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THE MECHANICAL EFFICIENCY OF TREADMILL RUNNING IN PRE-PUBESCENT BOYS

by

© JOHN C. GRIFFIN

A THESIS

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IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE
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EDMONTON, ALBERTA

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "The Mechanical Efficiency of Treadmill Running in Pre-Pubescent Boys" submitted by John C. Griffin in partial fulfilment of the requirements for the degree of Master of Science.

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Date . June 7/74 . . . .

ABSTRACT

The primary purpose of the present investigation was to determine the maturity of the running pattern of prepubescent boys on the basis of measurements of the mechanical efficiency of submaximal, steady state running. Secondly, the height, weight, body surface area, leg length, lower leg length, leg strength, and stride length were assessed as to their influence on the mechanical efficiency of horizontal running at a constant speed. Finally, the effects of three repeated trials on the mechanical efficiency scores were determined.

Forty-six boys from the ages of 9.3 to 12.9 years were classified into three groups with respect to age. Each subject was tested three times within a span of seven weeks.

Measures of mechanical efficiency were determined as the quotient of the rate of energy expenditure to the rate of doing work. Energy cost was determined from measures of oxygen consumption and the exercise respiratory quotient. The external work accomplished was estimated as the product of the subject's gross weight and the velocity of the treadmill.

Measures of weight, height, leg length and lower leg length were taken. Body surface area was calculated. Isometric leg strength at a knee angle of 115° was assessed using a dynamometer. The number of strides taken during the period of gas analysis were used to determine the average stride length during each trial.

Results indicated that there were no significant differences between the age groups; however, the older group of boys attained the highest mechanical efficiencies. The mean mechanical efficiency for the entire sample was 23.82%.

Stride length (r=0.44) and leg strength (r=0.32) correlated significantly with mechanical efficiency The application of partial correlations on these variables revealed that when age was held constant, the correlation of stride length and mechanical efficiency remained significant (r=0.37); however, much of the relationship of leg strength with mechanical efficiency and stride length was by virtue of its relation to age in submaximal running. The simple regression equation derived to predict mechanical efficiency was: Mechanical efficiency = 15.796 + 9.111 (stride length). The correlation between observed and predicted mechanical efficiency was significant at the 0.01 level (r=0.43).

There was shown to be a significant improvement in mechanical efficiency between both the first and second trials and the second and third trials. The oldest group demonstrated the greatest rate and extent of skill improvement over the three trials. This period of pre-pubescence appears to be a time when practice will elicit significant improvements in the pattern of running.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Economy of effort is the result of skilled movements of the body and its ability to adapt to the rate and [illegible] work being accomplished (9). Work is done uneconomically when a new skill is being learned (100). The degree of skill demonstrated by an individual may be influenced by such variables as age, amount of practice, structural and physiological qualities (44).

Three main objectives of the study are outlined below. First, the effi[illegible] of running will be examined among various age groups [illegible] later childhood period. Secondly, several variables will be assessed as to their influence on the effi[illegible] running. Finally, the extent of skill improvement [illegible] trials will [illegible] determined.

Astrand (7:[illegible]) has [illegible] oxygen intake is regarded as an important factor in determining fitness [illegible] endurance work, the mechanical efficiency or skill must be regarded as another decisive factor. Henry (59:461) described the efficiency of the working human body as the ratio of external work accomplished to the metabolic cost of that work over and above the resting metabolism. It is the ability of a person to perform work as economically as possible and thus transforming a comparatively great part of the energy developed into specific work.

Much of the motor growth and development information in the literature has been descriptive (30,103). Furthermore, the picture has been drawn with broad strokes that represent changes in form and character of performance in the most general terms. Too little consideration has been given to measurement of neuromuscular patterns which grant the movement qualities so readily recognized as skill.

Because of the wide range of speeds obtainable, running affords a striking illustration of the close relationship between the speed of motion and the energy cost. The energy necessary for speed maintenance in running has been measured from the oxygen consumption when the speed is such that a steady state can be attained and no oxygen debt is contracted during the period of measurement (85:354).

A problem in the evaluation of the mechanical efficiency of most human activities lies in obtaining an accurate estimate of the ex[illegible]. However, efficiencies may be computed without exact knowledge of work done (71). Cavagna (16:[illegible]) defined "external work" as that fraction of total mechanical work necessary to sustain the vertical work against gravity.

The mechanical work output is mainly employed for speed maintenance. Due to the geometry of the body and to the mechanism involved in running, the body is subjected to a deceleration at each step (negative work) which must be compensated by positive work performance to maintain a steady energy level (85). A fraction of the negative work (stretching of contracted muscle by inertial or gravitational forces) can be given back as positive [illegible] the following phase of the muscular contraction without [illegible] chemical energy expenditure. A number of studies (29, [illegible], 78, [illegible], 110, [illegible]) reported high values of mechanical efficiency which have been explained as due to this contribution of a [illegible] amount of stored energy.

Measurements of running speed, stride length and lower limb size have been used to establish their effect on energy expenditure with adults (15, 38, 52, 63, 64, 65, 75, 94, 97, 98, 106, 112). Factors such as these would obviously vary with the [illegible] development of a child. What are the effects of these variables on the basic running pattern as assessed by mechanical efficiency?

Changes in the mechanical efficiency have been reported as due [illegible] (18, [illegible]) [illegible] involves new motor skills [illegible] no previous experience. [illegible] in this instance is uneconomical until the new skill pattern is learned and the necessary adaptation is made.

Statement of the Problem

The problem in question is a [illegible] one [illegible] it is necessary to assess the motor patterns involved in running for boys aged ten to twelve years. On the basis of measurements of the mechanical efficiency of steady-state running, it is the purpose of the present investigation to determine the maturity of the running pattern of pre-pubescent boys classified by age. Secondly, the height, weight, body surface area, leg length, lower leg length, leg strength and stride length will be measured and used to assess their influence, if any, on the mechanical efficiency of horizontal running at a constant speed. In addition, a multiple regression equation for the prediction of mechanical efficiency will be presented. Finally, three repeated trials will be taken, over approximately a month, in an attempt to determine the effects of learning the [illegible] of treadmill running.

The following null hypotheses will be tested:

1. No difference in mechanical efficiency exists between the different age groups.

H_{01}: the mean values for mechanical efficiency show no differences between the age groups (A, B, C). H_{A1}: $A < B < C$

2. Mechanical efficiency has zero correlation with age, body surface area, weight, height, leg length, lower leg length, leg strength and stride length.

H_{02}: rho (m.e., x) = 0

H_{A2}: rho (m.e., x) > 0

where x is one of the above variables.

3. No Difference in mechanical efficiency exists from one trial to the next.

H_{03}: The mean values for mechanical efficiency do not change between repeated trials (T_1 T_2 T_3).

H_{A3}: $T_1 \neq T_2 \neq T_3$

Justification of the Study

On the subject of running, most coaches are able to point out differences in running style of the highly skilled vs unskilled and the old vs young which may be affecting the efficiency of performance. Knowledge of the efficiency of running and the functional and structural factors and their respective contributions would provide teachers, coaches and parents with a tool whereby specific help based on recognized need could be extended to the runner.

Statements made in the literature concerning mechanical efficiency have dealt almost exclusively with adults and primarily with a few well-trained athletes (16, 85, 93). The time of a boy's life immediately preceding the pubescent growth spurt is characterized by slow and constant growth. It is also a period of rapid learning, perfection and stabilization of previously acquired skills and abilities (44). Neuromuscular skills, such as running, should, therefore, show some improvement in this age group. A lag in the development of motor ability and a recession in performance have been reported during pubescence, approximately between the chronological ages of 12.5 and 14 years (56). Astrand (6) reported that young subjects had higher energy expenditures per kilogram of body weight than older boys and adults when running at a given speed on a treadmill. He explained this lower efficiency as partly a result of a greater stride frequency.

Various exercise tests have been used to determine mechanical efficiencies, but they differ widely in detail, making comparisons difficult (5, 58, 59, 100). In general, basic standardization data are not available on energy costs, skill factors, efficiency, and inter- and intra-individual variability. There has been common agreements on the superiority of the bicycle ergometer and treadmill to ensure exact reproducibility of work loads. The treadmill was preferred for several reasons:

1. The work load on the treadmill is fixed without any requirement for the subject to keep time.

2. A larger total energy expenditure is obtainable on the treadmill.

3. On the treadmill, the work load is automatically adjusted to the [illegible].

4. Running is a more [illegible] skill upon which many other motor patterns are built.

5. Implications for young track athletes are possible.

An objective standard of measurement of running ability varies considerably from one study to another. Oxygen consumption has been utilized to estimate the potential of an individual to run under aerobic conditions. Most practitioners employ a time-distance measurement. Other researchers have outlined a biomechanical analysis of what they consider a mature running pattern (78). Track coaches and physical educators still rely upon their ability to observe the form in running.

For many years the systematic study of the development of running was neglected simply because there was no apparent reason to seek additional information (81:25). A growing concern for effective movement has stimulated some research in the mechanics of the running pattern and the developmental changes (23, 54, 81).

Although the research is sparse, there have been attempts to study the metabolic cost (7, 102) and biomechanics (23, 81) of running in children of different ages. However, these factors are limited in their ability to provide an accurate indication of the effect that a child's structure and function has on his performance. The degree of skill with which a child is able to perform is a measure of his mechanical efficiency; that is, the ability to perform work by utilizing the least possible energy (7). As motor, structural, neuromuscular, and physiological developments take place in the maturing child, it is expected that his running form adapts to function more efficiently.

The variables of weight, height, age, body surface area, stride length, leg size and strength are suspected to have an influence on the movement patterns of children. Knuttgen (75), Hogberg (64), and Hoffman (63) have indicated that pace length, stride frequency and height affect energy output and performance and there appears to be an optimal stride length for every speed. However, Van Der Walt et al. (112) excluded pace length from his regression equation for predicting oxygen uptake. Hogberg (64) also stated that the most important method of increasing the length of stride was by a more powerful leg drive. Since leg strength is a limiting factor in children (53), it was chosen as a variable to be examined. In addition, the tibia and fibula are the last leg bones to grow; therefore, it may be a major limitation to increasing stride length (38, 70, 80, 106). Finally, Astrand (8) stated that young children are at a mechanical disadvantage when running on a treadmill owing to their shorter legs.

It is believed that the effect of learning would be of considerable interest in prepubescent boys. Conflicting results have been reported concerning the effect of training on mechanical efficiency (7). Repeated testings have shown that the efficiency of running increases as the subject becomes accustomed to the work (15, 32). Shephard (100) measured a 7% decrease in oxygen consumption over the first three treadmill runs and attributed it to skill learning.

To the knowledge of the author, there exist no data on many of the relationships to be examined in this study.

Assumptions

In this study, the following assumptions were made:

1. Determination of prepuberty will be on the basis of secondary sex characteristic of underarm hair. The upper

the range will be less than 13 years; therefore, limiting the chance of testing a subject who has reached puberty.

2. The subjects will work at a steady-state metabolism judged on the basis of steady, submaximal heart rate. The energy requirement will be basically from aerobic processes.

3. The total external work done per minute in running has a value of 0.25 Kcal/Kg.Km (16, 84).

Limitations

This study was subject to the following limitations:

1. The population was defined as boys aged ten to twelve years; therefore, the conclusions drawn from the research could be generalized only in this group.

2. Only submaximal, steady state running at a constant speed was investigated.

3. [illegible] techniques [illegible] estimating the amount of work [illegible] other studies difficult.

4. [illegible] an approximation of over-[illegible] of wind resistance, [illegible] and [illegible] differ somewhat between [illegible].

Delimitations

For reasons of time, availability of children and finances, this study was subject to the following delimitations:

1. Forty-six boys aged 9.3 to 12.9 years were randomly chosen from various programs of Edmonton Parks and Recreation to act as a sample representative of healthy prepubescent males.

2. Stratification into three subgroups based on age was done following the random sampling (<10.5; 10.5-11.4; >11.4)

3. The speed on running was determined on the basis of eliciting a steady state at approximately 85% of maximum (e.g. 70 Kg. man having a maximum heart rate of 195 b.p.m. would run at a dynamic equilibrium of 170 b.p.m.).

4. The length of the test was restricted to approximately five minutes (gas analyzed in final minute) since children tend to reach a steady state and fatigue more quickly than adults (9).

