revised. Depending upon age, distance runs of 800, 1600 and 2400 meters were included. The project resulted in the CANPER Fitness Performance II manual (1980) from which the tests and standards for the revised Canada Fitness Award were derived.

The Manitoba Department of Education had earlier included these endurance runs in the Manitoba Physical Fitness Performance Test Manual (1977) to establish norms of aerobic fitness for Manitoba school children. In the United States, the 9 minute run and the 1 mile run were implemented in the revised youth fitness test manual AAHPERD (1980).

Numerous investigations have explored the validity of distance runs in field tests of aerobic power for a variety of age groups. Perhaps the best known field test of aerobic power is the 12 minute all-out run of Cooper (1968). This particular test is derived from 2 earlier tests, Cureton's 1 mile timed run (1947) and Balke's 15 minute run (Balke (1954)).

In well-motivated young men, Cooper (1968) found correlations of 0.90 between running speed and VO_2 max. Doolittle and Bigbee (1968) after testing 153 grade 9 boys, found the 12 minute run to be a reasonably valid indicator of aerobic power, $r=0.70$. Maksud and Coutts (1971) also substantiated the use of the 12 minute run for adolescent

boys. They hesitated, however, in predicting oxygen intake from run-walk performances.

In contrast, Cureton (1974) noted non-significant correlations, $r=0.4$ between the 12 minute distance run and VO_2 max measures in 7 to 12 year olds.

Jackson & Coleman (1976) reported correlations between $VO_{2\max}$ and distance covered in a 9 minute run to be 0.82 for male and 0.71 for female children grades 4 to 6. Krahenbuel et al (1978) employed specific distances of 800, 1200 and 1600 meters with special attention paid to test/retest results of timed runs. Both the 1200 and 1600 meter runs were found to be significantly correlated to VO_2 max in a sample of 83 children. The 1600 meter run proved to be the best indicator for both sexes with a moderate correlation of $r=0.60$.

The energy cost of running per unit of body mass is known to be higher in a child than in an adult (Shephard & Lavallee, 1974; Davics, 1980). Previous investigations relating run time to direct measures of oxygen uptake have hypothesized that discrepancies in data may be partly due to age differences in the O_2 cost - running speed relationship. To this effect, MacDougall et al. (1983) investigated the effect of age upon the O_2 cost of running at different speeds to devise a predictive method for estimating aerobic power from field test results. Distance runs of 9 or 12 minutes were administered to 2,683 school children, aged 7-16 years. Oxygen uptake was subsequently measured during treadmill running for a range of speeds, in a random sample of 134 children. The VO_2 -

running speed relationship was found to be age related, with the younger children having a greater VO_2 per unit of body mass than older children when running at the same absolute speed. A correlation of 0.65 was obtained between measured VO_2 max and predicted values from the field test performances when corrected for age related differences in running efficiency.

The evidence thus suggests that while significant relationships exist between timed distance runs and the directly measured VO_2 max, the magnitude of these correlations is moderate at best. The reason for this is perhaps that the results depend largely upon motivation, efficiency of running, and the ability to choose an appropriate pace (Krahenbuel et al., 1978). A further important difficulty with all-out distance runs is that too often a near maximal effort is required.

One suggestion for improving pace judgement is to have a tester or a pre-recorded tape set the speed of running. Such a procedure is utilized in the Universite de Montreal Track Test (Leger & Boucher, 1978) and in the 20 Meter Shuttle Run Test (Leger et al., 1983). This latter test is a maximal multi-stage running test, designed to estimate MAP. The subject is required to run back and forth, on a 20 meter course, at a speed that is increased every minute by 0.5 km h⁻¹ until the subject is exhausted. The starting speed is normally set at 8.5 km h⁻¹. VO_2 max values have been predicted from the maximal speed or stage attained, using a

regression equation which takes into account the lower levels of mechanical efficiency of subjects below the age of eighteen (Leger et al. (1983) established in 1981 norms for the francophone school children of the Province of Quebec based on a sample of 3669 boys and 3355 girls aged 6-17 years. The predicted VO_2 max values were obtained from another validation study on 200 males and females aged 6-19 years). The correlation between predicted values and VO_2 max was $r=0.71$ for boys and girls aged 6-19 years.

While the 20 meter shuttle run test incorporates correction for efficiency changes with age, and controls pacing with a graded intensity of running, it nevertheless still requires a maximal effort on the part of the child, which may be difficult to realize.

One approach that minimizes the disadvantages of maximal or near-maximal body effort is the Canadian Aerobic Fitness Test (originally Canadian Home Fitness Test)(Bailey et al., 1976; Jetté et al., 1976). With this test, subjects are required to ascend and descend a pair of steps of a moderate height (20 cm) at an age and sex-specific rate. In adults, correlations of up to 0.9 have been reported between directly measured VO_2 max and predictions based on a validated regression (Jetté et al., 1976). More recently, as part of a validation study for the assessment of aerobic power in 7-14 year old children (Jetté et al., 1984), combinations of stepping height and stepping cadence were systematically investigated. The double 20 cm steps, employed by Bailey et al. (1978) and utilized in

the Canadian Aerobic Fitness Test (Shephard et al., 1976; Jetté et al., 1976) was found to be the most practical and economical procedure. The specific ascents and cadences for the 3 stages of stepping were modified in order to elicit approximately 60, 65 and 70 percent of the assumed $\text{VO}_2 \text{ max}$: (45 ml/kg x min in 7-10 year olds; 50 ml/kg x min in 11-14 year olds). Multiple regression analysis using weight, sum of skinfolds, post-exercise heart rate and the individually predicted oxygen requirements revealed a high degree of correlation with the direct $\text{VO}_{2\text{max}}$ measures; correlations ranged from 0.87 to 0.95.

