The Oxygen Cost of Horizontal and Grade Running on the Treadmill with Female Runners

by

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Abstract

The purpose of this study was to examine the vertical component of the American College of Sports Medicine (A.C.S.M.) Guidelines equation to predict the oxygen cost of grade running. The A.C.S.M. Guidelines equation is: VO_2(ml/kg.min) = 3.5 + 0.2 speed(m/min) + 0.9[speed(m/min) * grade(frac)]. Twenty-three female runners (20 to 33 years) participated in (1) a VO_2max test, (2) five 6 min running economy (RE) tests at 133 m/min, (3) five 6 min RE tests at 160 m/min, and (4) three 6 min RE tests at 186 m/min. The RE tests at 133 and 160 m/min were performed at the following grades: 0, 2.5, 5.0, 7.5, and 10.0%. The RE tests at 186 m/min were performed at 0, 2.5, and 5.0% grade. The RE tests were administered in random order. There was a linear relationship between VO_2 and horizontal running velocity with a slope of 0.20 ml/kg.m ($r=0.996$; $p<.01$). There was a linear relationship between VO_2 and percent grade when running on a treadmill. The correlations for the regression equations at speeds of 133, 160, and 186 m/min were 0.90 ($p<.01$), 0.86 ($p<.01$), and 0.73 ($p<.01$), respectively. Inclusion of a grade component in the regression analysis equation increased the accuracy for predicting the VO_2 of grade running. VO_2 consumption for grade running can be predicted using the following equation: VO_2 (ml/kg.min) = 3.5 + 0.198[speed in m/min + 0.932 grade(%)] + 0.006[speed(m/min) * grade(%)]. The new equation explained 99.5% of the variance (R^2) compared to the 78.0% of the variance (R^2) that was explained by the A.C.S.M. Guidelines equation.

Résumé

Le but de cette étude etait d'examiner la relation entre l'inclinaison et le VO_2 pour la course et de comparer l'équation obtenue avec l'équation de prédiction des coûts en oxygène pour la course avec inclinaison de l' American College of Sports Medicine (A.C.S.M.). L'équation de l' A.C.S.M. est: VO_2(ml/kg.min) = 3.5 + 0.2 vitesse(m/min) + 0.9[vitesse (m/min) * inclinaison(frac)]. Vingt-trois sujets féminins de 20 à 33 ans furent soumis à (1) un test de VO_2max, (2) cinq tests de 6 min d'économie de course (EC) à 133 m/min, (3) cinq tests d'EC à 160 m/min et (4) trois tests de 6 min d'EC à 186 m/min. Les tests d'EC à 133 et 160 m/min furent exécutés avec les inclinaisons suivantes: 0, 2.5, 5.5, 7.5, et 10.0%. Les tests d'EC à 186 m/min avec les inclinaisons de 0, 2.5, et 5.0%. Les resultats démontrèrent une relation linéaire entre le VO_2 et la velocité de course à l'horizontal avec une pente de 0.2 ml/kg.m ($r=0.996$; $p<.01$). Une relation linéaire entre le VO_2 et le % d'inclinaison fut obtenue pour la course sur tapis roulant. Les corrélations pour les équations de régressions étaient de 0.90 ($p<.01$) à 133 m/min, de 0.86 ($p<.01$) à 160 m/min et de 0.73 ($p<.01$) à 186 m/min. La précision de la prédiction du VO_2 pour la course avec inclinaison était plus élevée avec une inclinaison. La consomation VO_2 pour la course avec inclinaison peut être prédite en utilisant l'équation suivante: VO_2(ml/kg.min) = 3.5 + 0.198[vitesse (m/min) + 0.932 inclinaison(%)] + 0.006[vitesse(m/min) * inclinaison(%)]. La nouvelle équation explique donc 99.5% de la variance (R^2) comparée à 78.0% pour l'équation de l'A.C.S.M.

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Introduction

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Sport has been described as a mirror of society - a reflection of sociocultural attitudes, beliefs, and phenomena (Puhl, 1986). Until the last 20 years, the limited participation of women in sport, particularly endurance activities, reflected society's view that women were capable of many physical stresses associated with everyday living but were not considered able to participate in endurance sports and activities associated with leisure pursuits (Puhl, 1986).

One researcher expressed an opinion that the "entire country has become a laboratory for testing the popular hypothesis that the differences in male and female responses to exercise prior to the 1970s could be ascribed in part to a cultural bias that discouraged females from participating in sports, particularly sports that require endurance, strength, and power" (Drinkwater, 1984, p. 21).

The enactment of Title IX legislation, in the United States, along with the onset of the jogging boom, dramatically changed the role of sport and exercise for females in our society (Drinkwater, 1984). Title IX ensured that women of all ages would have opportunities to participate in organized sports in the educational system and exercise programs in the community. Female athletes faced another challenge; the long tedious route towards participating in endurance events which males have traditionally been involved. This challenge was mostly due to the lack of knowledge and physiological research involving the female athlete.

Until the 1960s, women were prohibited from running any race longer than 800 meters. They were barred from official participation in the marathon event until the early 1970s (Drinkwater, 1986; Sparling, Nieman, & O'Conner, 1993). In 1973, Miki Gorman's world record marathon time for women was 2:46.36. In 1983, Joan Benoit finished the Boston Marathon in a world record 2:22.42 (Drinkwater,1986). Almost a decade has passed since the female runner was allowed to participate in the marathon event in an Olympiad (Los Angeles, 1984). In 1994, many female runners are involved in marathon racing and are repeatedly running 2:24 for the marathon.

Jogging is becoming increasingly accepted as a pastime. Numerous events such as marathons and 10 km races include shorter distances. Races have grown to the point where both male and female participants face the decision of not only which event to enter, but where to compete on a given day.

1.1 Nature and Scope of the Problem

Successful performance in competitive middle and long distance running has been attributed to certain physiological characteristics. These include maximal oxygen uptake (Noakes, 1988), running economy (Conley & Krahenbuhl, 1980), fractional utilization of maximal oxygen uptake (Costill et al, 1973), and the amount of blood lactate accumulation during submaximal exercise (Costill et al, 1973; Svedenhag & Sjödin, 1985).

The concept of running economy (RE) has received much attention and continues to challenge researchers (Noakes, 1988; Daniels, 1985). Running economy (RE) is defined as the rate of oxygen consumption (VO_2) at a given submaximal running velocity (Bailey & Pate, 1991). The ability to describe VO_2 (ml/kg.min) related to a particular running velocity "provides a useful way of comparing individuals, or any individual with himself or herself under various conditions" (Daniels, 1985, p. 332). The runner who can achieve running velocities at a lower oxygen cost may "prove to have the competitive advantage" (Wilcox & Bulbulian 1984, p. 321).

1.2 Significance of the Study

Most running teams and clubs have a large group of athletes and a low budget. Since a direct VO_2max test for every athlete may not be financially feasible and since there are many time constraints; many coaches rely heavily on field tests (Léger & Boucher, 1980), equations, and pre-established tables (American College of Sports Medicine, 1991, p. 296, 299) to predict the VO_2max and VO_2 of running for their athletes. Training programs are frequently created with the use of these equations and tables.