Definition [illegible]

The foll[illegible] hold for the terms used in this study:

Apparent me[illegible]. The ratio of the external work rate, [illegible] against gravity, and the corresponding n[illegible] [illegible]lic [illegible] the metabolic rate at zero load [illegible] [illegible]ted).

External work. The [illegible] total mechanical work necessary to sustain the [illegible] work against gravity (16).

Healthy. Free from disease or disability, and engaging, at least minimally, in recreational activity.

Inter-individual variance. That difference attributed to true differences between individuals.

Intra-individual variance. That difference attributed to biological variation in the functional status of the individual.

Oxygen uptake. The volume of oxygen (at 0°C. 760 mm Hg., dry, S.T.P.D.) extracted from the inspired air, usually expressed as litres per minute (VO_2). If the body is in steady state, the oxygen uptake equals the volume of oxygen utilized in the metabolic oxidation of foodstuffs.

Partial correlation. An observed relationship between two variables when other variables, which may have an influence, are kept constant (101:223).

Prepubescence. The period before which the secondary sex characteristics appear (109).

Running pattern. A coordinated movement of body parts used voluntarily or involuntarily to achieve a model which is basically characterized by continuous phases of support and recovery (81:32, [illegible]).

Steady state. The period during which the pulse rate and other organic functions have adapted to the work being performed.

CHAPTER II

REVIEW OF THE LITERATURE

Particular aspects of the energetics and mechanics of human locomotion have received considerable attention. Studies concerning children, however, have been few. The literature related to the mechanical efficiency of running is presented with emphasis placed upon the age and developmental factors.

The need for further research was outlined earlier. This chapter will deal with the literature in three main sections. The first section relates studies of energy expenditure and work production to mechanical efficiency. Various development characteristics of children and the effects on the mechanics of running are discussed in the second section. Finally, the effects of motor learning and training on the skill of running are presented.

Mechanical Efficiency: Energy Expenditure and Work Done in Running

Shortly after the turn of the century, there was evidenced an interest in the efficiency of the working human body as a machine. Efficiency has usually been defined as the ratio of external work accomplished to the metabolic cost of that work over and above the resting metabolism (59).

The energy necessary for speed maintenance in running has been measued from the oxygen consumption when the speed is such that a steady state can be attained and no oxygen debt is contracted during the period of measurement. At a constant and submaximal load, it has been shown that the more efficient person would have a lower oxygen intake during exercise as well as a smaller oxygen debt (5, 8, 59). It has also been found that under steady state conditions, the energy expenditure perkilometer of body weight, and per meter covered amounts to about 1 Kcal/m/Kg., independent of speed for a wide range (15, 28, 78, 85, 86, 92). Sargent (98) was one of the first researchers to establish this linear relationship between metabolic rate and speed of running. In addition, an increase in stride length was found to be directly related to the increase in running speed in trained runners (15, 64, 75).

Several attempts have been made to derive a general formula relating energy expenditure to speed and other variables (14, 34, [illegible] 102, [illegible]). Factors of speed, slope, load, weight and terrain [illegible] utilized to predict the energy cost of the horizontal and vertical components of running (34, 49). However, in most of these studies, the validity of the form of the equation used and the significance of the different terms of the equation have not been assessed. In an attempt to develop a simple statistical model to describe energy expenditure, it was shown that leg length and stride length significantly influenced the energy cost of running (112). Other researchers have used time/

distance relationships of performances to estimate and compare energy expenditures over varying distances (77, 79, 83).

Silverman and Anderson (102) ran children aged 6-11 years at treadmill speeds slightly slower than those used in the present study. The results were expressed in terms of multiple regression analyses relating oxygen consumption body weight, treadmill speed and gradient. Small differences that were observed when compared with other studies may be accounted for by the standard respiratory quotient (0.86) used to calculate the energy expended.

Astrand (6, 7) found that adult men of varying ages had similar oxygen uptakes per Kg. body weight at a given submaximal speed; however, children had relatively higher metabolic rates than adults reducing their mechanical efficiency. It has been suggested that the obvious differences between the energy expended by old and young are brought about mainly by variations on the economy of muscular movement and in the amount [illegible] activity (90). In some early experimental studies it was observed that no significant changes occurred with age after maturity, but boys from 6-13 years had lower mechanical efficiencies than older people (9). Various factors such as cardiac output, lung ventilation, respiratory quotient and muscle lactate concentrations have been shown to be lower in children than adults (31, 41).

Good agreement has been reported between average values of various methods of determining energy expenditure in pre-pubertal boys (60). However, the intra-individual differences were considerable. Inter-individual variances for running at a submaximal speed have also been reported between children of different ages (107).

Various size indices have been related to energy expenditure both for adults and children. The metabolic cost of running has been shown to be predicted accurately by gross body weight; in fact, a linear proportionality appears to exist (87, 90). Statistical analyses showed that no significant predictive value was gained by taking into account height, lean body, mass, body surface area, chest circumference, abdominal circumference, or resting metabolism (87, 95).

Knowledge of the mechanical work performed in the run has been very convenient because it allows the use of the treadmill as an ergometer. The work involved in running has been shown to be dissipated both internally and externally. It has been divided into [illegible] categories, energy dissipated because of frictional and viscous resistances in joints and muscles, and energy used in the continuous accelerations and decelerations of the mass of the body and of the limbs (74). An exact analysis of these requirements has been a problem because of geometrical complexities. As early as 1930, Fenn demonstrated that the vertical movements of the body, changes in horizontal velocity and kinetic energy of the limbs accounted for an appreciable fraction of the total energy of a sprint (46, 47). Using similar motion picture analysis, Elftman (38) has determined the resultant moments of force of the muscles acting about the joints of the limbs, and the rates at which they do work for a running step.

Cavagna et al. (16) reported that in running, the work due to forward speed changes (variation in kinetic energy) and to vertical displacement of the centre of gravity (variation in potential energy), were substantially in phase throughout the step cycle. A straight line was obtained by plotting the total external work done per minute in running against the speed. The slope of the line was a constant, independent of speed, having a value of 0.25 Kcal./Kg. Km.. Mechanical efficiencies of 40% to 50% were obtained with several healthy males aged 25-30 years.

Several methods have been used to estimate the mechanical work done in running. While running against a horizontal impeding force, it was noted that the mechanical efficiency was higher than that accepted for cycling and grade walking, and higher than the 25% often assumed to apply to running (78). The overall mean from these experiments was 36.1%. Pugh (93) provided results showing that the apparent efficiency of work against wind (69.0%) was greater than the apparent efficiency of the corresponding work against gravity (45.6%), as in running on a gradient. The rate of work done against the vertial force of gravity by a person running on a treadmill was calculated as a function of the speed and gross weight raised. Lukin et al. (82) have shown that the energy expenditure was a linear function of the gravitational work and appeared to be dependent upon the vertical lift per step multiplied by the number of steps taken per minute. Margaria (84) found that the potential energy and kinetic energy increased at the same time and the total positive work performed was the sum of the potential and kinetic changes.

In biochemical terms, the high efficiency values as those obtained by Pugh (93) have been questioned. At least half of the ATP energy has been lost as heat in running, implying that values for whole-body efficiency above 35% were unlikely (78). A substantial difference has been noted between direct measurements of the mechanical work performed and the positive and negative work calculated from the energy expenditure of level running (84). When running on the level, the negative external work was approximately equal to the positive work. The positive work performed in a step cycle in running has been found to be very high as compared with the energy expended, resulting in high efficiency values. This phenomenon has been interpreted as due, in part at least, to the elastic recoil of the contracted muscle stretched by inertial and gravitational forces (16, 17, 32, 46, 48, 61, 62, 74, 78, 84, 85, 110). The question of whether any negative work can be recovered in the reversal of energy-yielding biochemical processes in the muscles has been seriously considered since the 1920's, when Fenn observed that lengthening of a muscle during contraction decreased the heat production in the muscle (74). The utilization of muscle elasticity during rebound-type exercises has been shown to elicit greater mean power and mechanical efficiency (110). If a contracted muscle is stretched by an external force, elastic energy must be stored according to its elastic properties, as has been studied particularly by Hill (61, 62). The importance of this property of the contracted muscle in running, however, has been somewhat neglected in the research.

Developmental Characteristics Affecting the Mechanics of Running

The subject of running, fundamental as it is in athletics, has still been one in which even tentative claims to finality would be foolish in the face of so much that lacks universal acceptance. Fortunately, however, some aspects of running have been well established (12, 23, 33, 35, 36, 39, 50, 65, 66, [illegible]8, 111, 113). Rigorous mechanical descriptions of a mature running pattern have been provided by several researchers (68, 108, 111).

Other authors (12, 33, 38, 50, 106) have done cinematographical and electrogoniometric analyses of leg and body movement in running. Deshen's (3) results tended to support the concept that efficient running is characterized by a high knee lift, long stride, and placement of the foot as closely as possible beneath the centre of gravity. These factors, however, may not produce greater running speed. Sinning et al. (106) showed that distance runners increased velocity by increasing both step length and frequency; length played a greater part at lower velocity and frequency played a greater part at faster speeds.

Much of the research has been done on a treadmill which produced some variations in the mechanics of running. Nelson et al. (88) found treadmill running to be characterized by longer periods of support, lower vertical velocity, and less variability in vertical and horizontal velocities as compared to overground running.

Many authors have reported results of various running tests for children; they have usually been included in a test battery to measure speed performance (11, 13, 18, 21, 22, 30, 31, 42, 43, 44, 69, 76, 81, 99, 103, 107, 109, 113).

In a kinematic analysis of the development of the running pattern in preschool boys, Clouse (23) examined angles at joints and angular velocities at selected positions during a stride. Among the developmental trends noted, a steady increase in running speed was found through this age period which can be explained in terms of the steady increase in body size. The subsequent increases in lever length and strength have provided an increased length and frequency of the stride.

The ages of about six to twelve years have been reported a relatively slow and constant growth trend leading up to the pubescent growth spurt (30, 43, 44, 51). It has been a time of rapid learning characterized by the perfection and stabilization of previously acquired skills (44). Latchaw (76) found differences in motor skills with age groups from nine to thirteen years. She concluded that it appeared as if experience, or some form of maturation, would be a more significant factor in determining performance than would age.

Cinematographical studies of running have given evidence of similar developmental trends in this later childhood stage:

1. An increase in the length of the running stride (resulting in an increase in running speed).
2. A decrease in the relative amount of upward movement of the body in each stride.
3. An increase in the extension of the propulsive leg.
4. An increase in the amount of time in the non-support phase of the stride.
5. An increase in the closeness of the heel to the buttock on the forward swing of the recovery leg.
6. An increase in the height of the knee at the end of the forward leg swing.
7. A decrease in the relative distance the forward foot is ahead of the center of gravity when it makes contact with the ground (113:28-29).

Fortney (113:27) found similar improvement for twelve boys aged seven to eleven years over a five-year period regardless of their initial classification. However, distinct traits were identified that distinguished the good runners.

The mature running pattern has been described as a refinement of a basic technique (42, 89). Nett (89) has explained it as the basic course of a technical process of movement into which gradual changes must be introduced. These refinements in the outer course of motion, he has explained, are adapted to the inner dynamics and the rhythm of motion.

In an analysis of mean running performance of children six to nine years of age, Seils (99) revealed a rather constant increase. He obtained the highest correlation (r = .51) between skeletal maturity and running performance. Similarly, Espenschade (43) found that, with boys aged 12-15 years, approximately 25% of the variance in running performance was accounted for by the combined factors of age, height, and weight.

Maximum running speed has been shown to be directly proportional to the maximum strength of the muscles and to the distance over which they can shorten, but inversely proportional to the mass which must be moved (3, 8, 9). Asmussen et al.(4) has shown that the large increases in acceleration with growth may be traced back to the additional increase in muscular strength. The fact that biological factors modify muscular dynamics would account for deviation in a strict body dimensional model. Running performance, which demands high muscular exertion, would increase with height at a much greater rate than predicted by dimensions (53). This increase in strength during growth has been explained as the result of a better mastery of the neuromuscular system, evidently aided by a consequent better muscular development (13, 109). It has been suggested that running at a steady state requires less skill than maximal running and that this skill or ability to coordinate increases between the ages of seven to sixteen years (4).

Gross strength tests were one of the best differentiators of athletic ability as shown in the Medford project (18). When activities were analyzed in terms of the amount of force or energy required, a substantial relationship was found to exist between static and dynamic strength (44). Most significant correlations were found for boys aged ten and twelve years.