Earlier in discussing the physiological determinants of aerobic power in children, body mass and percentage body fat were identified as key factors associated with their $\text{VO}_2 \text{ max}$. Cumming (1971) suggested that for the purpose of estimating the aerobic powers of children, the use of anthropometric data alone could be as accurate as predictions based on data gathered from submaximal exercise tests. This rationale is based on the contention that since the aerobic power of the average child is within a relatively narrow range in comparison to adults, submaximal work tests may not be sufficiently sensitive to allow for high predictive accuracy. In adults, where the range of fitness is much wider, submaximal work tests would be of more value.

Numerous studies (Metz & Alexander, 1971; Bonen et al., 1979; Cunningham et al., 1981; Jetté et al., 1984) have indicated the importance of anthropometric characteristics

such as height, weight and skinfolds as explanatory variables for the prediction of VO_2 max based upon multiple regression analysis, and the apparently weaker relationship with submaximal exercise test parameters.

More recently, Cunningham and Paterson (1985) concluded that in boys aged 12 to 15 years, approximately 80% or more of the variance in VO_2 max could be accounted for by age-specific equations employing mass, height and sum of skinfolds as variables. Up to 70% of the variance was explained in 10 and 11 year olds utilizing the same parameters. Heart rate and oxygen consumption were not considered useful for predictive purposes by themselves or in combination with anthropometric measures. However, their use of exercise data gathered from a cycle ergometer test to predict a treadmill $\text{VO}_{2\text{max}}$ may account to some degree for the low relationship.

Nevertheless, in view of the large difference in body size among children during the developing years, these findings suggest that anthropometric and structural factors such as body mass, height and body fatness be evaluated whenever predictions of aerobic power are required.

Part 3 MODE OF ERGOMETRIC TESTING

Ergometric devices employed in maximal effort tests (general)

Factors affecting performance

Clearly, all fitness testing ergometers should be evaluated in terms of criteria such as 1) accuracy and reproducibility

of measurement, 2) facility of monitoring, 3) safety, and 4) system and instrumentation cost (Cardus, 1978). In this context, it is essential that any ergometric device employed yield reproducible results and obtain a well-defined end point, ie. MAP.

As for adults, the choice of testing mode for the direct assessment of MAP in children lies among the treadmill, the cycle ergometer or the step ergometer. The relative merits of these various ergometers for both maximal and submaximal testing have been extensively discussed (Cardus, 1978; Keren et al., 1980; Taylor, 1969; Shephard, 1977).

Treadmill

For the purpose of maximal testing, the main advantages are:

1. the pace is set by the apparatus rather than the subject,
2. effort is normally centrally limited provided the subject is motivated to continue working at a high level of intensity,

The main disadvantages include cost, bulk and the noise level.

The treadmill can also appear to be a daunting piece of machinery for the child. This generates anxiety in some young children with the result that heart rates even at moderate levels of oxygen consumption are elevated (Shephard, 1974). There is also a risk of falling when children are required to work at high power outputs, since a short stride length makes

it difficult to effectively match the imposed speed of leg movement to the required load (Davies, 1980). These considerations may help explain why different treadmill protocols appear to yield discrepant results in children.

Cycle ergometer

For maximal test purposes, the important features include:

1. the subject is relatively stationary, thereby enabling ancillary measurements such as ECG monitoring and blood pressure to be made easily;
2. since the task is familiar to most young subjects, anxiety and learning of the test are minimized.

The less desirable features are:

1. since the work load is set by the child, the task can become self-limited, making it difficult to obtain maximum effort in all but the most highly motivated (Astrand, 1952; Cumming and Friesen, 1967),
2. a high proportion of the power output is developed by the quadriceps muscle, with the required effort often being large relative to muscle strength; this can reduce blood flow to the contracting muscles with the result that effort may be limited by muscular pain and weakness rather than central factors (Cumming & Friesen, 1967).

Step ergometer

For maximal testing purposes, the major advantages are:

1. mechanical simplicity, versatility, and minimal cost,
2. ease of measurement of the ECG and collection and

analysis of expired gas (Shephard et al., 1968; Shephard, 1977; Keren et al., 1980).

The major disadvantage is that small children have difficulty in stepping with a consistent rhythm at high power outputs, particularly at high bench heights. This frequently leads to early test termination, with values not being representative of a true maximal effort (Funakawa et al., 1973).

Submaximal testing in children utilizing the treadmill and cycle ergometer: factors affecting performance

Theoretically, any ergometric device enabling the child to perform suitably graded intensities of exercise could be used in submaximal testing.

In investigations involving adults, the I.B.P. team (Shephard et al., 1968) found few significant differences among step, cycle and treadmill ergometers in terms of physiological responses to submaximal exercise in adult populations at identical power outputs. However, data provided by other investigators (Nagle et al., 1971; Keren et al., 1980) do not completely agree with that from the I.B.P. team. The discrepancies in physiological and metabolic responses may largely be attributed to differences in the amount of active muscle mass utilized during performance, as well as variations in mechanical efficiency among the different ergometers.

It is widely accepted (Astrand & Rodahl, 1977; Davies, 1980; Shephard & Lavallée, 1974; Von Döbeln & Eriksson, 1973;

MacDougall et al., 1983) that mechanical or work efficiency (ie. the relationship between external workload and oxygen consumption) is lower in young children than in adults. The factors known to influence an individual's mechanical efficiency include: body size, body weight, gait, and limb length. In activities such as running, this low level of efficiency may be due to less economical coordination in children (VO_2 Dobein and Erickson, 1973), too short a stride length (Shephard and Lavallée, 1974) or that their lighter bodies do not provide enough kinetic and gravitational potential energy to be stored in the series elastic elements of muscle during the eccentric phase of contraction and then subsequently made available for concentric work (Davies, 1980; Astrand and Rodahl, 1977). In this regard, Davies (1980) has suggested adjusting treadmill speed and/or the rate of elevating treadmill slope in view of the low body mass and short stride length of children in an effort to optimize mechanical efficiency.