The American College of Sports Medicine (A.C.S.M.) has published a series of equations and tables for predicting the oxygen cost of different modes of exercise. The book, "Guidelines for Exercise Testing and Prescription", also describes equations to predict the oxygen cost of horizontal and grade running on a treadmill.

The A.C.S.M. Guidelines equation for grade running is:

$$VO_2\ (\text{ml/kg.min}) = 3.5 + 0.20\ \text{speed(m/min)} + 0.9\ [\text{speed(m/min)} \times \text{grade(frac)}]$$

The A.C.S.M. Guidelines equation is derived from the sum of three components representing the oxygen requirement of rest, horizontal work, and vertical work. The resting component is represented by the factor 3.5 ml/kg.min. The horizontal component is represented by the factor 0.20 speed(m/min). The vertical component is represented by the factor 0.9 [speed(m/min) X grade(frac)]. This equation includes an interaction factor but no main effect for grade.

Past research (Bunc et al, 1988; Hinch & Morez, 1981; Conley & Krahenbuhl, 1980; Bransford & Howley, 1977; McMiken & Daniels, 1976; Costill & Fox, 1969; Kollias et al, 1967; Margaria et al, 1963) have examined the oxygen cost of horizontal running. These studies support the concept that the aerobic requirements of horizontal running can be described by a linear regression line with a slope of approximately 0.20 ml/kg.m of running. However, only a few studies have examined the oxygen cost of inclined running.

1.3 Statement of the problem

The aim of this study was to examine the grade-VO_2 relationship for running and to compare it to the A.C.S.M. Guidelines equation for predicting the oxygen cost of grade running, and if necessary suggest a new equation.

1.4 Hypotheses

1. There is a linear relationship between VO_2 and horizontal velocity of running with a slope of 0.20 ml of O_2/kg.m.

2. There is a linear relationship between VO_2 and percent grade when running on a treadmill.

3. The vertical component to predict the oxygen cost of grade running is better described with an equation containing a grade component compared to the existing equation published in the A.C.S.M. Guidelines for Exercise Testing and Prescription.

4. There will be a significant difference between the predicted VO_2 for grade running from the A.C.S.M. Guidelines equation and the value predicted by the new equation.

1.5 Operational Definitions

1. Maximal oxygen consumption: The maximum amount of oxygen (ml/kg.min) that can be consumed per unit of time (ie. 60 second time period) by an individual during large muscle group activity of progressively increasing intensity that is continued until exhaustion (Thoden, 1991).

2. Running economy: The rate of oxygen consumption (VO_2) at a given submaximal running velocity (Bailey & Pate, 1991).

1.6 Delimitations

1. Conclusions are limited to the experimental population of:

a) trained female runners and female athletes that include running as part of their training.

b) subjects between the ages of 20-33 years.

2. The variables measured in this study (VO_2 and HR) were assumed to remain constant during the testing period, even though the subjects continued to train.

1.7 Limitations

1. Day-to-day variation in VO_2max is expected among trained subjects.

2. Day-to-day variability in running economy is also a possible factor which occurs among trained subjects. (Williams et al, 1991).

3. The researcher did not have control over the athlete's training program.

CHAPTER II

Review of the Literature

This chapter is divided into the following sections:

2.1 The relationship between VO_2 and speed

The relationship between VO_2 and speed has been extensively investigated and well documented. It has been repeatedly demonstrated that the relationship is linear on the treadmill regardless of gender or training status (Léger & Mercier 1984; Conley et al, 1981; Hagan et al, 1980; Bradford & Howley, 1977; McMiken & Daniels, 1976; Costill & Fox, 1969; Dill, 1965).

Hill and Lupton (1923) were two of the early researchers to express a belief that the oxygen requirement rises continuously as the speed increases to 260 m/min. Beyond that speed, it was believed that the oxygen requirement was too much to maintain steady state. Many studies since then have supported the theory that VO_2 increases with speed. In these studies, the subjects were able to maintain steady state at speeds over 260 m/min (Costill et al., 1973; Conley et al., 1986; Boileau et al., 1982; Bradley et al., 1986; Daniels & Daniels, 1992). This could be explained by a different population being tested than earlier research and by the higher caliber of athletes today. Speeds up to 390 m/min have been recorded for male runners and speeds up to 350 m/min have been recorded for female runners (Daniels & Daniels, 1992).

Bunc et al. (1985) evaluated differently trained athletes (male long distance runners, male and female middle distance runners, and male cross country skiers) and untrained middle aged males. The researchers were interested in the relationship of energy expenditure and running speed. Speed varied according to the training state of the group, age, and gender. For young female middle distance runners, speeds of 8, 10, 12, 13.5, and 16.5 km/h were run for 3.5 minutes at each velocity. In adult female middle distance runners and young male cross country skiers, the speeds were 10, 13, and 16 km/h and in male long distance runners, the speeds were 12, 15, and 18 km/h. The adult athletes ran for 6 minutes at each velocity. For untrained persons, velocities of 4.7 and 9 km/h were run for 4 minutes.

A linear relationship was found between oxygen consumption and the range of submaximal work loads (20-90% of VO_2max). The researchers also commented that the relationship between oxygen consumption and speed was influenced by the degree of training (i.e., adapting to the workload which changes mostly the mechanical efficiency) and also by gender and natural talent for running.

Costill et al. (1973) assessed 16 highly trained male distance runners. These researchers reported mean VO_2 values of 44.7, 50.3, and 55.9 ml/kg.min for submaximal speeds of 241, 268, and 295 m/min respectively. They concluded that the aerobic requirements of running a pace between 241 and 295 m/min can be adequately described by a linear equation.

Conley and Krahenbuhl (1980) studied 12 highly trained male distance runners. The authors confirmed the results of Costill et al. (1973) reporting comparable mean VO_2 values of 45.6, 51.7, and 59.0 ml/kg.min for the same submaximal speeds.

Daniels et al. (1986) evaluated 30 long and middle distance female runners using elite and sub-elite categories according to results from past performances. The runners performed four 6-minute submaximal runs at speeds of 230, 248, and 268 m/min with a 4-7 minute recovery given between submaximal runs. All runners, regardless of training level, increased oxygen consumption linearly with increases in speed.

Brandsford & Howley (1977) also demonstrated that VO_2 and speed increased linearly within a given range of speeds regardless of gender or training status. The speeds for the untrained subjects ranged from 144 to 225 m/min (65-88% of VO_2max), while the trained subjects ran at speeds of 144 to 307 m/min (57-85% of VO_2max). Significant differences in VO_2 of running were found between trained and untrained groups and between male and female subjects.

Dolgener (1982) reported similar results with 38 females grouped as 13 untrained females, 13 sprint trained females, and 12 endurance trained females. The protocol involved walking at 80.2 m/min followed by running at 160.4 m/min. Each lasted six minutes with a 10 minute recovery period between workloads. The three groups increased their oxygen consumption as speed increased.