With the steady increments that have been reported in body size and in strength, there can be expected consistent increments also in the basic skill of running during later childhood. Longitudinal data have indicated that peaking of the strength spurt occurs about one and one half years after peak height increases and about a year after peak weight gains (44). In general, the pubescent boy gains steadily in running performances when speed is the criterion; however, Clearley (22) determined that the relationship between performance [illegible] six-second run, age, height and weight for the boys aged [illegible] years was nonlinear.

The steady increase in running speed during the period of prepubescense has been explained in terms of the steady increase in lever length and strength providing increased stride length and frequency (15, 54). The essence of steady-speed running has been regarded as the exact, alternate repetition, by arms and legs of the movement pattern associated with each stride and described as the relation: running speed = stride rate x stride length.

By means of closed path tracings of the ankle joints of a sprinter and a miler, Hopper (65) has treated these quantities with a different perspective. He has suggested that the above relation was reversed and that the rate at which the grounded foot passed under the body was the main factor which determined both stride frequency and stride length. Rapp (94) reported that changes in the velocity of the runner resulted in significant differences in the mean stride length between a 2-mile pace and an 880-yard pace, as well as between the 2-mile pace and a sprint.

Boje (15) found that increased speed was compensated for by a greater length of stride. Coefficients of correlation have been reported which have shown a more significant relationship between the length and frequency of stride with the leg length than with height among top class sprinters (63). The studies of Knuttgen (75) and Hogberg (64) have indicated that an optimum stride length exists for every speed and runner and this length provided the highest mechanical efficiency. [illegible] Wait and Wyndham (112) have shown that differences between individuals' stride length and leg length significantly influenced the energy cost of running. The most important factor effecting the stride length has been suggested to relate back to the power of the leg drive (64).

Clouse (23) reported an increased ratio of length of stride to length of extremity in the running pattern of preschool boys, probably due to increased strength.

Slightly older children were found to be at a mechanical disadvantage owing to their shorter legs which was suggested as a possible reason for the increased oxygen consumption per Kg. body weight (6, 90).

Trained Versus Untrained: Motor Learning of the Running Skill

Many track and field events have been classified as technique skills; that is, skills where the motor action itself is of paramount importance (24, 35, 89). People have demonstrated that they learn in various ways, but the learning processes are affected by two major factors: the learner's attributes, and the skill being learned (24, 25, 30, 89, 104, 113). Economy of effort has been the result of learned and skilled movements of the body and its ability to adapt to the rate and load of work being accomplished. It has been shown that at a constant and submaximal load, the more efficient person would have a lower oxygen intake during exercise (7).

Much of the variance in mechanical efficiency scores for running has been due to the extent of training of the runners (16, 47, 77, 79, 93). Hubbard (66) has reported fundamental differences in the actions of certain key muscles of the lower limb between trained and untrained runners.

Several early studies were conducted on other basic motor skills in relation to the effects of training and learning. For adult subjects the training effect for walking was minimal (29, 40). It was suggested that the reduction in the energy expenditure during training was the result of better muscular coordination rather than increased muscular efficiency (29). Hellebrandt et al. (57) explained that the pattern of central nervous integration expands with growth and development of all the mechanisms evolved to generate and release the energy quantum required.

Research concerning improvements in energy cost and mechanical efficiency of running have reported varying findings. The evidence that there are no significant metabolic differences in repeated performance of standardized muscular work, however, has not been great. Most subjects who were well trained runners showed little, if any, improvement in running skill and efficiency (32, 78). It has also been demonstrated that with longer training periods, there appeared to be a plateau in the running efficiency. It has been suggested that the technique of superior runners and that of a slightly inferior [illegible] differ little and can be presumed to be very nearly perfect in an athletic exercise like running (15, 86).

Boje (15) found no certain differences in energy consumption in trained runners while it was slightly higher in untrained subjects. Margaria et al. (86) reported the mechanical efficiency of running to be about 5-7% higher in the athletes than in untrained subjects. A 7% decrease in oxygen consumption over the first three treadmill runs was observed by Shephard (100), which he presumed to be due to learning. A change of this order could have arisen purely from a decrease in "lift work," without other changes in efficiency (29). Davies and Barnes (32) have stated that the efficiency of both positive and negative work depend on the degree of habituation. However, they added that although adult subjects had habituated to the exercise, the learning and increased skill of performing may have been minimal.

Many track experts have been in agreement concerning the effects of repeated exercise on young athletes (7, 10, 35). Several authors have cited that the fine form in skills, like running, must be effected at an early age and the extent and rate of learning are influenced by the age of the learners (13, 24, 89, 103, 104, 113). However, Heilebrandt et al. (57) have emphasized that the learned aspects of skill cannot be differentiated unequivocally from the patterning of the neuromuscular response. Astrand (8) has recently stated that the improvement in performance with age is partly a question of increased body dimensions, but also a "maturity" of the central nervous system, an eventual effect of practice.

Retention of motor skills has been shown to increase between the ages of 2 to 6 years (103). Although developmental trends may be due to growth and maturation or gain in skill due to experience, several authors have outlined characteristic changes in the running pattern during later childhood (12, 30, 44, 52, 54, 76, 81, 109, 113). It has been shown that well trained athletes were able to freely choose their most economical stride length; however, no evidence appears to exist concerning children (15, 64, 75).

Summary

The following brief generalizations were made in an attempt to summarize the major findings of the research.

1. The energy necessary for speed maintenance in running has been measured from the oxygen consumption when the speed is such that a steady state can be attained and no oxygen debt is contracted during the period of measurement.

2. The energy expenditure per kilogram of body weight and meter covered has been found to amount to about 1 Kcal./m.Kg., independent of speed for a wide range.

3. Several attempts have been made to derive a general formula relating energy expenditure to speed and other variables.

4. Higher metabolic [illegible] economy of muscular movement have been suggested as reasons for lower mechanical efficiencies with children.

5. Gross body weight was reported as being the best indicator of energy expenditure for running.

6. The total positive work performed has been estimated by summing the potential and kinetic energy changes.

7. High values reported for mechanical efficiency (40-50%) have been suggested to be the result of substantial

storage of elastic recoil energy from stretched contracted muscle.

8. Research examining the characteristics of a mature running pattern have been described.

9. Cinematographical studies of running have given evidence of similar developmental trends in the later childhood stage.

10. Increases in size, strength, and coordination have been discussed with respect to their effects on running with children. Special emphasis was given to the stride length.

11. Most well trained athletes showed little, if any, improvement in running efficiency; however, their scores were generally 5-7% higher than untrained subjects. A similar decrease in energy cost over the first three treadmill runs has been reported.

12. Characteristic developmental trends have been suggested as due to growth and maturation or gain in skill due to experience and [illegible] neuromuscular response.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this chapter is to identify the various research procedures used in the study. Topics include identification of population and sampling techniques, design of the study, test descriptions and instrumentation, administration of tests, and statistical treatment.

Identification of Population and Sampling Techniques

A group of randomly selected boys was taken as a sample which represented healthy pre-pubescent males. The [illegible] Recreation Department provided registration information from a number of programs (Fall, 1973). Letters of [illegible] (Appendix A) were mailed to all boys aged nine to twelve years (N = [illegible]). Forty-nine responses were received of which forty-[illegible] were affirmative. Scheduled test times [illegible] completed three [illegible].

The subjects were placed into one of three groups with respect to their ages: (a) under 10.5 years; (b) 10.5 to 11.4 years; and (c) over 11.4 years. This classification [illegible] groups of twenty, thirteen and thirteen; their respective age ranges were 9.3 to 10.4 years, 10.5 to 11.4 years and 11.5 to 12.9 years.

Design of the Study

Following a short pilot project, data collection covered a period of seven weeks. Every subject was given three dates to be tested, each two weeks apart. The two-week period was considered sufficiently short to allow the investigation of a possible 'learning' trend.

Several measures were repeated at each test session. These included weight, 'standing' metabolic rate, steady state oxygen consumption, number of strides, heart rate, and environmental data. Puberty identification and anatomical measurements were done only during the first testing. Leg strength measures were taken during the final test session.

Test Descriptions and Instrumentation

Prior to any data collection, each boy performed what the author termed the "Pass-Fail One Arm Reach Test." The period of prepubescence has been functionally defined as the period before which the secondary sex characteristics appear (109). The test was performed with no shirt and was designed to detect the presence of under arm hair.

In preparation for the pilot project (N=1), the following instruments were calibrated: treadmill (27:33); electrocardiogram (paper speed); Beckman oxygen analyzer (model E2 manual): Godart carbon dioxide analyzer (manual); Beckman dry gas volumeter (against a calibrated Tissot gasometer); strength dynamometer (105); and the Honeywell Biomedical Recorder (manual). The E.C.G., gas analyzers, and dynamometer were calibrated each day of testing. The pilot project provided several procedural improvements. Smaller nose clips and mouthpiece were used for the actual study. Tape was also placed on the wall facing the treadmill to aid in body alignment and line of vision while running on the treadmill.

The rate of oxygen consumption was measured while standing on the treadmill with no support once the heart rate had fallen below 100 b.p.m. (26:337). The subject was then given instructions for stepping on a moving treadmill. Once the subject demonstrated the ability to walk and run slowly, the treadmill speed was raised in small increments until the heart rate maintained a desired steady state level for at least one minute. The desired heart rates ranged from 176 b.p.m. to 183 b.p.m. depending on age (9:312). This procedure was generally [illegible] four to six minutes long. The rate of oxygen consumption was again measured during the next minute of steady state submaximal running (26:343). The number of strides was counted for the minute of inspired air measurement.

The caloric equivalents for oxygen uptake were obtained from the calculated respiratory quotients (27:439). The differences between the running and standing energy expenditures provided a measurement of the energy cost of running. The rate of doing work was calculated using the subjects' weight and the speed of the treadmill (W=Fv) and a standard conversion to energy units (29, 74, 84, 93). The apparent mechanical efficiency was determined as the ratio of the external work rate and the corresponding increase in metabolic rate.

The height and weight were recorded and the body surface area was obtained from this data (27:27). A Gulick tape was used to measure leg length and lower leg length. With no shoes worn, the distance from the floor to the iliac crest was taken as the leg length (112:559). The lower leg length was the distance from the floor to the medial articulation line of the knee (15:365). The leg strength was determined as the maximum isometric force produced at a knee angle of 115°. A reliable (r=0.97) continuous recording from the load cell of the dynamometer was provided by the Honeywell recorder (105). The average distance travelled in one step or stride length was the quotient of the distance travelled and the stride frequency for the minute of gas analysis.

Administration of Tests

Four examiners were used in administering the various testing procedures. The chief investigator and two trained assistants collected the metabolic data. A third assistant tested leg strength and recorded the anatomical measurements of leg size. Each examiner performed a specific function during the entire collection of data.

The subjects were instructed to wear running shoes and shorts or non-restrictive pants. A minimum of instruction was given, although ample warmup time was provided. Parents and other observers were not permitted entry into the research laboratory until completion of the test.

Temperature, barometric pressure, and relative humidity were recorded for each subject prior to the treadmill testing.