Early studies investigating the mechanical efficiency of cycling in children found that children attained values lower than the supposed adult average of 23% (Shephard, 1968). Subsequently, it was suggested that standard cycle ergometers should be modified when testing small children.

Klimpt and Voigt (1971) suggested that an optimal work rate was 12 kgm/min, with a pedal rate of 50 rev/min and a knee joint angle of 150 degrees. Furthermore, the crank length should increase from 13 cm for six year olds to 15 cm for

eight and ten year olds. Several protocols suitable for the evaluation of various age groups of children have been proposed (A.H.A., 1982). The cycle ergometer has been found to be a popular form of test with children and has been recommended as the procedure of choice for submaximal exercise when a wide range of physiological parameters are to be examined (A.H.A., 1982).

The step ergometer: factors affecting and determining performance

During the Second World War, the Harvard Step Test (Brouha, 1943) was developed as a screening test for selection of combat officers according to their physical fitness. The height of the bench (50 cm or 20 inches) and the stepping frequency (30 steps/minute) were chosen so that, roughly, only one third of the subjects should be able to perform the test for a 5-minute period. The heart rate was counted during the recovery from exercise with the subject sitting on the bench (from 1 to 1.5 min., 2 to 2.5 and 4 to 4.5 min. after exercise). The lower the number of heart beats during the recovery and the longer the work time, the higher was the score.

ic. Fitness Index = test duration (sec) X 100

2 X pulse sum (1-1.5)+(2-2.5)+(4-4.5)

In general, it was noted that the subjects with high scores also had a better performance in many activities demanding a high aerobic power than did those with low scores. Subsequent to this, the Harvard Step Test became extensively applied as a method for measurement of physical working capacity and the protocol in various guises remains in use for the evaluation of Olympic athletes (Ishiko, 1967; Shephard, 1982).

However, ever since its inception as a testing protocol, it has been criticized to varying degrees. Since the test employs a rather high stepping height (20 inches, 50 cm), it was suggested early on that the nature of the stepping task measured local leg muscle strength rather than general circulatory efficiency (Cook and Wherry, 1950; Montoye, 1953). It was found that employment of the Harvard protocol could cause localized fatigue and cramps in the large leg

muscles (Kasch et al., 1965; Kurucz et al., 1969; McArdle et al., 1972). The general validity of the test has been investigated by correlating test results with the results of other tests purported to measure similar factors. More recently, Harvard Step Test scores on Japanese boys did not correlate highly with the directly measured treadmill VO_2 max (Miyamura et al., 1975). This study raised doubts about the Harvard Test in particular and other stepping protocols in general as valid discriminators of cardiorespiratory fitness. Conversely, Ishiko (1967) has argued that the Harvard Test may give a better prediction of endurance performance than does a measure of aerobic power alone since it indirectly measures another important criterion: that of motivation of the subject. Perhaps for this reason, this particular test remains in the fitness testing repertoire, especially when evaluation of highly competitive performers is desired.

Among all fitness testing devices, there are differences in work setting accuracy and ease of calibration. While there is no mechanical variation in the height of the standard stepping device, step height and rate of ascent are not the sole determinants of external work. The reproducibility in measuring work also depends on the subjects' ability to elevate his/her center of gravity to the same point during each cycle and to maintain a constant stepping cadence (Cardus, 1978). Reproducibility of measurement depends on the subject's sense of timing and motion. As a consequence, the efficiency of effort is somewhat more variable in stepping than is most other forms of exercise (Shephard, Allen et al., (1968), Matsui et al., 1975). Cardus (1978) also noted that in the step test, since most patient monitoring

is more difficult, the possibility of injury from falling or the possibility of unnoticed adverse cardiovascular reactions are greater than in a test procedure where the ECG can be monitored continuously and blood pressure can be recorded every minute or so. The author claims that such ancillary measures are more difficult to obtain while performing a step test. The resulting data tends to be contaminated with artifacts and the subject's motion becomes limited. Conversely, Shephard (1977) argues that the quality of the chest ECG is usually good during stepping, only fair during cycling and much poorer on treadmill running. Shephard states that especially on the treadmill, an obese subject may develop large movement artifacts that a novice examiner has difficulty in distinguishing from ECG abnormalities such as ST segment depression and extrasystoles.

Notwithstanding the claimed limitations of the step ergometer, there are sufficient reasons justifying its continued use. First and perhaps foremost, stepping is still the most universal form of exercise (Kasch et al., 1965). Requirements in the simplest protocols are quite minimal. The only essential piece of apparatus being some form of bench or stepping block with an adequate width of tread and a non-slippery surface. For many purposes, a version of the double domestic or laboratory staircase has proven to be very suitable (Jetté et al., 1976; Bailey and Mirwald, 1978; Jetté et al., 1984).

Also, since most predictive tests are performed on bicycle ergometers or treadmills, such tests cannot be applied to large numbers of subjects outside of physiological laboratories. Thus, the step ergometer becomes far more practical compared to other ergometers, particularly in situations where considerably large

numbers of subjects are to be evaluated in a limited period of time (Shapiro et al., 1973; Keren et al., 1980).

As indicated earlier, a high percentage of the variance in the $\dot{V}O_2$ max among children tested on the cycle ergometer was explained by the calculated leg dimensions. That is, the width, size and volume of the lower limbs contributed significantly to the observed aerobic power.

Those individuals with stronger and larger leg muscles were expected to and ultimately performed better than individuals with weaker legs. This is supported by the findings that the strength of the active muscles determines to a considerable extent the influence of a given workload on local blood flow (Royce, 1959; Lind and McNichol, 1967; Cumming and Friesen, 1967).