These studies and others clearly state that as the work becomes more demanding, more oxygen is used to meet this demand: as running speed increases, oxygen consumption increases until VO_2max is achieved.

2.2 The effects of training on running economy

Past studies have questioned the concept of running economy (RE) from several different approaches. Trained subjects have been found to be more economical than untrained subjects (Bradsford & Howley, 1977; Patton & Vogel, 1977). Patton and Vogel (1977) evaluated two groups of 60 male military personnel. They reported that a six month endurance training program (2-4 miles per day at 8-9 minutes per mile pace) significantly improved RE in 120 untrained and trained subjects. The trained subjects had been involved in the same endurance program for five months prior to the six month endurance training period. During this six month training period, VO_2max improved only in the untrained group with values similar to the trained group. Since VO_2max did not increase in the trained group, the researchers suggested that the increase in RE may have been due to a change in work efficiency, treadmill habituation, training, or a combination of these factors.

Training programs which comprise long, slow distance training, moderate distance training, and interval training have repeatedly demonstrated a reduction of the aerobic demand of running (less oxygen cost for the same work). This has been repeatedly demonstrated with both trained and untrained subjects (Daniels et al., 1978; Morgan et al., 1989).

The following studies indicate that RE is a better indicator of performance times than VO_2max values in trained subjects. Conley and Krahenbuhl (1980) studied 12 male runners with comparable performance times and VO_2max values. Good correlations were found between the oxygen cost of running at 241, 268, and 295 m/min and 10 km performance time ($r = 0.83$, $r = 0.82$, $r = 0.79$, $p <.01$; respectively). The runners who used the least amount of oxygen at each of these running velocities were the most efficient and had the lowest performance time for a 10 km race. It was found that 65.4% of the variation in performance time was explained by RE. Sjödin and Schèle (1982) demonstrated that RE at 15 km/h had a higher correlation ($r = -0.74$) with running velocity in a 5 km race than did VO_2max ($r = 0.59$). Morgan et al. (1989) studied 10 male runners of similar VO_2max values. They noted that a high correlation ($r = -0.87$) existed between 10 km performance time and predicted running velocity whereas the correlation with VO_2max was only $r = -0.45$. These studies suggest that RE and performance time are positively related when subjects have similar VO_2max values.

Studies which involve elite male runners have also reported an improvement in RE with training. Svedenhag and Sjödin (1985) evaluated 10 elite male runners on four occasions over a period of one year. The researchers stated that even though the runners had reached their highest possible VO_2max values, slow but steady improvement still occured in RE.

The next study involves one elite male runner. Conley and Krahenbuhl (1981) followed one athlete's progression during an 18-week training period using both interval and endurance running. His RE at 295 m/min improved from 58.7 to 53.5 ml/kg.min. He decreased his oxygen cost of running from 83.5% to 71.5% of VO_2max. "Most improvements in RE were noted during or immediately after weeks of increased interval training" (Conley et al., 1981, p. 107). It was concluded that interval training appeared to enhance RE. The researchers also recommended that interval sessions be included in training programs. These interval sessions should be at velocities which equal or slightly exceed the pace at which optimal economy is desired. In support of the above study, Sjödin et al. (1982) reported an improvement in RE in highly trained middle and long distance runners. For a period of 14 weeks, a weekly 20 minute run was added to the athletes' regular training programs. This interval session was performed at a velocity which elicited a blood lactate concentration of 4 mmol/l. The one intense workout which was performed may have improved running style, oxidative capacity, and mechanical efficiency without a significant change in VO_2max.

One study (Conley et al., 1984) which has received attention involved elite miler Steve Scott. Scott was evaluated for VO_2max and RE on three occasions (offseason, preseason, and beginning of the outdoor season) over a nine month period. After building up an aerobic base (during preseason) with distance work, intervals were later incorporated (beginning of outdoor season). As expected, his VO_2max and RE increased by 8% and 5% respectively as he approached his competitive outdoor season. During this season, he was predicted to produce a peak performance and break the American mile record. Throughout the study, Scott was compared with Jim Ryun who was America's mile record holder at the time. Both runners had identical VO_2max values but Scott's RE was better. Scott used less oxygen for the same running velocity. Thirty-six days after the final laboratory test, Scott competed and shattered Ryun's 14 year American record!

Scrimgeour et al. (1986) studied 30 long distance runners with comparable VO_2max values. The runners were divided into three groups according to their weekly mileage. The researchers reported that the runners who trained more than 100 km/week had significantly faster performance times (19.2%) in all events (10-90 km) than those training less than 100 km/week. Runners with higher mileage were found to be more economical (19.9%) and had the highest race velocity. Thus, at the same percentage of VO_2max, runners with higher mileage had better performance times and used less oxygen to run at a particular velocity.

It has been suggested that long distance (over 3000m) and elite runners are more economical than middle distance (800-1500m) runners. This may be attributed to higher VO_2max values and higher mileage characteristics of long distance running (Morgan et al., 1989; Boileau et al., 1982). Boileau et al. (1982) evaluated 32 elite male long distance (LD) runners and 42 elite male middle distance (MD) runners at four different running velocities. The running economy of the MD and LD groups was compared both in terms of the aerobic demands and the percentage of VO_2max. The groups were similar for the oxygen costs of running expressed relative to body weight across the four running velocities. However, the researchers noted a significant difference (8%) between groups when the oxygen costs were expressed relative to VO_2max values. The LD group worked at a lower % VO_2max at each running velocity. This result may be due to the higher VO_2max of the LD group.

It appears that in groups of trained subjects with similar VO_2max values, RE may be a factor in determining performance time. However, in groups of trained subjects with different VO_2max values, RE has not been proven to be an indicator of performance time.

The results and discussions of several studies (Powers, 1983; Sjödin & Svedenhag, 1985; Kearney & Van Handel, 1989) clearly demonstrate that many years of training improves RE. This has been demonstrated for developing runners (Krahenbuhl & Pangrazi, 1983; Daniels et al., 1978; Krahenbuhl & Williams, 1992; Kearney & Van Handel, 1989) as well as mature runners (Sjödin & Svedenhag, 1985; Kearney & Van Handel, 1989). Training may be the most practical option of improving RE since little can be done to change age, gender, or biomechanical factors. High intensity interval training (Sjödin et al., 1982; Conley et al., 1981) and high mileage programs (Scrimgeour et al., 1986; Daniels et al., 1978) have produced favorable results. Caution must be taken when increasing mileage since it has been reported that a sudden increase in mileage is associated with an increased rate of injury (Noakes, 1991). A combination of interval sessions and slow, long distance running may be the prescription to improve running economy.

2.3 The relationship between VO_2 and grade running

Fewer studies have investigated the relationship between VO_2 and grade running in contrast to horizontal running. Early works (Margaria et al., 1963; Dill, 1965; Dean, 1965) didn't use many subjects and concluded that further research was required.

Margaria et al. (1965) evaluated the caloric values for two athletes running at different speeds up to 22 km/hr at grades from -20% to +15%. Caloric expenditure per kilogram of body weight was found to be linearly related to speed at all the grades.