Statistical Treatment

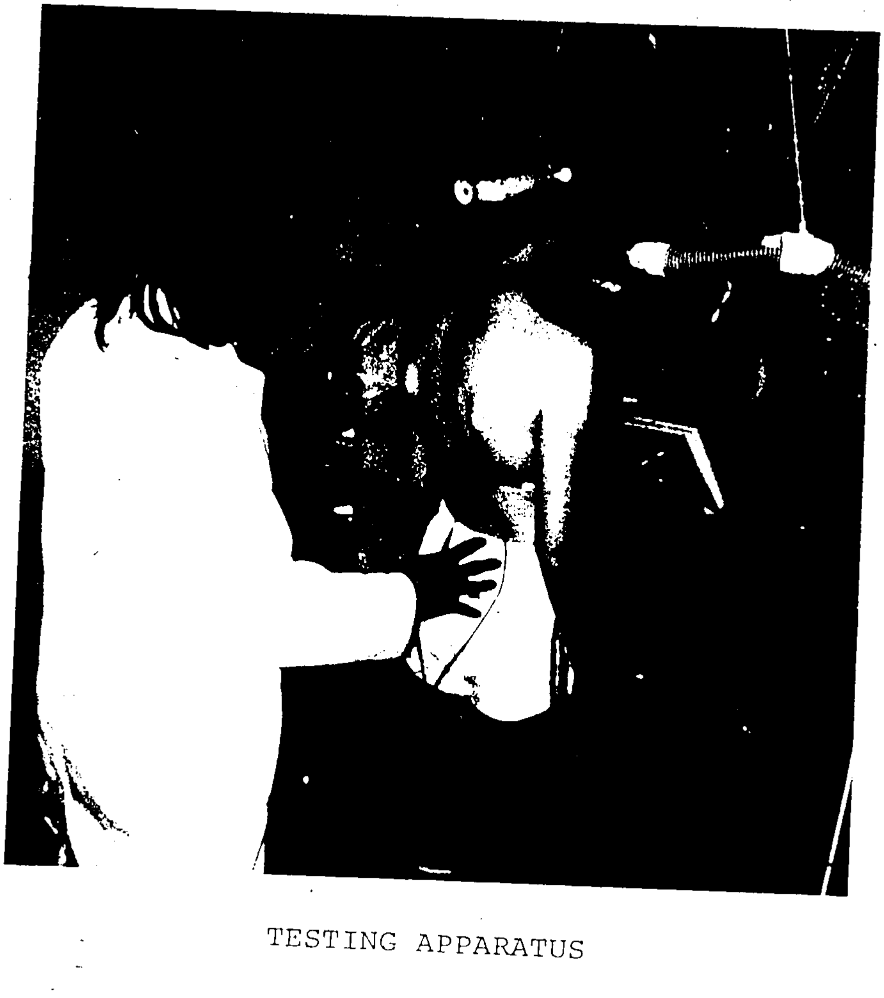
Preliminary calculations of the metabolic data were done utilizing an APL/1500 terminal and a Sony Sobax calculator. Statistical treatment employed the Communications Terminal of an IBM 360/67 computer located in the Physical Education Building at the University of Alberta.

Existence of differences in mechanical efficiency scores between the three age groups were tested for significance by a one-way analysis of variance (114). The significance level of 0.05 was set prior to the treatment.

Following a description of the means and standard deviations of the variables in question, a multiple correlation matrix was obtained (1, 114). Correlations with mechanical efficiency were tested for significance at the 0.05 level (114). Several partial correlations, keeping age constant, were calculated for selected variables (101, 114). Utilizing eight predictor variables and the criterion of mechanical efficiency, a stepwise regression was applied

(114). The percent of the variance accounted for in each step was tested for significance at the 0.05 level. At the same confidence level, the significance of prediction was tested using a Student's t-test (1).

The differences in mechanical efficiency between the three trials with each age group was tested by means of a two-way analysis of variance with repeated measures on the trial factor (114). A t-test comparing related or dependent means was applied between trials to locate significant mean differences at the 0.05 level.



TESTING APPARATUS

CHAPTER IV

RESULTS AND DISCUSSION

Physical Characteristics of the Subjects

Mean and range values for age, height, weight and body surface area are depicted in Table I. The forty-six male subjects who participated in the investigation were classified by age into groups A (N=20), B (N=13), and C (N=13). Total group data are also displayed.

Differences in Mechanical Efficiency Between Age Groups

A primary objective of the present investigation was to determine the maturity of the running pattern of prepubescent boys on the basis of measurements of the mechanical efficiency. For this purpose, an average value of mechanical efficiency was taken between the second and third trials. It was believed that this would provide the best indication of the subjects' running efficiency (44, 100, 104).

The differences in mechanical efficiency between the three age groups are shown in Table II. A comparison of these main differences may be graphically seen in Figure 1. The average mechanical efficiency for the entire sample was 23.82 percent.

TABLE I

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

PARAMETER	GROUP	MEAN	RANGE
AGE (Years)	A	9.8	9.3 - 10.1
	B	10.9	10.5 - 11.4
	C	12.3	11.5 - 12.9
	TOTAL (N = 46)	10.8	9.3 - 12.9
HEIGHT (cms.)	A	140	127 - 152
	B	148	137 - 161
	C	153	141 - 164
	TOTAL (N = 46)	146	127 - 164
WEIGHT (Kgs.)	A	32.4	24.5 - 42.5
	B	37.2	32.4 - 47.0
	C	44.0	34.2 - 58.4
	TOTAL (N = 46)	37.0	24.5 - 58.4
BODY SURFACE AREA (M^2)	A	1.12	0.91 - 1.34
	B	1.24	1.11 - 1.41
	C	1.37	1.16 - 1.54
	TOTAL (N = 46)	1.23	0.91 - 1.54

TABLE II

DIFFERENCES IN MECHANICAL EFFICIENCY BETWEEN AGE GROUPS

GROUP	NUMBER IN GROUP	MEAN MECHANICAL EFFICIENCY	STANDARD DEVIATION
A	[illegible]	23.93%	2.59
B	[illegible]	23.24%	1.85
C	[illegible]	25.06%	2.44
TOTAL	[illegible]	23.82%	2.41

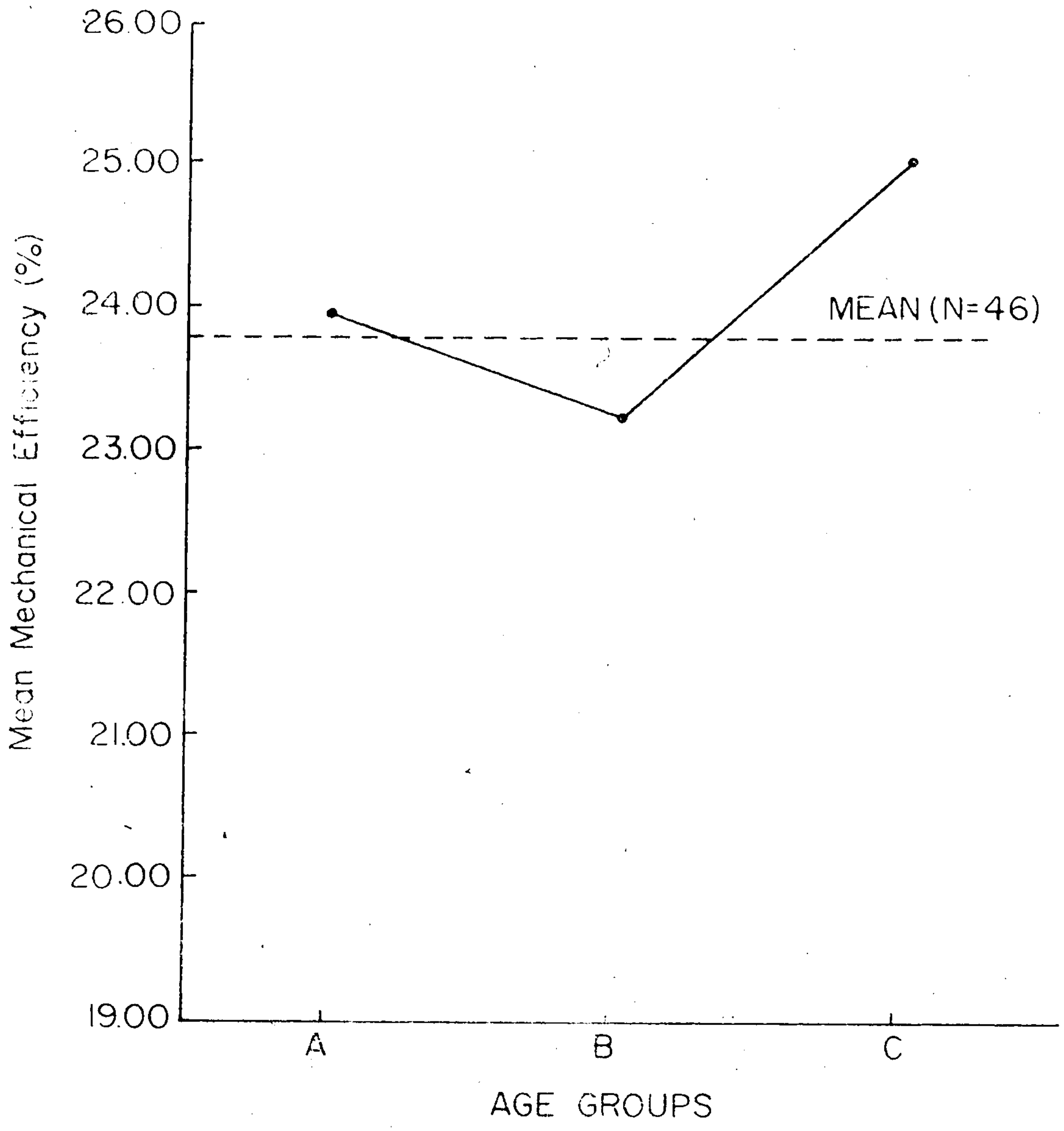


FIGURE 1

DIFFERENCES IN MECHANICAL EFFICIENCY

BETWEEN AGE GROUPS

The significance of the differences between age groups was tested by a one-way analysis of variance. Table III indicates a summary of the analysis. Although group C demonstrated an increased mean score for mechanical efficiency no significant differences were noted between age groups at the 0.05 level.

Influence of Selected Variables on Mechanical Efficiency

The mean and standard deviation of a number of variables measured are presented in Table IV. They were average values for the entire sample (N=46).

Inter-correlation matrix. Nine of the above variables were selected for correlation procedures: age, height, leg strength, leg length, lower leg length, body surface area, weight, average stride length, and average mechanical efficiency (T_2 and T_3). Inter-correlations may be seen in Table V.

The significance of the correlation between the first eight variables and the average mechanical efficiency was examined at the 0.05 level (14). The Pearson Product-moment correlation coefficients for stride length (r=0.44) and leg strength (r=0.32) were significant. The highest correlation coefficient between mechanical efficiency and age, weight, or body surface area was age (r=0.25). Between the linear measurements of height, leg length, and lower leg length, it was found that leg length correlated most highly with mechanical efficiency of running (r=0.20).

TABLE III

ONE-WAY ANALYSIS OF VARIANCE BETWEEN MEAN AGE GROUP SCORES FOR MECHANICAL EFFICIENCY

SOURCE OF VARIATION	SUM OF SQUARES	MEAN SQUARE	DF	F
GROUPS	27.82	13.91	2	2.49[1]
ERROR	240.37	5.59	43	

---

[1] P(F) = 0.095 Not significant at the 0.05 level.

TABLE IV

DESCRIPTION OF VARIABLES

VARIABLE	MEAN	STANDARD DEVIATION
Age (Years)	10.80	1.12
Height (cms.)	145.7	9.2
Leg Strength (Kgs.)	93.6	27.6
Leg Length (cms.)	89.98	7.35
Lower Leg Length (cms.)	42.78	3.55
Speed (M/sec.)-T_1	2.53	0.28
Stride Length (m)-T_1	0.82	0.11
Speed -T_2	2.72	0.27
Stride Length -T_2	0.87	0.12
Speed -T_3	2.79	0.27
Stride Length -T_3	0.90	0.12
Average Stride Length (T_2,T_3)	0.88	0.12
Weight (Kgs.)	37.02	7.01
Body Surface Area (M^2)	1.225	0.153
Mechanical Efficiency (%)-T_1	20.24	4.11
Mechanical Efficiency (%)-T_2	23.06	3.48
Mechanical Efficiency (%)-T_3	24.60	3.56
Average Mechanical Efficiency (T_2,T_3)	23.82	[illegible]

[illegible]

	AGE 1	HEIGHT 2	[illegible] 3	[illegible] 4	LOWER LEG LENGTH 5	BODY SURFACE AREA 6	WEIGHT 7	AVERAGE STRIDE LENGTH 8	AVERAGE MECHANICAL EFFICIENCY 9
1	1.000	[illegible]	[illegible]	[illegible]	[illegible]	0.737	0.707	[illegible]	0.249
2		1.000	[illegible]	[illegible]	0.924	0.934	0.81[illegible]	0.61[illegible]	0.15[illegible]
3			[illegible]	[illegible]	0.217	0.306	0.327	0.39[illegible]	0.324*
4				[illegible]	0.951	0.913	0.900	0.611	0.214
5					1.000	0.922	0.930	0.62[illegible]	0.151
6						1.000	0.958*	0.55[illegible]	0.183
7							1.000	0.525	0.214
8								1.000	0.436*
9									1.000

*Significant at the 0.05 level. Critical value = 0.291

Partial correlations. Of particular interest were [illegible] relations between stride length and mechanical [illegible] and leg strength and mechanical efficiency. [illegible] partial correlations allowed an examination of the relationships [illegible] with the effects of a third variable [illegible]. When age was held constant, the correlation [illegible] between mechanical efficiency and leg strength [illegible] than between efficiency and stride [illegible]. Table VI displays the coefficients of correlation [illegible] percent variance accounted for. The relationship [illegible] stride length and leg strength (r=0.40) was [illegible] the effect of age was eliminated (r [illegible]).