If the muscles are exercised at such a fraction of their maximum voluntary strength so that circulation is limited during their contraction phase, the deficit of blood flow cannot be made up during the remainder of the movement cycle, and lactic acid accumulates. Stronger leg muscles would thus be of benefit, permitting the subject to reach a workload where the cardiovascular system was fully taxed before local circulatory problems arose. If the muscles were stronger, it would also be possible to sustain submaximal exercises for a much longer period of time (Lind and McNichol, 1967).

Cullumbine (1949) was among the first to observe significant relationships between anthropometric measures of leg musculature and Harvard Step Test scores in his Ceylonese subjects. In this early study, those subjects with greater leg muscle mass performed better; this being reflected in higher test scores.

The observations of Hettinger et al. (1961) and Shephard, Allen et al. (1968) which found that many subjects complained of leg muscle weakness in the quadriceps and triceps surae during their test sessions, and those of Davies and White (1982) who reported weakness and discomfort subsequent to a submaximal task lends support to the concept advanced earlier with respect to the arduous nature of the Harvard protocol. This stated that peripheral fatigue can often limit performance when doing step work. Such an occurrence has been indicated to be even more prevalent with small children than with adults, partly because the muscles are weaker leading to problems of perfusion in the vigorously contracting muscles, and partly because short limbs in relation to the height of the majority of stepping platforms may create problems in working efficiency (Funakawa, 1973; Matsui et al., 1975).

The early study of Elbel (1957) reported significant correlations between Harvard Test scores and a subject's height and weight (.01 level) and leg length (.05 level). The authors stated that further investigations in anthropometric measures and their relationship to step test performance was warranted. Keen and Sloan (1957), however, found no significant correlations between Harvard Test scores and an individual's anthropometric measures. Results of their study failed to justify lowering of steps for shorter individuals. On the other hand, the observations of Ariel (1969) regarding knee joint angle influencing step test scores was important in that it further advanced the concept of limb length as well as the degree of muscular leverage affecting performance in stepping.

His study indicated how a subject's "fitness index" might be

dependent on the height of the bench on which the step test was performed. He expressed the height of the bench relative to the subject's limb length by an angle (α) measured as the angle between the upper and lower limb when the foot was placed flat on the bench (a low bench would be indicated by a large angle). He concluded that the smaller this angle was, the more difficult would be the subject's performance as reflected in lower test scores. The author remarked that any test of similar nature would produce comparable results.

Holt and Cooke (1974) classified subjects according to a leg length/weight ratio and found that the component of knee joint angle as determined by leg length was effective in classifying subjects, in addition to the body weight measure. The addition of the leg length components favored the high index ie. (high LL/wt. ratio) group in the stepping exercise. The larger the LL/wt. ratio, the less difficult was the performance at the three stepping heights of 17, 20 and 23 inches. Within the subject group chosen, it was observed that the scores obtained by the "high index" group on the 20 in. stepping height were in close agreement with those obtained by the Medium and Low Index groups on the 17 inch stepping height. The authors concluded that by having subjects with a high index perform the step test on a 20 inch height and by having subjects with a low to medium index perform the test on a 17 inch stepping bench, all subjects would be evaluated cardiovascularly on the same scale.

Shahnawaz (1978) had subjects perform a standard workload at varying bench heights with correspondingly adjusted stepping rates. At the standardized work rate (10 meters/min) employed, it was found that for most subjects, minimum levels of oxygen intake and consequently

optimum working efficiency were obtained when work was performed at a bench height equal to a rather high 50% of the subject's leg length. There was found to be a compromise between a low stepping rate and a high bench. In other words, the metabolic cost for the given rate of work was lowest at an "optimal" stepping height which required a specific cadence. Nagle et al. (1965) fractionated the energy costs of stepping into three components of vertical lift, stepping down and stepping back and forth on a level surface. This last factor was seen to be directly related to the stepping cadence. These findings indicated that the horizontal component of stepping was a major component to the total energy cost. Thus, cadence or stepping rate was determined to be of comparatively greater significance than stepping height to the cost of exercise. The implications of this finding suggested that if the overall work rate were to be held constant, the oxygen cost would be least at the lowest cadence and highest at the fastest cadence.

The early work of Ramsey and Street (1940) on isolated muscle preparations demonstrated that the tension exerted by a stimulated muscle in a single twitch or in full tetany depended on the initial muscle strength. Maximum (isometric) tension developed by a stimulated muscle occurred when the initial length of the muscle at the time of stimulus was about 20% above the equilibrium length. The amount of tension fell linearly at lengths below this optimum and was zero when the muscle was maximally shortened. When stretched beyond this "optimal" length, tension development also fell.

In the human body, however, the external forces that can be generated at any given muscle length are greatly influenced by

considerations of leverage. In any movement throughout the range of motion, the amount of force exerted varies because of changing moment arms (Broer, 1973). The EMG studies of Bigland and Lippold (1954) and Bouisset (1973) indicated that at constant velocity of shortening or lengthening, electrical activity was directly proportional to the developed tension. These authors also found that the force developed by a given motor unit was greater for eccentric than concentric contraction. Therefore, fewer motor units were needed to sustain a given tension during eccentric activity. Finally, at constant tension, the electrical activity was found to increase linearly with the velocity of shortening. In this regard, Astrand and Rodahl (1986) state that the oxygen consumption of the active muscles should roughly reflect the number of active motor units and their frequency of excitation, that is, the electrical activity displayed.