Dill (1965) studied three subjects. He reported an increase from 0.17 to 0.20 ml/kg.m as speed increased from 150 to 350 m/min. He also indicated that the oxygen cost of the vertical component in grade walking was 1.53 ml/kg.m for a moderately trained individual. The oxygen cost of the vertical component in both grade walking and running was 1.31 ml/kg.m for a highly trained individual.

Gregor and Costill (1973) investigated the energy expenditure during positive and negative grade running. The energy requirements at the various grades were determined by testing ten conditioned distance runners. Three seven minute runs were performed by the subjects at 200 m/min on (1) a level treadmill, (2) a 6.0% incline, and (3) a 6.0% decline. The VO_2 requirement to run up a 6.0% grade was 1.92 times that for running down a 6.0% grade. Positive grade running (+6.0%) required 39.9% more energy than did level running (0%) while performance with negative grade (-6.0%) required 27.1% less energy.

After comparing these three running conditions, the researchers concluded that positive work costs approximately twice as much work as negative work. To further support this finding, fractional utilization of the aerobic capacity varied from 47% for the 6.0% downhill running to 78% of the VO_2max during the 6.0% uphill running. Thus, grade running or a running course which includes hills would require greater energy expenditure for the same speed and distance.

In 1981, Hinch and Morez investigated the metabolic cost of uphill and downhill treadmill running in seven male distance runners. The VO_2 was measured during steady state running at level grade, at uphill gradients (2.0%, 4.0%, 6.0%, 8.0%, and 10%) and downhill gradients (-3.0%, -6.0%, -9,0%, -12%, -14%, and -16%) at running speeds of 167, 208, and 236 m/min. The authors agreed with previous reports that VO_2 (ml/kg.min) increases linearly with running speed for level running and with percent grade for uphill running at a constant speed.

2.4 Running equations to predict VO_2

Numerous studies have reported the energy cost of horizontal treadmill running. Few studies have discussed the energy cost of grade running. The A.C.S.M. (1991) has attempted to standardise the energy cost of running. They have published VO_2 values for horizontal running speeds as well for grade running (A.C.S.M. Guidelines equation, 1991, p. 296, 299).

Horizontal running economy values from several studies are reported for males and females in Tables 1 and 2 respectively. In studies where the RE speeds were not the same, the respective researcher's VO_2-speed regression equation was used to calculate the values given in Tables 1 and 2.

Table 1. Horizontal running economy (ml/kg.min) of trained male runners.

Reference	n	Speed (m/min) 188	215	241	268
ACSM equation	-	41.1	46.5	51.7	57.1
Trained runners					
Bransford & Howly (1977)	10	34.6	40.1	45.3	50.8
Hagan et al. (1980)	67	34.4	40.1	45.7	51.4
Mayhew (1977)	9	36.6	42.0	47.1	52.5
McMiken & Daniels (1976)	8	37.7	42.3	46.8	51.4
Ramsbottom et al. (1987)	69	37.1	42.3	46.3	52.5
Highly trained runners					
Boileau et al. (1982) MD*	42	36.8	42.6	48.2	54.1
Boileau et al. (1982) LD*	32	39.4	44.3	49.1	54.0
Conley & Krahenbuhl (1980)	12	33.6	39.3	44.7	50.3
Costill & Fox (1969)	6	33.1	38.6	43.9	49.4
Costill et al. (1973)	16	31.8	38.6	45.2	52.0
Daniels (1977)	10	34.4	39.0	44.6	50.5
Daniels & Daniels (1992)	45	26.0	35.5	41.7	48.2
Pugh (1970)	4	33.9	38.7	43.3	48.2

* MD and LD denote middle distance and long distance runners, respectively.

Table 2. Horizontal running economy (ml/kg.min) of trained female runners.

Reference	n	Speed (m/min) 161	188	215	241	268
A.C.S.M. equation	-	35.7	41.1	46.5	51.7	57.1
Bransford & Howly (1977)	10	32.8	37.7	42.6	47.4	52.3
Conley et al. (1981)	11	30.6	34.6	40.4	47.1	52.7
Daniels et al. (1977)	10	28.7	34.4	40.7	46.0	51.5
Daniels et al. (1986)	30	26.5	33.0	39.5	45.8	52.3
Daniels & Daniels (1992)	20	26.5	32.3	38.0	43.5	49.3
Fay et al. (1989)	13	-	-	42.8	47.3	-
Wilcox & Bulbulian (1984)	7	-	-	40.9	46.5	-

The subjects of the studies presented in Tables 1 and 2 used approximately 5-10 ml/kg.min less than predicted by the A.C.S.M. Guidelines equation for treadmill running. The A.C.S.M. equation is probably designed for an "average" population. The subjects in the studies presented in Tables 1 and 2 are more economical than the average untrained individual.

Linear equations (Table 3) are often reported relating oxygen consumption with running speed. Daniels & Daniels (1992) evaluated the RE of 45 male and 20 female elite runners. Submaximal test speeds were 248, 268, 290, and 310 m/min for both genders. The males also ran at 330 and 350 m/min. Some males were able to run at 370 and 390 m/min. The linear regression equations were:

$VO_2 = - 16.094 + 0.240(\text{speed})$ and $VO_2 = - 7.55 + 0.212 (\text{speed})$, respectively.

Conley & Krahenbuhl (1980) evaluated the RE of 12 highly trained male runners at speeds of 241, 268, and 295 m/min. Their linear regression equation was: $VO_2 = - 5.67 + 0.209(\text{speed})$.

Hagan et al. (1980) evaluated the RE of 67 male and nine female well conditioned runners at speeds of 147.8, 174.7, 201.6, 228.5, 255.4, and 282.2 m/min. The one-variable linear regression equation was $VO_2 = 5.66 + 0.213(\text{speed})$.

From the horizontal running economy data presented in Table 3, the "slope" variable is in agreement with the A.C.S.M. equation. The slope of the VO_2-speed line is the same for runners of various training statuses, but the intercept decreases with training status.

At least three curvilinear equations have been reported (Table 4).

Table 3. Linear regression equations to predict the gross energy cost of horizontal running.

Reference	n	Gender	Training status	Slope	Intercept
A.C.S.M. equation				.200	+3.5
Bransford & Howley (1977)	10	M	T	.203	-3.562
	10	F	T	.182	+3.511
	10	M	UT	.204	-0.510
	10	F	UT	.151	+10.942
Boileau et al (1982)	42	M	E (MD)	.216	-3.812
	32	M	E (LD)	.183	+4.973
Conley & Krahenhuhl (1980)	12	M	E	.209	5.67
Costill & Fox (1969)	6	M	E	.204	-5.24
Costill et al (1973)	16	M	E	.252	-15.54
Daniels et al (1977)	10/10	M+F	E	.211	-5.29
Daniels & Daniels (1992)	45	M	E	.240	16.094
	20	F	E	.212	-7.555
Dressendorfer et al (1977)	19	M	T	.158	+6.0
Hagan et al (1980)	76	M+F	T	.213	+5.66
Mayhew (1977)	9	M	T	.199	-0.82
McMiken & Daniels (1973)	8	M	T	.172	+5.363
Pugh (1970)	4	M	T	.179	+4.245
Rambottom et al (1987)	69	M	T	.193	+0.72

UT, T, and E denote untrained, trained and elite individuals. MD and LD denote middle distance runners and long distance runners.