[illegible]. In an attempt to examine the [illegible] mechanical efficiency, a stepwise regression [illegible] applied [illegible]. The first eight variables [illegible] order of their value as pre[illegible] [illegible] leg strength, [illegible] length, [illegible]. [illegible] from 14.98 with [illegible] eight variables, there were no [illegible] after the first variable was [illegible].

[illegible] a brief summary of the [illegible] equation used to predict the mechanical efficiency [illegible], steady-state running in pre-pubescent boys:

[illegible] efficiency = [illegible] + 9.111 (stride length).

TABLE VI

PARTIAL CORRELATIONS BETWEEN SELECTED VARIABLES

VARIABLES CORRELATED	VARIABLES HELD CONSTANT	CORRELATION COEFFICIENT	% OF RESIDUAL VARIANCE ACCOUNTED FOR
Mech. Effic. & Stride Length		0.436	19.01%
Mech. Effic. & Stride Length	Age	0.372	13.84%
Mech. Effic. & Leg Strength		0.324	10.50%
Mech. Effic. & Leg Strength	Age	0.226	5.11%
Stride Length & Leg Strength		0.399	15.92%
Stride Length & Leg Strength	Age	0.140	1.96%

TABLE VII

SUMMARY AND DESCRIPTION OF THE STEPWISE REGRESSION

VARIABLE	WEIGHT	CONSTANT	% VARIANCE ACCOUNTED FOR	STANDARD ERROR OF PREDICTION	R (OBSERVED, PREDICTED)	t VALUE
Stride Length	9.111	15.976	18.98	2.23	0.425*	0.151[1]

*Significant at the 0.01 level.
[1] Not significant at the 0.01 level.

The correlation coefficient between observed and predicted values of mechanical efficiency was 0.425 which was significant at the 0.01 level. At the same level of confidence, a t-test revealed no significant differences between the mean values of observed and predicted scores (Table VII). A graphic comparison may be seen in Figure 2.

Differences in Mechanical Efficiency Between Test Sessions

A final objective of the present investigation was to determine the effect of repeated trials on the scores of mechanical efficiency of running. Mean mechanical efficiency values and mean differences are shown in Table VIII. Improvement was assessed for each age-group and a total for the three trials. The greatest improvement over the three test sessions was demonstrated by the older group C (6.18). The sample as a whole demonstrated a greater improvement between trial one and two (2.82%) than between trial two and three (1.54%). General rate and extent of improvement between trials for each age group may be seen in Figure 3. The average values for the sample (N=46) are also plotted. In addition, increases over the three trials were also found for average speed and average stride length (Table IV).

The significance of the differences between trials with each age group was tested by a two-way analysis of variance with repeated measures of mechanical efficiency for the test sessions. Table IX provides a summary of the

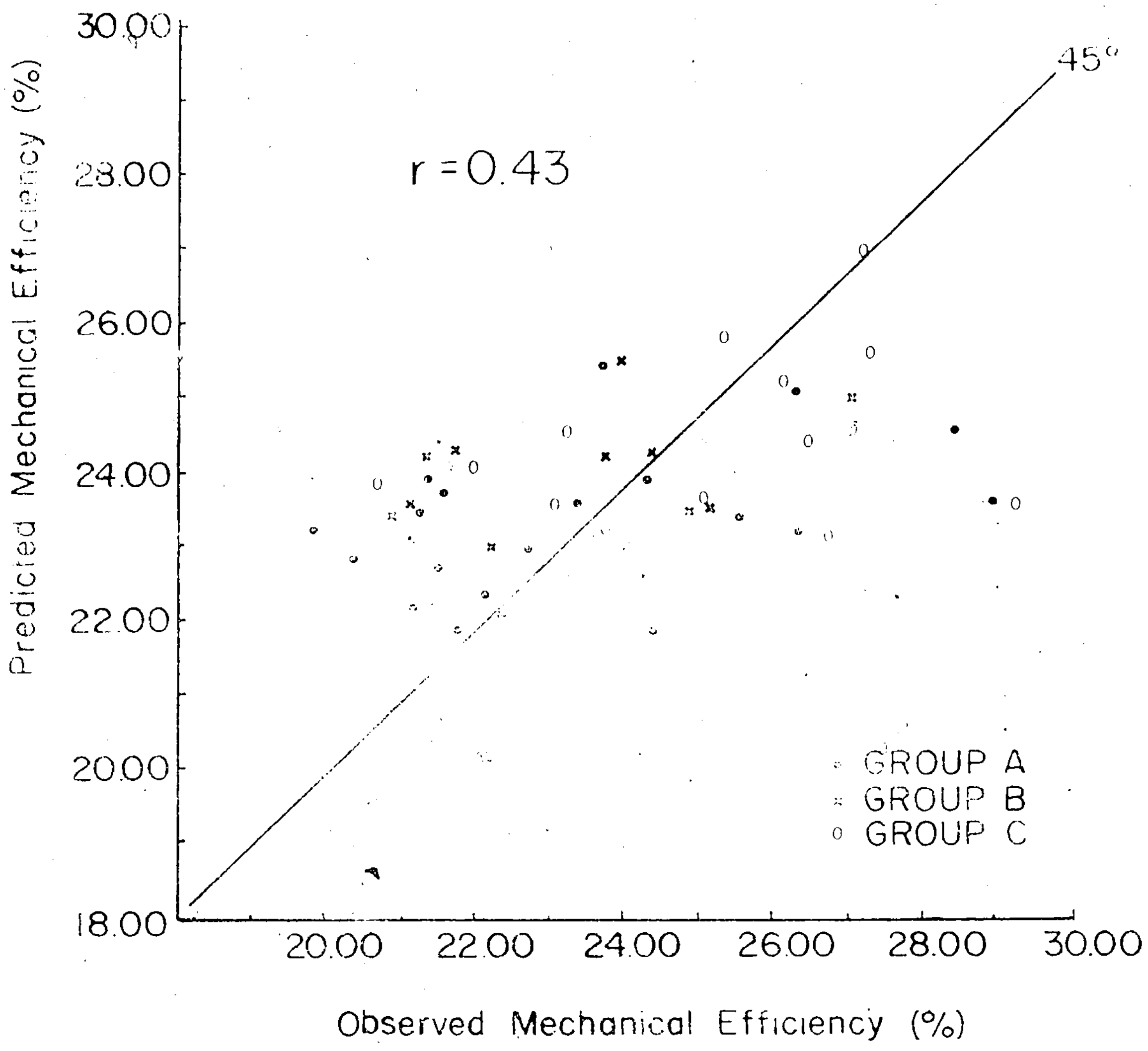


FIGURE 2

COMPARISON BETWEEN OBSERVED AND PREDICTED VALUES FOR MECHANICAL EFFICIENCY

TABLE VIII

DIFFERENCES IN MECHANICAL EFFICIENCY

BETWEEN TRIALS

	MEAN MECHANICAL EFFICIENCY (MEAN DIFFERENCES)					
TRIAL NUMBER	1		2		3	TOTAL
Group A	20.51%	(2.56)	23.07%	(0.66)	23.73%	3.22
Group B	20.[illegible]	(1.51)	21.86%	(2.74)	24.60%	4.25
Group C	19.[illegible]	(4.53)	24.23%	(1.65)	25.88%	6.19
TOTAL (N = 46)	[illegible]	(2.62)	23.06%	(1.54)	24.60%	4.36

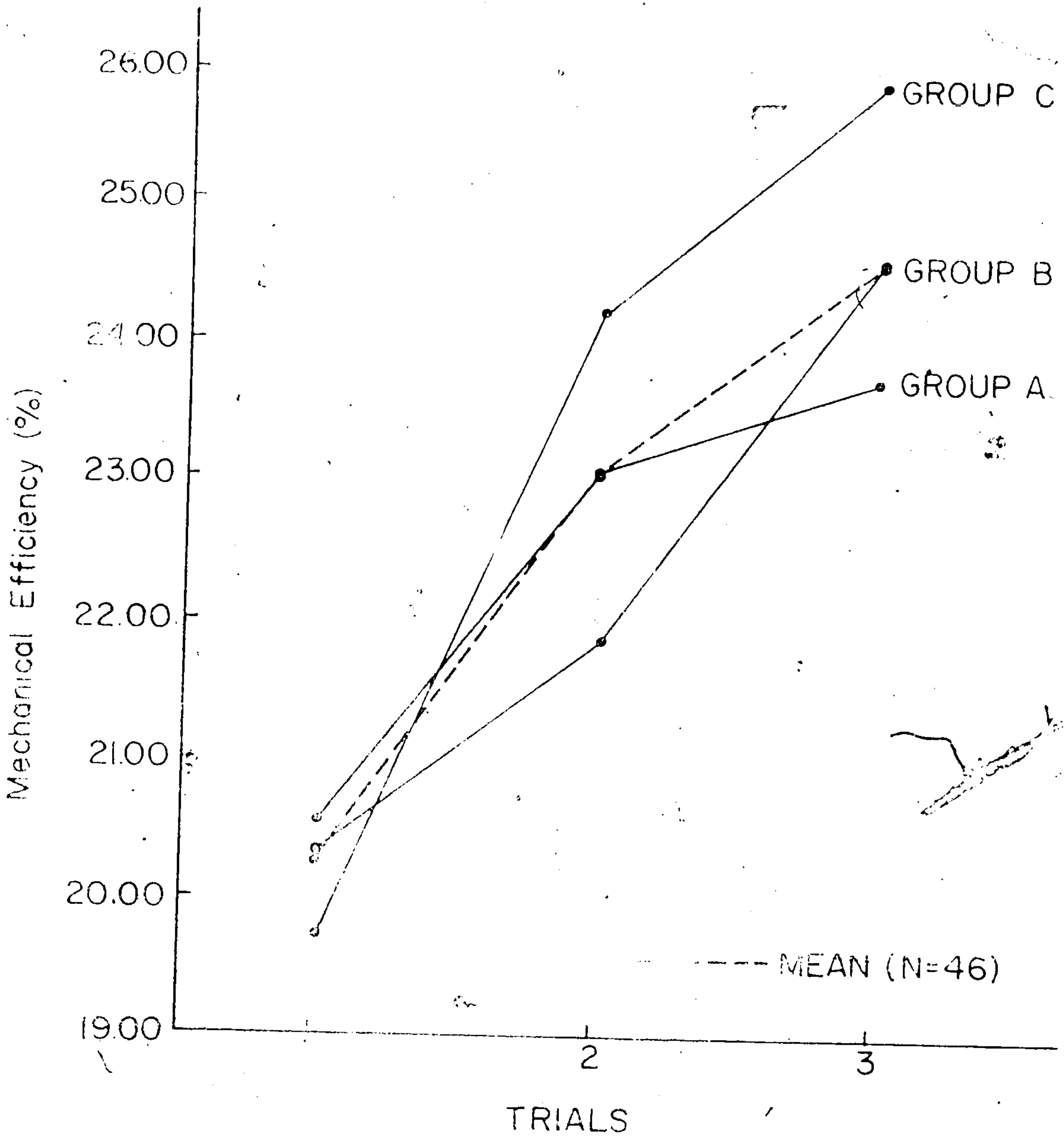


FIGURE 3

DIFFERENCES IN MECHANICAL EFFICIENCY

BETWEEN TRIALS

TABLE IX

TWO-WAY ANALYSIS OF VARIANCE WITH REPEATED MEASURES OF MECHANICAL EFFICIENCY FOR THE TEST TRIALS

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F
Between Groups 'A'	25.41	2	12.71	0.690
Error 'A'	791.50	43	18.41	
Between Trials 'B'	466.63	2	233.32	19.990*
AB Interaction	55.87	4	13.96	1.196
Error 'B'	003.75	86	11.67	

*Significant at the 0.05 level.

analysis. As demonstrated earlier, there were no differences between the age groups. In addition, the interaction between age and trials was not significant. However, a significant B or trial effect was found at the 0.05 level.