The EMG work of Bigland and Lippold (1954), Bouisset (1973) and Milner-Brown and Stein (1975) would therefore seem to corroborate the oxygen consumption findings of Passmore and Durnin (1955), Nagle et al. (1965) and Kamon (1970) who found that the oxygen cost of eccentric activity in descending from a stepping device, or as in the latter study, climbing down a ladderhill accounted for approximately 1/3 of the metabolic cost of exercise.

Considerations as to the influence of limb length on step test performance have been put forward by a number of investigators. It has been shown that the quadriceps muscle group has comparatively good leverage for extension, a leverage which becomes increasingly more effective as the knee is extended (Brunnstrom, 1972). In weight bearing situations such as step climbing, the extensors have to act

against the superimposed body weight of the individual. As Ariel (1969) pointed out, the shorter (legged) individual with the characteristically smaller knee joint angle when stepping onto a bench is at a disadvantage in step climbing as reflected in test scores. Increasing the stepping height for a given individual creates the need to lift the superimposed body weight over a greater distance. This tends to increase considerably the level of muscle tension. Davies and White (1982) in fact point to the large increases in the forces involved and the developed muscle tension when climbing a 0.5 meter step at a standardized submaximal work rate.

The empirically determined oxygen consumption seen in the study of Nagle et al. (1965) illustrated the extent to which metabolic activity matched the level of muscle activity when subjects were required to climb increasingly higher distances at a fixed cadence.

Further evidence in favour of an "optimal" stepping height is provided in a study by Shapiro et al. (1976). Here, subjects performed a submaximal stepping exercise at three different heights (25 cm, 32.5 cm and 40 cm). The pulse recovery scores (electrographically determined) were correlated to predicted VO_2 max measures on a bicycle ergometer. Highest correlations (.809) were attained at the median height of 32.5 cm. As was the case in the experiment of Shahnawaz (1978), more "skill" was apparently needed when performing the test at the higher step height. This was thought to require an increased postural compensation and balance which created an elevation in oxygen consumption in the study of Shahnawaz (1978), or in the case of Shapiro et al. (1976), elevated pulse recovery scores. The low correlation witnessed between VO_2 max and recovery pulse rates on

the lowest bench was explained as the result of too low a workload being imposed upon the subjects.

It was mentioned earlier that Miyamura et al. (1975) compared "Harvard Step Test" scores with directly measured VO_2 max in young boys. In addition, various step heights were utilized to examine the effect of limb length on performance. No significant correlations were observed between maximum aerobic power and step test scores employing a 40 cm high bench. Thirty-seven of 69 subjects carried out the step test on varying heights of bench adjusted to the differing statures of their subjects. Adjusted heights of bench were 22, 24, 25, 26, 27, 28, 29 and 30% of the body height, respectively. There again, no significant correlations were observed. Their results showed no justification for alterations in platform height to match boys with differing statures. On the other hand, the authors did not ensure that the overall work rate was held constant for successive tasks. Without such a measure of control, it seems unlikely that a thorough evaluation could have been conducted. This factor undoubtedly influenced the resulting analysis.

The finding is, in addition, indicative of one of the more serious limitations with protocols such as the Harvard Test and its derivatives when pulse recovery scores are taken. It is desirable that the heart rate be measured during rather than following exercise. However, if readings are taken within the first 15 seconds of the completion of a stepping sequence, there is a fair correspondence with the measures taken in the final few seconds of exercise (Bailey et al., 1976; Jetté et al., 1976).

When observations are delayed for 30 seconds or more, the

correlation between the pulse rates during submaximal work and the recovery measures drops to below 0.8 (Ryhming, 1954; Shephard, 1967). This implies that about 36% of the variation in the recovery heart rate is attributable to extraneous factors such as a) the extent of the reflex increase in heart rate during exercise, b) the heart load imposed by the exercise and body build (obesity), c) pooling of blood in the legs following exercise and d) the extent and repayment of any oxygen debt (Shephard, 1977). From this, it is evident that the recovery heart rate gives only a rough idea of the heart rate attained during work if the results are compiled from many different subjects.

Therefore, the contention of Miyamura et al. (1975) regarding the lack of significant correlations between maximum aerobic power and recovery heart rate may not be justified owing to the way in which the pulse rate was measured. The complicating factors outlined above may have negatively affected relationships which otherwise might have been significant.

Howe and Collis (1973) validated the "U Vic" step test of Morton and Docherty (1970), a multi-stage progressive design utilizing an 18 inch platform height. This particular protocol was shown in college age males to be a discriminating measure of cardiorespiratory efficiency. It was stated that structural features such as leg length, body bulk measures and local leg muscle strength were not related to performance. However, it should be noted that no attempt was made by the investigators to vary variables such as stepping height in order to accommodate subjects with differing statures. Without making allowances for the different characteristics of their subjects, their conclusion that structural features are non-significant with respect

to performance cannot be accepted at face value.

The physical movements involved in stair stepping are in many respects identical to those in walking up and down stairs. Broer (1973) points out in his discussion of stair climbing that the chief problem in stepping up is the conservation of energy, while that of descending, is primarily safety. He goes on to state that when climbing upwards, the center of gravity is shifted forward so that the reaction force from the back leg's push is in a diagonally forward and upward direction. This forward inclination is from the ankles keeping the body segments in their same relative alignment. Leaning forward from the hips adds some strain to the lower back, but as in walking up an incline, the bend from the hips enables the strong gluteal muscles to work to good advantage reducing the workload on the legs and thereby making more force available. Those individuals with weaker leg muscles (small children) may at times need the additional muscle power (Matsui et al., 1975). However, if excess compensatory muscular activity is involved, then, as indicated by Cardus (1978), reproducibility of work performed on the step may be compromised since the center of gravity could shift and not always be elevated to the same point during each cycle.