Table 4. Curvilinear regression equations to predict VO_2 from running speed.

Reference Equation	n/Gender	Training status
Daniels et al. (1977) VO_2 (ml/kg.min) = 14.77 + 0.056(m/min) + 0.000279(m/min)^2	10M/10F	T/T
Fellingham et al. (1987) VO_2 (l/min) = 0.5993 + 0.0137(kg) + 0.008846(kg)(km/h)^2	24M	T
Van der Walt & Wyndham (1973) VO_2 (l/min) = −0.419 + 0.03257(kg) + 0.000117(kg)(km/h)^2	6M	UT

2.5 Gender differences

Gender differences in various types of physical performance has been a growing interest to exercise physiologists. Numerous researchers (Wells & Plowman, 1983; Puhl, 1986; Drinkwater, 1984) suggested that gender differences in athletic performance are largely due to variations in body size, body composition, aerobic power, and muscular strength.

Wilmore and Brown (1974) evaluated 11 elite female distance runners and 17 sedentary females. Each runner performed a VO_2max test and a hydrostatic test (to determine relative total body fat and lean body weight). These two groups of female subjects were further compared with other studies involving males. Basic physiological differences existed between males and females although these differences were not as great as the data obtained from a sedentary population. The researchers stated that further training, better coaching, better equipment, and increased emphasis on sport will close the gap between the sexes.

Wilmore (1979) stated that while there are substantial physiological differences between the average male and female, these differences are reduced considerably when comparisons are made between highly trained male and female athletes who are competing in the same event or sport. He concluded that highly trained male and female athletes are similar in lower body strength expressed per unit of body weight; cardiovascular endurance capacity; body composition; and muscle fiber type.

Some factors affecting cardiorespiratory endurance will be discussed. These include: maximal aerobic power or $\dot{V}O_2$max (body weight, body composition) and haemoglobin concentration, (Pate & Kriska, 1984).

Much of the research on the gender difference in cardiorespiratory endurance has focussed on VO_2max and it's determinents (body weight and body composition)(Pate & Kriska, 1984). Males and females have been found to differ significantly in VO_2max values. This inter-gender variance has been accounted for on the basis of differences in cardiovascular dimensions, blood constituents, body size, and body composition (McArdle et al., 1986; Pate & Kriska, 1984; Sparling & Cureton, 1983).

Sparling (1980) published a meta-analysis of 13 studies comparing the contribution of body size and percent of bodyfat to the difference in VO_2max in men and women. The male values were 56% higher than the female values in absolute VO_2max and 28% higher in relative VO_2max. Thus, one-half of the variance was explained by knowing the gender of the subject. When the variability in aerobic capacity due to body size and body fatness was removed, the magnitude of difference in VO_2max between males and females is substantially reduced. When VO_2max was expressed relative to fat-free weight, the inter-gender variance decreased to 15 percent. This strongly suggests that differences in body composition account for some of the gender differences in relative VO_2max (excess fat tissue contributes to total bodyweight but, unlike muscle tissue, cannot contribute importantly to oxygen consumption) (Pate & Kriska, 1984).

The percentage of body fat is much greater in females than males (Wilmore & Brown, 1974; Wells & Plowman 1983). In both sedentary and active populations, training does not eliminate the impact of body composition on the gender difference in VO_2max (Pate & Kriska, 1984; Fleck, 1983; Cureton & Sparling, 1980).

Cureton and Sparling (1980) assessed metabolic responses to submaximal and maximal treadmill running and 12-min run performance between 10 male and 10 female physically active subjects. The males were assessed under two conditions (1) with normal body weight and (2) with external weight added to the trunk so that the total percent excess weight (%EW) was equal to the percent fat of a matched female. Under the added-weight condition, %EW of the males was increased by an average of 7.5%, treadmill run time was increased by 32%, and the 12-min run performance time was increased by 30%.

These researchers concluded that females utilize more oxygen per unit FFW to run at any submaximal speed because of thier higher body fatness. VO_2max expressed relative to body weight is lower and, as a result, average speed for the 12-min run or other similar distance running events are slower than for males. Since the gender-specific, essential fat of women cannot be eliminated by diet or training, it has been suggested to provide part of a biological justification for separate standards and expectations for men and women.

Several basic physiological differences between males and females are found among hematological indices (Drinkwater, 1984). Females have lower haemoglobin concentration (Hb), lower hematocrit, higher concentration of high-density lipoproteins (HDL), higher estrogen and lower androgen levels than males (Drinkwater, 1984).

The average range for Hb in females is 12-16g/100ml whereas males usually show Hb values in the range of 14-18g/100ml (Pate & Kriska, 1984). This gender difference in Hb has been reported in both sedentary and trained groups. Also, endurance-trained male and female athletes manifest lower Hb than sedentary groups (Pate, 1983; Miller, 1990).

Since Hb determines the oxygen-carrying capacity of the blood, the female's lower Hb results in a lower oxygen-carrying capacity of the blood (Astrand et al., 1964; Pate & Kriska, 1984).

The lower Hb for females has also been proposed as a contributing factor to a lower VO_2max value. Cureton and his associates (1986) attempted to equate the Hb concentration of 10 male and 11 female subjects. All subjects were similarly trained. The amount of blood was withdrawn from the male subjects to equalize their Hb concentrations to those of the female subjects.

Significant changes occured in the males' VO_2max values, hematocrit values, and total endurance time. Equalizing the Hb concentrations reduced the mean absolute VO_2max of the males by 7.5%, the mean relative VO_2max by 6.9%, and the mean VO_2max expressed relative to fat-free weight (FFW) by 7.7%. Hematoctit values and total endurance time were both reduced by 5.0%. The researchers concluded that the gender difference in Hb accounts for a significant, but relatively small portion of the gender difference in VO_2max.

The current gender gap in long distance running as represented by world records by year has been attributed primarily to basic biological differences between males and females. Some of these inherent gender-specific differences are in: aerobic power, body composition, and hematological indices. Performance results for both genders continues to improve, slowly; however, performance-related biological differences between males and females are unlikely to change (Sparling et al., 1993).

Chapter III

Methods and Procedures

This chapter is divided into the following sections:

3.1 Selection and treatment of subjects

3.2 Laboratory testing apparatus

3.3 Laboratory testing procedures

3.4 Experimental design and statistical analysis

3.1 Selection and treatment of subjects

The subjects in this study were 23 female athletes between the ages of 20 and 33 years. They were volunteers from university cross country and track teams, other running club members, and athletes that included running as part of their training program.