In order to determine specific mean differences, a t test for comparing dependent or related means taking two at a time was employed. Significant differences were found to exist between all comparison (T_1 vs T_2; T_1 vs T_3; T_2 vs T_3) at the 0.05 level. A summary of the analysis is depicted in Table X.

Discussion

The human body, viewed as a machine, is far more involved than even the most modern mechanism of the times. However, the degree of skill demonstrated by the individual may be influenced by such factors as age, size, strength, and amount of practice. Several studies have examined the skill of running by means of mechanical efficiency measures in adults and athletes ([illegible], 78, 81, [illegible]). Few considerations have been made, however, with respect to children (7, 102). The purpose of the present investigation was to examine the mechanical efficiency of steady state running in preadolescent boys. In addition, several factors were assessed as to their influence on the economy of running. And finally, the effect of repeated trials on the efficiency was considered.

TABLE X

T-TEST FOR DEPENDENT TRIAL MEANS

T_1 vs T_2	T_1 vs T_3	T_2 vs T_3
0.271	r = 0.189	r = -0.017
4.54*	t = 6.58*	t = 2.08*

*Significant at the 0.05 level. t(0.95, 45) = 1.681

Differences in Mechanical Efficiency Between Age Groups

Various authors have provided descriptive evidence of general biomechanical trends in the development of a more mature running pattern in children (12, 23, 54, 113). The present study has utilized the measure of mechanical efficiency to determine the economy of effort and skill involved in steady state running.

Comparisons with other studies involving athletes is difficult due to the varied methods of assessing the total work accomplished by each runner. Margaria (84) has claimed that the efficiency of vertical work is similar to that contracting muscle; that is, about 25 percent. However, other researchers have reported much higher efficiencies, especially in grade running (16, 17, 78, 92, 93).

Nonetheless, comparisons within the sample can be made. Differences in mechanical efficiency between the three age groups are summarized in Table II and III and Figure [illegible]. No significant differences were reported; however, the older group of boys demonstrated a somewhat higher score than the younger groups. Although comparisons with other studies should be made with some reservation, the mean mechanical efficiency for the entire sample of pre-pubescent boys was 23.82%.

The fact that the range of ages was not large, and secondly, the speed of running was adjusted to the physiological capabilities of the subjects would provide some explanation for the absence of significant differences. The apparent upward trend in the older group demands further investigation. Reasons for the increase just prior to the age of puberty are speculative, but the greater height, speed and stride length may have contributed to the efficiency. The possibility exists that energy stored when stretching the contracted muscles can be utilized as elastic recoil energy (16, 17, 32, 48, 61, 62, 74, 84, 85, 93, 110).

Very few spurious results occurred; however, those that were recorded had respiratory quotients greater than 1.0. In these isolated circumstances, the activity of anaerobic energy sources may have effected and measured energy expenditure (67).

Influence of Selected Variables on Mechanical Efficiency

It has been noted that from the age of about ten, the body proportions are similar (9, 51). For 11 to 12-year old boys there is no significant variation in speed with body size (8, 43, 44). Other research has indicated that energy expenditure may be affected by weight, body surface area, and stride length (15, 22, 43, 60, 64, 72, 87, 90, 95, 102). The assessment of the influences of such variables is especially critical when examining children.

The only variables which significantly correlated with mechanical efficiency were stride length and leg strength. The contributions of age, height, leg length, body surface area, and weight were below the critical correlation value. Cearley (22) has also reported little relationship between running performance and age, height, and weight in children.

The utilization of partial correlations enabled comparisons of two variables with the effects of age nullified. With the influences of age upon both mechanical efficiency and stride length ruled out, the correlation between the two was still significant (r=0.37). However, when age was held constant for the correlation of leg strength and mechanical efficiency, the result was not significant (r=0.23). The correlation between stride length and leg strength was 0.40 and the correlation between stride length and age was 0.51. By partialing out age, it was found that the correlation between leg strength and stride length nearly vanished ($r^2=1.96\%$). It appears that leg strength as such has no bearing upon stride length when running at a submaximal speed. This lack of relationship may not apply to sprint running.

The application of a stepwise regression revealed that no significantly greater account of variance could be made by using more than one predictor variable. The relationship between running performance and age, height, and weight have been shown to be nonlinear in children (22). Although leg strength was the second predictor variable entered, it was shown by partial correlation that its association was by virtue of its relation to age. Van Der

Walt (112) has used stride length in combination with mass, speed, and leg length to predict the energy expenditure of running. The mechanical efficiency in the present investigation was predicted with reasonable precision (r 0.43) from the average length of stride in a submaximal, steady state run.

Since no significant differences were noted between age groups, the regression equation may be considered to be applicable to boys in the few years preceding puberty. Although the standard error of prediction was quite high (2.23), the equation may be a useful estimate of running efficiency if the runner has reached a submaximal steady state comparable to the method used in the present investigation.

It has been suggested that the energy cost of running on the level is greater in children owing to their shorter strides and is dependent on their ability to adjust the stride length to adapt to a selected speed (7, 75, 90). Several cinematographical analyses have shown that an increase in the length of the running stride is a distinct developmental trend (12, 113).

Differences in Mechanical Efficiency Between Test Sessions

It has been found in several studies that the efficiency increases as the subject becomes accustomed to the work (15, 100). Economy of effort is the result of skilled movements of the body and its ability to adapt to the rate and load of work being accomplished. However, in trained athletes, the influence of habituation on mechanical efficiency has been [illegible] significant (78). Improvement in the ski[illegible]mill running may be expected with children.

Differences in mechanical efficiency for each age group between trials has been summarized in Tables VIII, IX, X, and Figure 3. When the entire sample was considered, there was shown to be significant improvement between both the first and second trials and the second and third trials. With the exception of group B, the rate of improvement was greater between the first two trials. The increase in stride length over the three trials seems to be an adaptive process to the speed of the treadmill (Table IV). The most economical stride length appeared to be chosen during the final trial for most of the subjects.

As can be readily seen in Figure 3, the oldest group demonstrated the greatest rate of [illegible] and [illegible] skill improvement over the three repeated trials. This in itself is an interesting finding. Astrand (8) has suggested that the better performance of 12-year-old to 11-year-old boys may be due to the maturity of the neuromuscular function, improving the coordination. Extra increases in strength during growth have also been explained as the result of a better mastery of the neuromuscular system in older children (3).

It is suggested by the author that the ability of the older boys to adapt to a more mature running pattern may be due to an increased kinesthetic sensitivity. Greater awareness of the kinesthetic sense would facilitate learning and refinements when performing a relatively new skill (13, 104). Whatever the explanation, the results indicate that the time immediately preceding puberty may be the best period to introduce and teach new or refinements of old motor skills.

Work is done uneconomically when a new skill is being learned. Work done in this instance is inefficient until the new skill pattern is learned and the necessary adaptation is made. The learned aspects of skill cannot be differentiated unequivocally from the autonomous adjustments in the patterning of the neuromuscular response to running (57).

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of the present study was to determine the maturity of the running pattern of pre-pubescent boys on the basis of measurements of the mechanical efficiency of steady state running. Secondly, the height, weight, body surface area, leg length, lower leg length, leg strength, and stride length were assessed as to their influence on the mechanical efficiency of horizontal running at a constant speed. Finally, the effects of three repeated trials on the mechanical efficiency scores were determined.

Forty-six boys from the ages of 9.3 to 12.9 years were selected from various recreational programs in Edmonton, Alberta, Canada. The subjects were all pre-pubescent and were classified into three [illegible] with respect to age. Each subject was tested three times within a period of approximately one month.

Mechanical efficiency measures were obtained by a ratio of the rate of energy expenditure to the rate of doing work. The energy necessary for speed maintenance in running was determined from the oxygen consumption when the speed was such that a submaximal steady-state was attained. The rate of caloric expenditure above that necessary to maintain a standing position was obtained by means of the exercise respiratory quotients., The total external work accomplished was estimated as the product of the subject's gross weight raised and the velocity of the treadmill. Mean values for mechanical efficiency were obtained by averaging the scores on trial two and three.

Measurements of weight, height, leg length, and lower leg length were taken. Body surface area was calculated from the subjects' height and weight. Isometric leg strength at a knee angle of 115 degrees was assessed using a dynamometer. The number of strides taken during the period of gas analysis were used to determine the average stride length during each trial.

The existence of differences in mechanical efficiency between the three age groups was tested for significance by a one-way analysis of variance. The influence of several variables on mechanical efficiency was assessed by an intercorrelation matrix. Several partial correlations on significant variables were calculated keeping the age factor constant. A stepwise regression was applied to determine the predictability of mechanical efficiency from these variables. Finally, the existence of differences in mechanical efficiency between the three test sessions was tested for significance by a two-way analysis of variance with repeated measures on one factor.

Results indicated that there were no significant differences between the age groups; however, the older group of boys demonstrated a somewhat higher mechanical efficiency than the younger groups. The mean mechanical efficiency for the entire sample was 23.82 percent.

The only variables that significantly correlated with mechanical efficiency were stride length (r=0.44) and leg strength (r=0.32). By partialing out age, the correlation with stride length was still significant (r=0.37); however, the correlation with leg strength was not significant (r=0.23). The significant relationship between stride length and leg strength (r=0.40) was found to almost vanish (r=0.14) when age was held constant. The simple regression equation derived to predict mechanical efficiency was: Mechanical Efficiency = 15.796 + 9.111 (stride length). The correlation between observed and predicted mechanical efficiency was significant at the 0.01 level (r=0.43).

There was shown to be a significant improvement in mechanical efficiency [illegible] both the first and second trials [illegible] the second and third [illegible]. The oldest group demonstrated the greater rate and extent of skill improvement over the three trials.

Conclusions

Based upon the results of this investigation and within the scope and limitations set forth for the study, the following conclusions seem warranted:

1. Despite a higher mean value of mechanical efficiency

for the oldest group, no significant differences were found between the three groups with mean ages of [illegible].8 years, 10.9 years, and [illegible] years.

2. Significant correlations of 0.44 and 0.32 were found to exist between mechanical efficiency and stride length and leg strength, respectively. Partial correlations revealed that much of the relationship of leg strength with mechanical efficiency and stride length was by virtue of its relation to age. In addition, a simple regression equation for the prediction of mechanical efficiency of steady state running from the stride length was presented (r=0.43).

3. Significant differences in mechanical efficiency were found to exist between each of the three repeated trials. The oldest group demonstrated the greatest rate and extent of skill improvement (6.18%).

Recommendations

After a review of the procedures and results of this study, the following recommendations seem appropriate:

1. Although measurement of oxygen consumption would be difficult, the present method of assessing mechanical efficiency should be extended to the period of early childhood. The study of adolescent performance may also provide information concerning the fine refinements of the running pattern.

2. A more accurate estimate of the total work accomplisted during running could be obtained by utilizing both

cinematographical analysis and an accelerometer to measure body [illegible]ments involved in [illegible] ide.

3. Future studies should be extended to investigate the effects of a carefully designed training program or at least a number of practice sessions prior to testing.

4. It has been suggested that the ability to learn a skill or make refinements on an old skill may involve an increased kinesthetic sensitivity. Although measurement of this may be difficult due to the specificity of running, it would appear to be a variable worth further investigation.

Application

In light of the findings of this investigation, the author feels the inclusion of the following brief practical application would be of value to the physical educator, coach and parents:

1. Although it did not appear that there were considerable differences in the efficiency of running between ten-, eleven- and twelve-year-old boys, there was evidence of significant improvement as the boys became more accustomed to the treadmill running. Therefore, this period of prepubescence should be one in which children are guided and exposed to a great number of locomotor skills. A great deal of running and activities such as track, lacrosse, field hockey, cross-country orienteering and soccer are suggested at this age. The present study has pr[illegible].

evidence to suggest that boys closest to the age of puberty would benefit most from this emphasis on locomotor skill refinement.

2. The most critical variable affecting mechanical efficiency examined in the investiation was shown to be the average running stride length: Trained athletes have been reported to be able to freely choose their most economical stride length at a given speed (64, 75). However, this may be a problem area with younger, untrained individuals. It is suggested that the physical educators and track coaches pay considerable attention to this aspect of the running pattern in pre-pubescent boys.