Broer (1973) continues by adding that a smooth ascent results from the coordination of the forces produced by both legs; the back leg pushing the center of gravity over the forward leg. If the foot is placed flat on the step, energy does not have to be expended to hold the heel up against the pull of gravity. The forces, as well as the concomitant increases in metabolic activity when standing or climbing on the ball of the foot, are due to significant levels of muscle

activity in the soleus and gastrocnemius muscles (Freedman et al., 1976).

As stated above, stepping down is largely a question of safety. Freedman et al. (1976) describe it as a matter of controlled "giving in" to gravity. The leg extensors becoming stretched while resisting the gravitational force creating "eccentric" contraction in the quadriceps muscle group. Significant levels of "eccentric" contraction in the triceps surae also control the rate at which gravity pulls the body down.

Typically, when work involved in a stepping exercise is calculated, it is customary to examine only the stepping up phase, which involves lifting the gross body weight vertically against gravity. For example, a man weighing 50 kg stepping onto a step 0.25 metres in height will perform $50 \times 0.25 = 12.5$ kg.m. of external work. If this amount of work is performed at a frequency of 20 ascents per minute, the amount of work or more accurately the work rate amounts to $12.5 \text{ kg.m.} \times 20/\text{min.}$, or 250 kg.m./min (Wyndham et al., 1968).

The overall efficiency of the usual laboratory step test amounts to approximately 16% (Ryhming, 1955; Shephard, Allen et al., 1968). The net efficiency is typically calculated as follows (Shephard, 1982):

$$\begin{aligned} \text{Net} &= \frac{\text{Work output}}{\text{total E.E.} - \text{R.E.E.}} & \text{Net} &= \text{net efficiency} \\ \text{Total E.E.} &= \text{total energy expenditure} \\ \text{R.E.E.} &= \text{resting energy expenditure} \end{aligned}$$

However, as has been pointed out earlier, considerable muscular activity is involved in the downphase of a stepping task. In fact, for every ascent, an equal number of descents are performed, with considerable muscular involvement of the quadriceps and the triceps

surae to control the rate of descent (Freedman et al., 1976). If due allowance is made for the energy expended during descent as well as the mechanical work involved during step down, the mechanical efficiency rises, in fact becoming similar to that of most other large muscle tasks ie. approximately 22 to 23% (Rovelli and Aghemo, 1963; Richardson, 1966; Oldenburg et al., 1979) or higher (Kamon, 1970).

Earlier, it was alluded to that Nagle et al. (1965) fractionated the energy cost of stepping. The total cost was found to be a composite of the positive work involved in lifting of the body onto a raised platform and the negative (eccentric) work involved in lowering the body back to base level. The negative work component was found to be approximately 1/3 of the total oxygen cost at each stepping rate and height attempted by their subjects. These results were validated by Kamon (1970) on an adjustable laddermill. However, here it was found that at higher rates of descent, the efficiency of "negative" work decreased substantially, as reflected by an increased oxygen cost. This was accounted for as an extra "non-negative" energy expenditure which was accompanied by a disproportionately high heart rate response.

Nagle et al. (1971) remarked that the HR- $\dot{V}O_2$ responses were high in a stepping exercise when compared to bicycle and treadmill work at comparable loadings, particularly over low workloads. Also, the variability over the entire range of loads in stepping was greater. Nagle et al. (1965) earlier noted that the heart rate response to identical $\dot{V}O_{2s}$ was also higher in stepping than in treadmill exercise. This was accounted for by the more violent vertical jerks of the body in stepping progressively higher, thereby affecting venous

blood return hydrostatically in such a way that a lower central venous pressure resulted. The respiratory pump mechanism might have been ineffective because inspiration, normally favorable for venous return coincided with sudden upward movements of the body. The elevated heart rate response in this case compensated for a somewhat lower stroke volume. Therefore, the suggestion here is that the higher stepping heights were at least in part responsible for the physiological responses observed.

Oldenburg et al. (1979) observed that when the calculated power for cycling and step climbing were identical, there were no significant differences in either heart rate or oxygen consumption between the two forms of exercise. The only significant source of difference between step climbing and cycling was in a lower CO_2 production while stepping. This was suggested to be related to a reduced lactate production as found in all their subjects, and thought to be the result of a larger muscle mass performing a given power output in step climbing compared to cycling.

Keren et al. (1980) examined the circulatory and metabolic responses to a "maximal" stepping exercise. The heart rate responses were found to be comparatively high next to bicycle ergometer work. In this study, maximal stepping was performed on a 12 inch bench. This was believed to largely eliminate the undesirable effects of localized muscle fatigue in the legs. The authors found that the oxygen pulse measure (an indirect determinant of stroke volume) computed as the ratio of maximal oxygen consumption to maximal heart rate (in ml/beats) was lowest in stepping. It was hypothesized that a reduced venous return (as with Nagle et al., 1965) during stepping up to the

erect position resulted in a lowered stroke volume which was compensated for by a higher heart rate. This finding is apparently at odds with the contention that a disproportionately high heart rate to metabolic demand is the result of the subject being required to work at an excessively high platform height. In either case, however, the possibility exists that too high a stepping height (Nagle et al., 1965) or too rapid a stepping cadence (Keren et al., 1980) reduces the efficiency of muscular effort and thereby creates imbalances in the circulatory/metabolic response. In agreement with the work of Oldenburg et al. (1979), Shephard et al. (1968) did not discover significant differences in circulatory response to maximal work on the treadmill, bicycle or step ergometer.