The subjects were asked to read, understand, and sign an informed consent form (Appendix A) prior to the first testing session. This form outlined the procedures for each test and indicated the risks associated with the tests. The Research Ethics Committee of the Faculty of Education at McGill University approved the procedures for collection and storage of data. The signed document is included in Appendix B.

A complete verbal explanation of the tests was given to the subjects by the investigator. Any questions by the subjects were clarified. All subjects were given the same instructions and verbal encouragement during the testing sessions.

Each subject was tested on four separate occasions. At least two days of recovery was given between each test. Subjects were asked to refrain from eating and exercising at least two hours prior to each test.

3.2 Laboratory testing apparatus

All four testing sessions took place at the Seagram's Sports Science Centre at McGill University. Standing height was assessed using a wall mounted stadiometer with the subject dressed in shorts, top, and socks. Body weight, including weight of running shoes (since these contribute to the running workload) was measured using a balance beam medical scale. Five skinfold sites (Canadian Standardized Test of Fitness) were measured using skinfold calipers (Bull). The five sites were: triceps, biceps, subscapular, iliac crest, and medial calf. Three measurements were taken at each site. The median score at each site was recorded.

A Quinton 645 treadmill with variable speed and grade was used for the running tests. The speed was checked with a 60s meter count for each workload. Grade was calculated from measurements of treadmill "rise" and "run".

Expired air was collected for analysis of ventilation, oxygen uptake, carbon dioxide production, and respiratory quotient using the Sensormedics 2900 Metabolic Measurement

Cart. The gas samples were collected and analyzed every 20 seconds. Prior to each testing session, the O_2 and CO_2 analyzers were calibrated using two concentrations of gas. Tank 1 had a concentration of 16.20% O_2, 3.84% CO_2, and 79.96% nitrogen. Tank 2 had a concentration of 26.00% O_2, 4.00% CO_2, and 70.00% nitrogen. Subjects wore a lightweight plastic headgear apparatus that supported a mouthpiece which was connected to a Hans-Rudolph valve and a low resistance flexible hose. The subjects also wore a noseclip during the testing sessions. Heart rate was monitored with a Sport Tester (Polar Vantage XL) with values averaged every 5 seconds.

3.3 Laboratory testing procedures

Subjects participated in: (1) a VO_2 max test, (2) five 6 minute running economy tests at 133 m/min, (3) five 6 minute running economy tests at 160 m/min, and (4) three 6 minute running economy tests at 186 m/min. The running economy tests at 133 and 160 m/min were performed at the following grades: 0%, 2.5%, 5.0%, 7.5%, and 10.0%. The running economy tests at 186 m/min were performed at 0%, 2.5%, and 5.0% grade. In general, if the combination of speed and grade resulted in a VO_2 above 90% of the subject's VO_2max or an R value in excess of 1.00, then the results were not included in the calculations.

<u>VO_2max treadmill test</u>: Each subject performed a direct, progressive, maximal treadmill test. A five minute warm up period of low intensity exercise preceeded data collection. The test began at 160 m/min and 0% grade for the first two minutes. For the following two minutes, the speed increased to 176 m/min with the grade remaining at 0%. For the next two minutes, the speed increased to 186 m/min with the grade remaining at 0%. After this stage, the speed remained at 186 m/min and the grade increased by 2% every 2 minutes until the subject reached volitional exhaustion (Table 5). A plateau or slight decrease in VO_2 with increasing workloads suggests achievement of VO_2max (Lamb, 1984; Shephard, 1992). Two of the following three criteria were present to determine that a subject had achieved her VO_2max (1) an R value > 1.10 (Shephard, 1992), (2) HR > age predicted HR_{max} (Shephard, 1992), and (3) a change of < 100 ml/min of VO_2 or a decrease in VO_2 when the workload was increased (plateau).

<u>Running economy tests</u>: A maximum of 13 running economy tests were performed over three days (four-five tests per session). The tests were performed at 133, 160, and 186 m/min. The tests at 133 and 160 m/min included five grades: 0%, 2.5%, 5.0%, 7.5%, and 10.0%. The tests at 186 m/min were conducted at 0%, 2.5%, and 5.0% grade. The tests (grade-speed combinations) were administered in a random

order. Subjects ran for six minutes at each grade-speed combination. Between tests, the recovery period was five minutes or when heart rate dropped below 120 beats per minute.

Table 5. Predicted VO_2 (ml/kg.min) for the VO_2max test.

Stage (#)	Time (min)	Speed (m/min)	Grade (%)	Predicted VO_2 (ml/kg.min)
1	0- 2	160	0	35.5
2	2- 4	176	0	38.7
3	4- 6	186	0	40.7
4	6- 8	186	2	43.6
5	8-10	186	4	46.5
6	10-12	186	6	49.3
7	12-14	186	8	52.2
8	14-16	186	10	55.1
9	16-18	186	12	58.0

Running economy was calculated as the average steady state oxygen consumption during the last two minutes of each running speed and grade (Daniels & Daniels, 1992). The R value was < 1.00 at each velocity during the running economy tests (Shephard, 1992). The predicted oxygen consumption based on the A.C.S.M. Guidelines equation for each speed-grade combination is outlined in Table 6.

Table 6. Predicted VO_2 (ml/kg.min) during treadmill running using the A.C.S.M. Guidelines equation.

Speed	Grade (%)				
(m/min)	0.0	2.5	5.0	7.5	10.0
133	30.1	33.1	36.2	39.1	42.1
160	35.5	39.1	42.7	46.3	49.9
186	40.7	44.9	49.1	-	-

3.4 Experimental design and statistical analysis

Descriptive statistics (mean and standard deviation) were calculated for the following physical characteristics describing the sample: age, height, weight, body mass index, and sum of five skinfolds. The 0.05 level of significance was used for all statistical analyses in this study.

The first hypothesis, examining the relationship between VO_2 and horizontal velocity was analyzed using stepwise regression analysis (with one independent variable: speed). The intercept for the Y-axis was set at 3.5 ml/kg.min since this value represents the resting oxygen consumption. This regression analysis determined the slope for the relationship between speed and VO_2.

The second hypothesis, examining the relationship between VO_2 and grade running was also analyzed using stepwise regression analysis. Using data at speeds of 133, 160, and 186 m/min, the regression analysis determined the relationship between VO_2 and grade. Data were collected at the following grades: 0.0%, 2.5%, 5.0%, 7.5%, and 10.0%. The experimental design for hypothesis 1 and 2 is presented in Table 7.

Table 7. Experimental design for hypothesis 1 and 2.

Speed (m/min)	Subjects	Grade (%)				
		0	2.5	5.0	7.5	10.0
133	1 2 3 . . . 23					*
160	1 2 3 . . . 23				*	*
186	1 2 3 . . . 23		*	*	X	X

* Reduced number of subjects due to the VO_2 required to complete the test under steady state conditions.

The third hypothesis examined the vertical component to predict the oxygen cost of grade running using an equation containing a grade component. The data were analyzed using multiple stepwise regression analysis. This statistical procedure was chosen in order to evaluate the relative contribution of the specific independent variables (speed, grade, and the interaction factor of speed and grade) to predict the oxygen cost of running. For this regression analysis, predictor variables for a regression equation were introduced one at a time until the next variable that entered the equation did not significantly increase the prediction accuracy of the multiple correlation (Steiner, 1986). The 0.05 level of significance had to be met for a variable to be added to the equation.