3. The following field test is proposed as a practical estimation of running efficiency for pre-pubescent boys:

The test may be used to determine possible potential of boys to perform aerobic-type running activities such as cross-country or [illegible] running. It may also serve as a method of [illegible] identification of boys for such sports as track and field. The test is in two parts and should require merely a one-hour period to examine approximately thirty boys. The first part requires each boy to run a quarter mile at a steady, submaximal pace. Heart rate is taken manually immediately following the run. Small adjustments in speed should be made in the second part if the heart rate is over 180 b.p.m. or under 170 b.p.m. The same procedure is followed for the second section of the test. In addition, the number of strides are counted for a distance of 100 meteres in the middle of the run. This field test requires little equipment and approximates the running conditions as outlined in the present investiation. The knowledge of the average stride length in a steady state submaximal run of this type would allow the calculation of mechanical efficiency from the regression equation proposed earlier.

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APPENDIX A

LETTER OF INVITATION

FACULTY OF PHYSICAL EDUCATION
THE UNIVERSITY OF ALBERTA
EDMONTON, ALBERTA, CANADA T6G 2H9

DEPARTMENT OF PHYSICAL EDUCATION

Dear

Through the cooperation of the Edmonton Parks and Recreation and the Faculty of Physical Education of the University of Alberta, plans have been made for a research study involving forty-five boys. [illegible] your son has been chosen to take part in this study, I would like to ask your permission for his involvement.

The purpose of the study is to examine the mechanical efficiency of running in boys nine to twelve years of age. The intensity of the exercise is not severe and does not involve any risk with respect to the safety of your son. It is hoped that the study will provide important information concerning the performance of the skill of running, which is so basic to most sports and the life style of a boy of your son's age.

Qualified research personnel will be studying various factors while the boys are running on a motor-driven belt (treadmill). Your son's results will be forwarded by mail as soon as they are available. In order to determine the extent of improvement that takes place it is necessary to have your son come to the university a total of [illegible] times. In an attempt to make these times as convenient as possible for both you and your son, the enclosed schedule has been arranged. Please check the [illegible] suited to you from each of the three columns.

If you do not wish to have your son take part in this study, it would be appreciated if you would simply send the plan [illegible] back to me. I thank you for your time and inconvenience and also for your role in this meaningful and necessary investigation.

Sincerely,

Mr. John C. Griffin
Faculty of Physical Education

APPENDIX B

RAW DATA

PHYSICAL CHARACTERISTICS OF SUBJECTS

[illegible] GROUP (N = 20)

Subject	Age (Years)	Height (cm.)	Wt. (kg.)	B.S.A. (m²)	Leg Strength (Kg.)	Leg Length (cm.)	Lower Leg Length (cm.)
1	10.[illegible]	[illegible]	[illegible]	1.2[illegible]	6[illegible]	9[illegible]	[illegible]
2	[illegible]	142	[illegible]	1.12	7[illegible]	8[illegible]	4[illegible]
3	[illegible]	[illegible]	28.[illegible]	[illegible].04	[illegible]	[illegible]8.7	[illegible]8.1
4	1[illegible]	[illegible]	[illegible]	0.98	11[illegible]	76.2	[illegible]
5	[illegible]	11[illegible]	31.[illegible]	1.08	55	82.6	[illegible]
6	[illegible]	152	[illegible]	1.34	89	91.4	[illegible].4
7	[illegible]	[illegible]	[illegible]	1.09	57	82.7	38.1
8	9.[illegible]	12[illegible]	2[illegible]	0.91	[illegible]	74.9	35.6
9	9.3	13[illegible]	2[illegible]	1.03	[illegible]	83.8	38.7
10	9.[illegible]	13[illegible]	3[illegible].7	1.21	77	94.0	4[illegible].1
11	9.5	[illegible]	26.[illegible]	1.00	102	78.7	38.[illegible]
12	9.7	14[illegible]	36.[illegible]	1.23	111	94.6	44.4
13	10.0	14[illegible]	[illegible]	1.20	120	88.9	43.2
14	9.6	13[illegible]	31.7	1.06	46	78.7	39.1
15	10.0	13[illegible]	31.[illegible]	1.09	82	83.2	39.4
16	9.3	131	29.5	1.02	70	81.3	38.1
17	10.[illegible]	[illegible]	31.9	1.30	75	95.2	4[illegible].7
18	9.4	140	35.[illegible]	1.13	102	84.5	41.9
19	10.0	144	31.7	1.13	86	90.[illegible]	41.9
20	9.6	147	31.7	1.14	61	86.4	4[illegible].3

[illegible] PHYSICAL CHARACTERISTICS OF SUBJECTS

IN GROUPS B (N = [illegible])

Subject	Age (Years)	Height (cm.)	Weight [illegible]	B.S.A. (M2)	[illegible] Strength (Kg.)	Leg Length (cm.)	Lower Leg Length (cm.)
21	[illegible]	[illegible]	[illegible]	[illegible]	105	[illegible]	43.8
22	[illegible]	[illegible]	[illegible]	1.20	75	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	1.23	123	[illegible]	41.3
24	10.9	[illegible]	[illegible]	1.11	103	[illegible]	38.7
25	[illegible]	[illegible]	[illegible]	1.31	84	94.0	45.7
[illegible]	10.8	[illegible]	[illegible]	1.41	84	91.4	43.8
[illegible]	[illegible]	[illegible]	[illegible]	1.30	52	101.	45.7
28	10.6	[illegible]	[illegible]	1.27	68	94.0	46.3
29	[illegible]	[illegible]	[illegible]	1.14	114	[illegible]	41.3
30	10.5	[illegible]	[illegible]	1.11	75	86.4	41.3
31	[illegible]	[illegible]	[illegible]	[illegible]	107	[illegible]	39.4
32	[illegible]	152	39.7	1.32	80	[illegible]	46.4
33	11.4	161	[illegible]	1.41	73	99.7	45.7

PHYSICAL CHARACTERISTICS OF SUBJECTS

IN GROUP C (N = 13)

Subject	Age (Years)	Height (cm.)	Weight (Kg.)	B.S.A. (M^2)	Leg Strength (Kg.)	Leg Length (cm.)	Lower Leg Length (cm.)
34	[illegible]	[illegible]	[illegible]	1.38	[illegible]	[illegible]	45.7
35	[illegible]	[illegible]	[illegible]	1.25	120	[illegible]	[illegible]
36	[illegible]	[illegible]	[illegible]	1.48	166	[illegible]	[illegible]
37	12.7	152	[illegible]	1.33	116	96.5	45.7
38	12.1	[illegible]	38.4	1.54	93	97.2	47.0
39	12.4	[illegible]	[illegible]	[illegible]	157	87.0	40.0
40	[illegible]	[illegible]	[illegible]	1.27	136	[illegible]	41.3
41	12.9	[illegible]	39.5	1.35	103	101.6	47.0
42	12.2	[illegible]	45.9	1.38	82	97.2	47.0
43	[illegible]	[illegible]	48.7	[illegible]	93	99.1	49.5
44	[illegible]	[illegible]	51.0	[illegible]	139	107.3	51.4
45	[illegible]	[illegible]	38.9	1.27	105	92.7	44.5
46	11.5	155	44.1	1.39	107	89.1	45.7

INDIVIDUAL RESPONSES TO THE FIRS[illegible] [illegible]DMILL

TESTING IN GROUP [illegible]

SUBJECT	STANDING VO$_2$ (l./min.)	EXERCISE VO$_2$ (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	[illegible] (Kcal./min.)	SPEED (m./sec.)	STRIDE LENGTH (m.)
1	.25	2.15	.76	9.01	1.62	2.68	.88
2	.24	1.85	.57	7.52	1.12	2.23	.72
3	.24	1.32	.81	5.21	1.09	2.57	.89
4	.19	1.54	.66	6.42	0.96	2.34	.63
5	.22	1.55	.80	6.44	1.21	2.62	.90
6	.33	2.11	.81	8.56	1.71	2.68	.88
7	.21	1.71	.77	7.19	0.98	2.01	.75
8	.23	0.9[illegible]	.85	3.27	0.72	2.12	.63
9	.22	1.6[illegible]	.67	6.50	1.10	2.37	.75
10	.29	1.[illegible]5	.84	5.17	1.29	2.34	.81
11	.23	0.[illegible]	1.06	2.88	0.81	2.01	.62
12	.30	2.0[illegible]	.82	8.31	1.59	2.79	1.09
13	.26	1.[illegible]9	.83	5.47	1.37	2.57	.83
14	.22	1.28	.84	5.12	1.03	2.17	.56
15	.18	1.53	.77	6.42	1.22	2.51	.74
16	.27	1.56	.79	6.14	1.15	2.63	.76
17	.25	1.91	.78	7.94	1.40	2.29	.69
18	.09	0.72	1.75	3.21	1.10	2.23	.79
19	.72	1.67	.67	4.43	1.12	2.34	.73
20	.29	1.63	.80	6.44	1.26	2.57	.80

INDIVIDUAL RESPONSES TO THE FIRST TREADMILL

TESTING IN GROUP B (N = 13)

SUBJECT	STANDING VO$_2$ (l./min.)	EXERCISE VO$_2$ (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (M./sec.)	STRIDE LENGTH (m.)
21	.31	[illegible]	.95	6.39	1.41	2.57	.88
22	.27	[illegible]	[illegible]	6.62	1.35	2.57	.82
23	.36	[illegible]	.90	7.54	1.45	2.57	.79
24	.20	1.68	.70	6.76	1.09	2.23	.70
25	.24	[illegible]	[illegible]	6.81	1.42	2.46	.80
26	.30	[illegible]	[illegible]	9.70	1.96	2.79	.84
27	.20	[illegible]	[illegible]	8.40	1.46	2.68	.91
28	.26	[illegible]	.81	7/61	1.42	2.46	.87
29	.29	[illegible]	.86	6.65	1.44	2.96	.94
30	.28	1.92	.70	7.68	1.30	[illegible]	.81
31	.59	1.21	.98	3.10	1.04	2.12	.66
32	.27	2.01	.83	8.44	1.41	2.48	.79
33	.31	2.30	.84	9.66	1.84	2.85	.96

INDIVIDUAL RESPONSES TO THE FIRST TREADMILL

TESTING IN GROUP C (N = 13)

SUBJECT	ST[illegible]NG ([illegible])	EXERCISE VO_2 ([illegible])	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (M./sec.)	STRIDE LENGTH (m.)
34		2.[illegible]	.86	9.42	2.08	3.24	1.1[illegible]
35	.[illegible]	2.[illegible]	.8[illegible]	8.46	1.67	2.85	.94
36	.32	1.9[illegible]	1.16	8.33	2.21	3.[illegible]	.99
37	.22	1.8[illegible]	.81	7.73	1.61	2.68	.90
38	.31	2.[illegible]	.66	8.99	2.01	2.29	.77
39	.23	1.[illegible]	.[illegible]7	8.60	1.60	3.10	.94
40	.26	2.[illegible]	.90	9.49	1.45	2.51	.84
41	.25	1.[illegible]	.76	7.28	[illegible].48	2.[illegible]2	.85
42	.27	2.[illegible]	.87	9.65	1.57	2.[illegible]	.84
43	.33	2.[illegible]	.7[illegible]	9.40	1.74	2.4[illegible]	.76
44	.35	2.02	.8[illegible]	11.85	2.26	2.[illegible]6	.96
45	.31	1.76	.80	6.97	1.42	2.46	.79
46	.24	2.[illegible]	.83	10.03	1.62	2.46	.82

INDIVIDUAL RESPONSES TO THE SECOND TREADMILL

TESTING IN GROUP A (N = 20)