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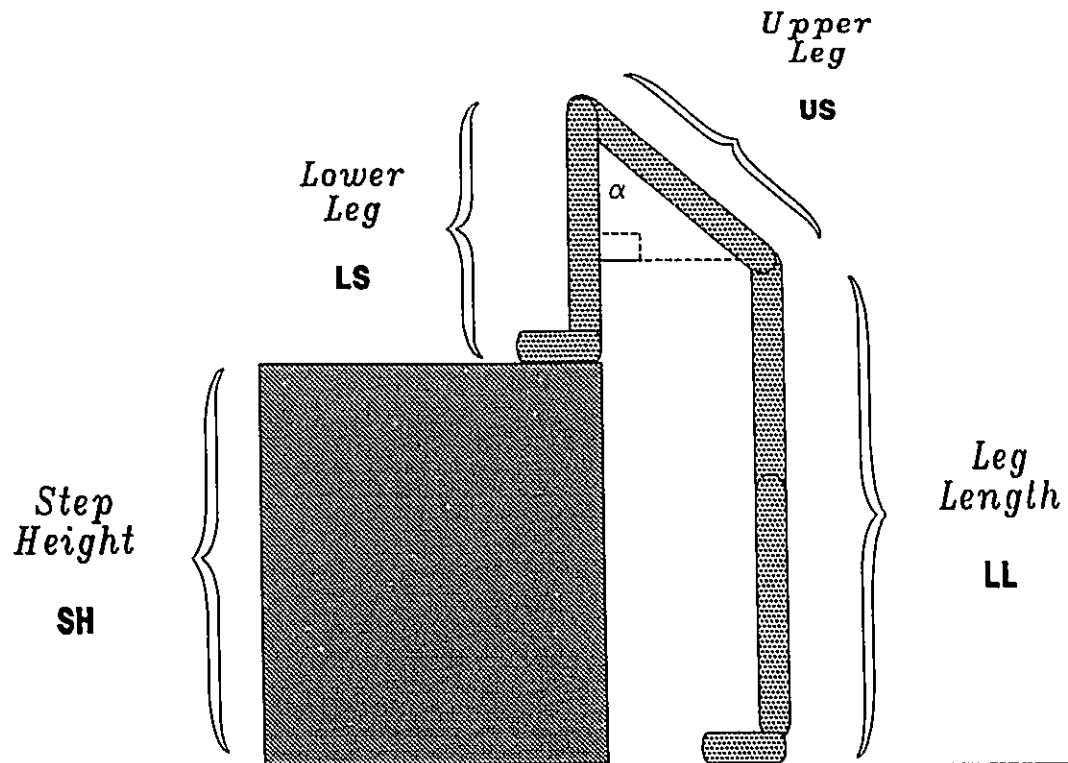
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Appendix B
Trigonometric Calculation
of Knee Joint Angle

Trigonometric Calculation
of Knee Joint Angle



$$\text{Knee Joint Angle } \alpha = \arccos \left[\frac{((LS + SH) - LL)}{US} \right]$$

Appendix C

Raw scores
Anthropometric measures

<u>Subject</u> (#)	<u>Age</u> (yrs)	<u>Height</u> (cm)	<u>Weight</u> (kg)	<u>Leg length</u> (cm)	<u>Leg length/ weight index</u>	<u>Upper leg</u> (cm)
1	9	144.8	36.5	71.4	1.96	32.5
2	9	140.5	32.6	67.8	2.08	34.2
3	11	149.0	43.2	78.0	1.80	34.4
4	11	147.1	33.4	73.6	2.20	33.6
5	10	140.4	39.0	67.5	1.73	32.4
6	12	148.0	39.1	70.1	1.79	33.5
7	9	131.2	30.0	63.4	2.11	31.5
8	12	153.1	38.8	77.1	1.99	37.3
9	8	132.4	30.1	62.7	2.08	29.3
10	12	153.5	47.3	77.2	1.63	36.9
11	9	132.2	25.0	67.1	2.68	34.7
12	12	143.5	28.8	70.2	2.44	33.6
13	12	155.0	47.1	79.1	1.68	42.3
14	10	133.8	34.0	69.0	2.03	35.3
15	8	134.5	27.1	70.0	2.58	34.8
16	11	157.6	39.0	78.0	2.00	35.0
17	10	142.0	30.5	69.9	2.29	32.9
18	10	152.5	43.0	77.7	1.80	40.4
19	9	133.6	32.4	64.2	1.98	32.8
20	10	150.2	37.3	76.8	2.06	35.2
21	9	134.4	31.0	63.9	2.06	31.7
22	10	151.6	39.1	75.5	1.93	35.4
23	10	138.8	33.2	70.2	2.11	34.5
24	10	140.5	37.6	71.5	1.90	35.2
25	11	143.2	37.0	70.6	1.90	33.8
26	10	136.0	29.0	69.3	2.39	33.3
27	10	135.7	31.6	67.5	2.13	32.3
28	11	140.4	33.0	69.4	2.10	31.2
29	10	136.4	27.5	69.1	2.51	34.0
30	9	145.2	38.1	71.0	1.86	33.5
X =	10.1	142.6	33.6	72.0	2.1	34.3
SD =	1.2	7.8	7.6	4.7	0.2	2.6

<u>Subject</u> (#)	<u>Lower leg</u> (cm)	<u>Upper leg/ lower leg</u>	<u>Knee angle</u> (°) (30%)	<u>Knee angle</u> (°) (40%)	<u>Knee angle</u> (°) (50%)
1	38.9	0.83	110	97	84
2	33.6	1.01	114	102	91
3	43.6	0.79	109	95	82
4	40.0	0.84	110	97	85
5	35.1	0.92	112	100	88
6	36.6	0.91	112	99	87
7	31.9	0.99	113	101	90
8	39.8	0.94	113	100	89
9	33.4	0.87	111	98	86
10	40.3	0.92	112	100	87
11	32.4	1.07	115	103	92
12	36.6	0.92	113	100	88
13	36.8	1.15	116	105	94
14	33.7	1.05	114	103	91
15	35.2	0.98	113	101	90
16	43.0	0.81	109	96	83
17	37.0	0.89	111	99	86
18	37.3	1.08	115	103	92
19	31.4	1.04	114	102	91
20	41.6	0.85	110	97	85
21	32.2	0.98	113	101	90
22	40.1	0.88	111	98	86
23	35.7	0.96	113	101	89
24	36.3	0.97	113	101	89
25	36.8	0.92	112	99	87
26	36.3	0.92	112	99	87
27	35.2	0.92	112	99	88
28	38.2	0.82	110	97	84
29	35.1	0.97	113	101	89
30	37.5	0.89	111	98	87
X =	36.7	0.94	112	100	88
SD =	3.2	0.09	1.7	2.3	2.8