The fourth hypothesis, examining the difference between the predicted VO_2 from the A.C.S.M. Guidelines equation and the value predicted by the new equation was analyzed by comparing the variability (R^2) explained by this new equation with the (R^2) obtained from the A.C.S.M. Guidelines equation.

Chapter lV

Results

This chapter is divided into the following sections:

4.1 Descriptive statistics

4.2 Results of the VO_2max test

4.3 Horizontal running economy data

4.4 Grade running economy data

4.5 Prediction of VO_2 during grade running

4.6 Comparison of the new regression equation with the A.C.S.M. equation

4.1 Descriptive statistics

The subjects for this study were 23 female athletes from university cross country and track teams, other running club members, triathletes, and athletes who include running as part of their training program. The subjects ranged in age from 20-33 years. The means and standard deviations for age, height, mass, sum of five skinfolds (SOS), and body mass index (BMI) are given in Table 8.

4.2 Results of the VO_2max test

The individual results and standard deviations for the maximal treadmill test are presented in Table 9. The mean values for the absolute and relative measures of maximal oxygen consumption (VO_2max) were 3.18 L/min and 53.5 ml/kg.min respectively. The mean maximal ventilation, heart rate, ventilatory equivalent for oxygen, and R value were 108.4 L/min, 194 beats/min, 34.2 L of air/L of O_2, and 1.13 respectively.

Table 8. Physical characteristics of the subjects.

Subject	Age (yrs)	Height (cm)	Mass (kg)	SOS (mm)	BMI (kg/m^2)
1	24	161.0	55.9	39.8	21.6
2	22	163.0	56.8	49.6	21.4
3	23	165.0	53.2	46.0	19.5
4	24	170.2	63.4	50.0	21.9
5	27	155.0	58.2	45.6	24.2
6	20	159.4	54.1	46.2	21.3
7	24	166.9	62.5	52.2	22.4
8	23	163.7	48.4	32.0	18.1
9	24	162.5	63.2	44.9	23.9
10	25	160.0	55.0	31.0	21.5
11	20	163.0	61.0	44.0	23.0
12	25	160.7	54.1	37.4	20.9
13	21	160.0	55.0	37.6	21.5
14	20	166.4	65.4	27.7	23.6
15	22	168.0	63.2	49.2	22.4
16	24	171.0	65.0	38.6	22.2
17	33	175.0	80.0	41.6	26.1
18	20	173.0	68.0	47.8	22.7
19	28	167.6	61.8	38.4	22.0
20	26	156.0	49.1	34.1	20.2
21	26	160.0	52.0	37.6	20.3
22	28	168.0	60.0	35.0	21.3
23	24	172.5	62.7	35.2	21.1
Mean	24	164.7	59.5	40.9	21.9
S.D.	3	5.4	6.9	6.8	1.7

Table 9. Results of the VO_2max test.

Subject	VO_2max (L/min)	VO_2max (ml/kg.min)	VEmax (L/min)	HRmax (bpm)	VeqO_2 (L of air/L of O_2)	R
1	2.78	49.7	93.3	195	33.6	1.12
2	3.28	57.7	95.5	183	29.1	1.10
3	3.15	57.9	106.0	206	33.7	1.10
4	3.22	50.8	102.1	204	31.7	1.18
5	3.20	53.7	105.6	201	33.0	1.14
6	2.72	50.1	101.0	187	37.1	1.10
7	2.89	46.2	104.3	199	36.1	1.16
8	2.42	50.0	87.1	195	36.0	1.15
9	3.53	57.5	108.4	199	30.7	1.10
10	3.06	55.8	109.5	198	35.8	1.16
11	3.33	54.6	113.7	204	34.1	1.11
12	3.56	65.8	128.2	188	36.0	1.13
13	3.00	54.7	120.3	195	40.1	1.10
14	3.80	58.2	126.9	195	33.4	1.11
15	3.13	48.9	109.5	206	35.0	1.10
16	3.20	49.1	103.4	188	32.3	1.11
17	4.20	52.6	131.5	177	31.3	1.17
18	3.31	48.7	134.0	193	40.5	1.11
19	3.26	52.8	114.7	179	35.2	1.15
20	2.96	60.3	107.0	192	36.1	1.20
21	2.73	52.8	76.4	196	28.0	1.05
22	3.12	52.0	106.0	175	34.0	1.12
23	3.20	51.1	109.0	197	34.1	1.10
Mean	3.18	53.5	108.4	194	34.2	1.13
S.D.	0.38	4.5	13.8	9	3.0	0.03

4.3 Horizontal running economy data

Horizontal running economy data were measured at speeds of 133, 160, and 186 m/min. Subjects ran for six minutes at each speed. Running economy was measured as the mean VO_2 for the last two minutes at each workload (Daniels & Daniels, 1992).

Individual results, means, standard deviations, and the A.C.S.M. predicted VO_2 values for the three horizontal speeds are presented in Table 10. Mean VO_2 values and standard deviations for this study are illustrated in Figure 1 along with the A.C.S.M. predicted VO_2 values.

From horizontal running economy data, the slope of the speed-VO_2 line in this study was found to be 0.201 ml/kg.m when the resting component of 3.5 ml/kg.min was forced into the equation (Figure 1). This is in agreement with the slope of the A.C.S.M. Guidelines equation (0.200 ml/kg.m).

4.4 Grade running economy data

Grade running economy was measured at speeds of 133, 160, and 186 m/min. The running economy tests at 133 and 160 m/min included the following grades: 2.5%, 5.0%, 7.5%, and 10.0%. The running economy tests at 186 m/min were performed at 2.5% and 5.0% grade.

Subjects ran for six minutes for each speed-grade combination. Individual results, number of subjects who performed each combination, means, standard deviations, and the A.C.S.M. predicted VO_2 values for the grade running economy tests at 133, 160, and 186 m/min are given in Tables 11, 12, and 13 respectively. Mean VO_2 values and standard deviations are illustrated in Figure 2 for the 13 speed-grade combinations.

Table 10. Running economy data (ml/kg.min) at 0% grade.