SUBJECT	STANDING VO_2 (l./min.)	EXERCISE VO_2 (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (M./sec.)	STRIDE LENGTH (m.)
1	.29	1.6[illegible]	.84	7.74	1.68	2.73	.84
2	.27	[illegible]	.90	6.59	1.11	1.68	.81
3	.22	[illegible]	.84	6.18	1.11	2.63	.87
4	.18	1.1[illegible]	.96	5.03	1.15	2.79	.75
5	.24	[illegible]	.85	5.00	1.32	2.85	.96
6	.35	1.8[illegible]	.84	7.44	1.79	2.85	.90
7	.19	[illegible]	.92	4.54	1.01	2.21	.73
8	.24	[illegible]	.85	4.11	.80	2.23	.65
9	.25	[illegible]	[illegible]	5.69	1.20	2.74	.72
10	.30	[illegible]	.86	6.10	1.42	1.55	.87
11	.21	[illegible]	.83	5.08	.91	2.29	.69
12	.32	1.5[illegible]	.84	6.08	1.73	3.02	1.04
13	.24	1.7[illegible]	.91	7.[illegible]	1.43	2.74	.85
14	.23	1.2[illegible]	.85	4.87	1.08	2.29	.65
15	.18	1.17	.81	4.78	1.32	2.74	.80
16	.28	1.[illegible]4	[illegible]	4.60	1.21	2.79	.77
17	.28	1.8[illegible]	.96	7.98	1.46	2.46	.81
18	.24	1.0[illegible]	[illegible].29	3.94	1.30	2.62	.87
19	.28	1.25	1.05	5.05	1.21	3.51	.82
20	.34	1.35	.92	5.02	1.27	2.68	.86

INDIVIDUAL RESPONSES TO THE SECOND TREADMILL

TESTING IN GROUP B (N = 13)

SUBJECT	STANDING VO_2 (l./min.)	EXERCISE VO_2 (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE	WORK (Kcal./min.)	SPEED (M./sec.)	STRIDE LENGTH (m.)
21	.24	[illegible]	1.05	6.66	1.50	2.74	.94
22	.28	[illegible]	.83	6.06	1.41	2.69	.85
23	.30	[illegible]	.84	7.93	1.43	2.57	.77
24	.19	[illegible]	.90	5.35	1.12	2.34	.70
25	.32	[illegible]	.76	7.19	1.56	2.63	.83
26	.31	[illegible]	[illegible]	9.60	2.04	2.91	.91
27	.27	[illegible]	[illegible]	6.38	1.66	3.12	1.03
[illegible]	.31	[illegible]	.58	7.18	1.53	2.42	.93
29	.28	[illegible]	.81	7.02	1.53	3.14	1.02
30	.31	[illegible]	.87	6.87	1.39	2.35	.84
31	.30	[illegible]	1.09	4.77	1.31	2.62	.79
32	.31	[illegible]	.98	6.92	1.47	2.46	.81
33	.33	2.25	.86	9.33	1.73	2.68	.91

INDIVIDUAL RESPONSES TO THE SECOND TREADMILL TESTING IN GROUP C (N = 13)

SUBJECT	STANDING VO_2 (l./min.)	EXERCISE VO_2 (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (M./sec.)	STRIDE LENGTH (m.)
34	.37	2.09	.91	9.42	2.22	3.41	1.05
35	.27	[illegible]	1.16	6.63	1.73	3.07	1.01
36	.41	[illegible]	.96	10.42	2.37	3.24	1.09
37	.22	2.05	.93	8.86	1.78	2.96	.97
38	.37	[illegible]	.85	7.80	2.04	2.34	.79
39	.30	[illegible]	.86	6.14	1.55	3.02	1.01
40	.26	[illegible]	[illegible]	7.07	1.52	2.57	.83
41	.32	[illegible]	.86	6.00	1.61	2.74	.84
42	[illegible]	[illegible]	.95	7.64	1.73	2.57	.93
43	[illegible]	2.05	.97	8.31	1.95	2.55	.90
44	.35	1.84	1.39	7.52	2.45	3.24	1.23
45	.31	[illegible]	.81	6.43	1.54	2.68	.78
46	.25	2.04	.94	8.89	1.74	2.62	.83

INDIVID[illegible]ONSES TO THE THIRD TREADMILL

[illegible] IN GROUP A (N = 20)

SUBJECT	STANDING VO_2 (l./min.)	EXERCISE VO_2 (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (m./sec.)	STRIDE LENGTH (m.)
1	.27	[illegible]	.92	8.2[illegible]	1.93	2.74	.86
2	.22	[illegible]	1.13	5.12	1.31	[illegible].68	.79
3	.26	[illegible]	.98	4.79	1.19	2.74	.93
4	[illegible]	[illegible]	.92	5.81	1.17	2.79	.80
5	.20	[illegible]	1.03	4.48	1.36	2.91	.99
6	.29	[illegible]	[illegible]	7.86	1.89	2.96	.96
7	.24	[illegible]	.86	4.81	1.06	2.23	.73
8	.23	[illegible]	.86	2.94	.86	2.34	.69
9	.20	[illegible]	[illegible]	6.47	1.27	2.96	.82
10	.26	[illegible]	[illegible]	6.05	1.53	2.85	.93
11	.31	[illegible]	.92	3.99	.97	2.40	.72
12	.27	[illegible]	.27	7.03	[illegible]	2.96	1.02
13	.26	[illegible]	.96	6.69	1.54	[illegible].85	.91
14	.21	1.22	.85	5.23	1.14	2.34	.68
15	.23	1.51	.95	5.38	1.34	2.79	.84
16	.32	[illegible]	.86	6.16	1.29	2.91	.82
17	.26	[illegible]	.74	7.66	1.60	2.68	.83
18	.43	1.47	1.00	5.24	1.31	2.62	.86
19	.54	1.48	.77	4.50	1.22	2.57	.85
20	.30	1.57	.92	6.30	1.36	2.85	.87

INDIVIDUAL RESPONSES TO THE THIRD TREADMILL

TESTING IN GROUP B (N = 13)

SUBJECT	STANDING VO2 (l./min.)	EXERCISE VO2 (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (m./sec.)	STRIDE LENGTH (m.)
21	.30	[illegible]	1.05	7.40	1.54	[illegible]	.95
22	.21	[illegible]	1.16	5.12	1.35	[illegible]	.84
23	.25	1.36	1.19	5.60	1.50	2.63	.81
24	.29	1.28	.97	4.98	1.17	2.40	.71
25	.25	[illegible]	1.04	5.70	[illegible]	2.79	.86
26	.30	1.80	[illegible]	7.96	2.09	2.96	.95
27	.19	[illegible]	[illegible]	8.20	1.78	[illegible]	1.11
28	.29	1.30	.92	5.42	1.48	2.57	.92
29	.30	1.25	1.34	4.79	1.54	[illegible]	1.02
30	.28	1.59	.96	6.75	1.45	[illegible]	.84
31	.26	[illegible]	.87	6.36	1.31	2.62	.81
32	.28	1.80	.97	7.61	1.60	2.68	.90
33	.32	1.75	1.04	7.24	1.74	2.68	.98

INDIVIDUAL RESPONSES TO THE THIRD TREADMILL

TESTING IN GROUP C (N = 13)

SUBJECT	STANDING VO_2 (l./min.)	EXERCISE VO_2 (l./min.)	EXERCISE R.Q.	ENERGY EXPENDITURE (Kcal./min.)	WORK (Kcal./min.)	SPEED (m./sec.)	STRIDE LENGTH (m.)
34	.39	1.77	1.02	6.97	2.23	3.41	1.10
35	.26	1.69	1.04	7.22	1.81	3.13	1.06
36	.32	2.06	1.00	8.74	2.42	3.30	1.13
37	.26	1.65	1.00	7.03	1.84	3.02	.97
38	.32	1.8	1.00	7.73	2.10	2.40	.83
39	.19	1.	1.05	5.60	1.55	3.02	.95
40	.26	1.53	.91	6.26	1.54	2.62	.90
41	.33	1.36	.98	5.18	1.65	2.79	.88
42	.28	2.31	.72	9.55	1.77	2.57	[illegible]
43	.31	2.40	.81	10.04	2.04	2.79	.94
44	.40	2.84	.87	11.96	2.57	3.36	1.28
45	.31	1.68	.94	6.83	1.60	2.74	.85
46	.24	1.43	.99	5.99	1.81	2.74	.87

SUMMARY OF MECHANICAL EFFICIENCIES

GROUP A (N = 20)

SUBJECT	TRIAL 1 MECH. EFFIC. (%)	TRIAL 2 MECH. EFFIC. (%)	TRIAL 3 MECH. EFFIC. (%)	AVERAGE MECH. EFFIC. (T_2, T_3)	PREDICTED MECH. EFFIC. (%)
1	17.93	21.69	20.85	21.27	23.54
2	14.86	19.83	25.52	22.67	23.08
3	20.93	18.01	24.56	21.28	23.39
4	15.32	22.87	20.17	21.52	22.81
5	18.83	26.42	30.39	28.40	24.73
6	19.97	24.02	24.01	24.01	24.16
7	13.63	22.15	22.11	22.13	22.44
8	21.89	19.37	29.30	24.33	21.90
9	16.96	21.00	19.56	20.28	22.90
10	24.98	23.19	25.22	24.20	24.00
11	28.09	18.00	24.16	21.08	22.26
12	19.14	28.40	24.00	26.20	25.18
13	25.11	19.80	23.06	21.43	23.81
14	20.08	22.16	21.29	21.72	21.90
15	18.94	27.63	24.83	26.23	23.27
16	18.73	26.28	20.91	23.59	25.52
17	17.61	18.54	20.93	19.74	23.26
18	32.44	32.90	24.96	28.93	23.77
19	25.34	23.87	27.17	25.52	[illegible]
20	19.51	25.22	21.51	23.36	[illegible]

SUMMARY OF MECHANICAL EFFICIENCIES

GROUP B (N = 13)

SUBJECT	TRIAL 1 MECH. EFFIC. (%)	TRIAL 2 MECH. EFFIC. (%)	TRIAL 3 MECH. EFFIC. (%)	AVERAGE MECH. EFFIC. (T_2, T_3)	PREDICTED MECH. EFFIC. (%)
21	22.03	22.53	20.80	21.67	24.36
22	20.31	23.28	26.39	24.83	23.54
23	19.16	18.10	26.29	22.20	22.99
24	16.08	20.86	23.43	22.30	22.17
25	20.80	21.75	28.57	25.16	23.54
26	20.20	21.23	26.20	23.72	24.27
27	17.42	26.00	21.72	23.86	25.54
28	20.32	21.35	27.37	24.36	24.26
29	21.97	21.81	32.08	26.95	25.09
30	16.91	20.17	21.42	20.80	23.44
31	33.55	27.36	20.58	23.97	23.08
32	16.68	21.22	20.97	21.10	23.54
33	19.08	18.54	23.98	21.26	24.36

SUMMARY OF MECHANICAL EFFICIENCIES

GROUP B (N = 13)

SUBJECT	TRIAL 1 MECH. EFFIC. (%)	TRIAL 2 MECH. EFFIC. (%)	TRIAL 3 MECH. EFFIC. (%)	AVERAGE MECH. EFFIC. (T_2, T_3)	PREDICTED MECH. EFFIC. (%)
34	22.02	23.50	32.01	27.72	25.64
35	19.76	26.80	25.09	25.95	23.27
36	26.47	22.72	27.69	25.21	25.91
37	20.79	20.04	26.24	23.14	24.63
38	22.39	26.21	27.19	26.70	23.18
39	18.66	25.17	27.68	26.43	24.45
40	15.31	21.48	34.56	28.02	23.63
41	20.35	26.77	31.92	29.34	23.63
42	16.23	22.60	18.54	20.57	23.90
43	18.54	23.47	20.31	21.89	24.17
44	19.06	32.65	21.49	27.07	27.18
45	20.45	24.01	23.42	23.72	23.27
46	16.11	19.59	30.28	24.98	23.54

APPENDIX C

STATISTICAL TREATMENT

STATISTICAL TREATMENT

Analysis of Variance

A one-way analysis of variance was employed to determine significant differences in the mean values of mechanical efficiency for the three age groups. The analysis was obtained by the use of the following program:

Program: ANOV15

Language: Fortran IV

Differences in improvement between the three repeated trials with each age groug were tested for significance by a two-way analysis of variance with repeated measures on one factor. The analysis was obtained by use of the following:

Program: ANOV23

Language: Fortran IV

Stepwise Regression

A stepwise regression analysis was applied to a number of predictor variables for the criterion of mechanical efficiency. A square symmetric inter-correlation matrix was obtained through the use of the following program:

Program: MULR06

Language: Fortran IV

Correlation Coefficient

A Pearson Product-moment correlation was calculated between observed and predicted values of mechanical efficiency. The following program was used:

Program: DEST02

Language: Fortran IV

A student's t-test was also applied to determine the significance of the differences between the means of observed and predicted mechanical efficiency (1). A t-test on depend means was used to determine the differences in mechanical efficiency between the three repeated trials (114). Both of these tests were calculated on a Sobax desk calculator.