Appendix D

Raw scores
Physiologic measures

Subject (#)	VO_2 at 30% (ml/kg.min)	VO_2 at 40% (ml/kg.min)	VO_2 at 50% (ml/kg.min)
1	26.1	21.2	20.8
2	20.9	20.6	20.7
3	24.7	27.2	25.9
4	26.2	27.1	27.4
5	21.9	17.2	15.4
6	21.5	20.5	23.0
7	17.0	17.3	21.1
8	20.0	17.9	18.4
9	19.3	21.1	22.0
10	20.0	22.7	21.8
11	23.3	24.3	25.6
12	26.5	26.1	24.5
13	20.9	23.0	25.6
14	15.6	19.8	18.7
15	20.9	18.6	19.6
16	20.5	20.6	18.3
17	21.5	18.5	21.7
18	21.0	18.4	20.1
19	17.2	18.2	21.0
20	21.1	17.2	19.3
21	18.7	20.5	21.8
22	19.5	22.3	20.6
23	21.2	22.4	23.7
24	23.3	24.5	25.2
25	19.3	18.5	19.7
26	19.8	19.3	20.9
27	21.9	21.4	21.4
28	21.9	20.0	22.8
29	17.8	19.2	19.4
30	19.2	20.2	18.5
X =	21.0	20.9	21.5
SD =	2.6	2.8	2.7

<u>Subject</u> (#)	<u>HR at 30%</u> (beats/min)	<u>HR at 40%</u> (beats/min)	<u>HR at 50%</u> (beats/min)
1	127	125	126
2	130	140	137
3	121	127	128
4	139	137	141
5	125	126	124
6	130	128	120
7	122	127	134
8	109	109	112
9	123	116	123
10	146	152	147
11	128	130	128
12	136	133	129
13	153	152	159
14	128	137	133
15	136	126	135
16	121	119	116
17	118	118	120
18	120	121	121
19	124	126	132
20	112	115	117
21	124	120	126
22	138	148	143
23	132	138	135
24	129	128	130
25	123	121	124
26	126	126	126
27	143	140	137
28	119	114	121
29	132	132	131
30	119	116	117
X =	128	128	129
SD =	9.7	11.0	10.1

<u>Subject</u> (#)	<u>Ventilation at 30%</u> (liters/min)	<u>Ventilation at 40%</u> (liters/min)	<u>Ventilation at 50%</u> (liters/min)
1	22.0	19.0	21.8
2	27.2	20.7	22.5
3	28.1	28.3	25.6
4	25.9	28.3	26.8
5	23.0	18.3	18.4
6	23.6	22.2	19.6
7	19.7	17.9	17.2
8	18.4	15.6	16.6
9	22.0	21.4	18.6
10	23.5	26.0	23.0
11	17.9	17.1	17.6
12	14.5	16.2	13.7
13	24.6	26.2	28.9
14	19.5	19.8	17.7
15	17.5	17.2	16.5
16	21.3	21.6	18.5
17	17.7	16.6	18.5
18	24.9	20.5	21.0
19	19.4	20.8	21.5
20	22.4	18.7	21.6
21	18.5	21.2	22.3
22	20.6	22.7	21.4
23	20.9	23.4	24.8
24	25.2	26.4	27.1
25	19.0	21.2	19.2
26	18.4	16.5	15.7
27	18.9	18.0	16.7
28	25.9	26.2	27.5
29	17.3	17.6	19.8
30	21.9	19.2	18.6
X =	21.3	20.8	20.6
SD =	3.4	3.7	3.9

Appendix E

Inter-individual grouping classifications

A) Knee joint angle expressed as (upper seg) ratio
(lower seg)

Large angle (N=10)
(Subject #)

2	1.01
7	0.99
11	1.07
13	1.15
14	1.05
15	0.98
18	1.08
19	1.04
21	0.98
23	0.97

X = 1.03
SD = 0.06

Small angle (N=10)
(Subject #)

1	0.83
3	0.79
4	0.84
9	0.87
16	0.81
20	0.85
22	0.88
27	0.92
28	0.82
30	0.89

X = 0.85
SD = 0.04

B) Leg length (cm)

Longest legs (N=10)
(Subject #)

3	78.0
4	73.6
8	77.1
10	77.2
13	79.1
16	78.0
18	77.7
20	76.3
22	75.5
24	71.5

X = 76.45
SD = 2.34

Shortest legs (N=10)
(Subject #)

2	67.8
5	67.5
7	63.4
9	62.7
11	67.1
14	69.0
19	64.2
21	63.9
27	67.5
29	69.1

X = 66.22
SD = 2.41

C) Leg length/weight index (cm/kg)

High index (N=10)
(Subject #)

4	2.20
7	2.11
11	2.68
12	2.44
15	2.58
17	2.29
23	2.11
26	2.39
27	2.13
29	2.51

X = 2.35
SD = 0.21

Low index (N=10)
(Subject #)

3	1.90
5	1.73
6	1.79
10	1.63
13	1.68
18	1.80
22	1.93
24	1.90
25	1.90
30	1.86

X = 1.80
SD = 0.10