Speed (m/min)	133	160	186
Subject 1	33.3	39.2	44.8
2	28.6	33.4	43.0
3	29.4	34.6	42.6
4	33.7	38.8	42.6
5	34.8	39.6	44.9
6	34.0	36.6	39.8
7	31.2	34.3	38.5
8	34.0	38.3	43.9
9	29.4	33.4	40.0
10	28.8	35.2	39.1
11	27.2	32.5	40.5
12	31.3	34.5	43.0
13	27.0	31.1	38.0
14	31.7	40.6	45.0
15	28.2	35.5	40.0
16	29.3	34.8	41.0
17	27.0	33.0	38.0
18	32.6	37.3	41.1
19	30.8	35.0	39.4
20	30.0	34.5	40.3
21	36.5	41.8	42.9
22	25.6	29.2	35.5
23	25.0	29.5	36.0
Mean	30.4	35.3	40.9
S.D.	3.1	3.3	2.7
Predicted VO_2 (A.C.S.M.)	30.1	35.5	40.7

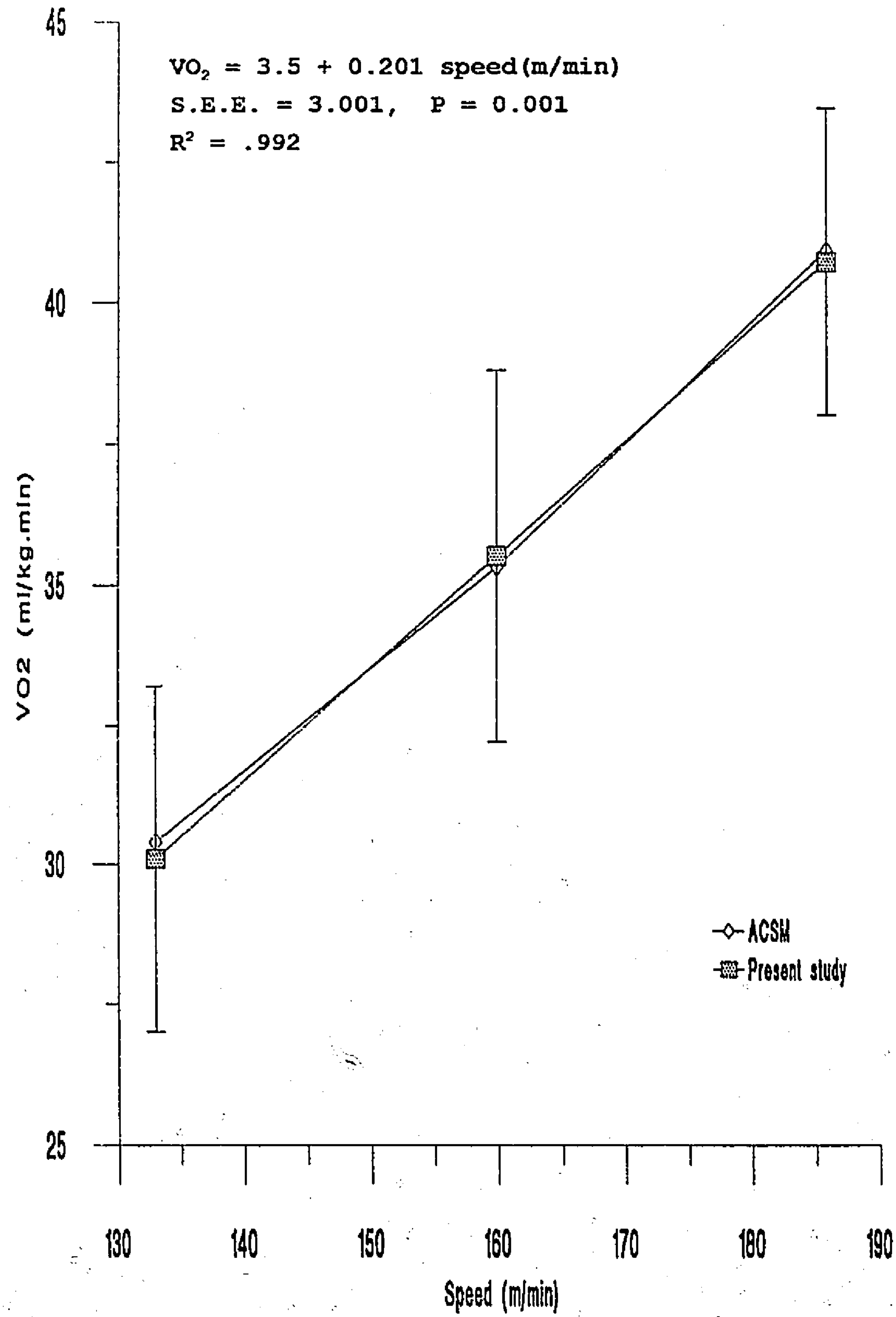

Figure 1 VO2 (ml/kg.min) versus speed at 0% grade

Table 11. VO_2 (ml/kg.min) at 133 m/min.

Grade	0%	2.5%	5.0%	7.5%	10.0%
Subject					
1	33.3	37.7	40.5	43.7	47.8
2	28.6	32.8	39.6	44.5	45.0
3	29.4	33.4	39.2	45.4	51.2
4	32.7	34.7	39.6	44.2	-
5	34.8	37.3	39.2	42.9	48.7
6	34.0	36.8	39.6	44.0	48.1
7	31.2	33.1	35.1	40.1	42.1
8	34.2	38.4	41.1	43.0	-
9	29.4	31.6	37.0	43.6	48.5
10	28.8	32.6	35.6	43.0	46.5
11	27.2	31.2	39.4	43.6	46.1
12	31.3	33.5	38.7	44.0	50.2
13	27.0	29.2	35.8	39.7	42.8
14	31.7	36.4	41.2	44.5	50.2
15	28.2	34.0	36.6	42.0	46.6
16	29.3	33.4	37.5	41.7	44.8
17	27.0	33.8	35.1	41.6	45.4
18	32.6	35.8	40.5	44.6	-
19	30.8	32.2	37.0	40.0	47.9
20	30.0	33.4	37.9	42.6	46.4
21	36.5	39.5	43.0	46.0	50.7
22	25.6	29.6	35.0	39.9	44.8
23	25.0	29.3	36.7	40.3	44.0
n	23	23	23	23	20
Mean	30.4	33.4	38.3	42.8	46.9
S.D.	3.1	2.8	2.2	1.9	2.6
Predicted VO_2 (A.C.S.M.)	30.1	33.1	36.2	39.1	42.1

Table 12. VO_2 (ml/kg.min) at 160 m/min.

Grade	0%	2.5%	5.0%	7.5%	10.0%
Subject					
1	39.2	43.6	47.1	-	-
2	33.4	38.9	44.8	49.5	-
3	34.6	40.0	44.6	51.6	-
4	38.8	42.0	46.1	-	-
5	39.6	42.1	48.0	-	-
6	36.6	39.4	44.5	-	-
7	34.3	36.0	41.3	-	-
8	38.3	40.6	48.1	-	-
9	33.4	40.0	43.5	49.9	54.4
10	35.2	38.0	44.3	47.0	-
11	32.5	37.3	44.1	47.1	-
12	34.5	41.0	46.4	52.2	56.4
13	31.1	35.0	40.8	47.2	52.3
14	40.6	43.6	47.6	51.9	56.7
15	35.5	39.0	43.4	-	-
16	34.8	39.0	43.2	-	-
17	33.0	36.7	45.4	49.8	-
18	37.3	41.4	43.5	-	-
19	35.0	36.2	42.7	50.2	-
20	34.5	40.4	45.1	50.1	53.8
21	41.8	45.3	47.9	52.1	-
22	29.2	34.1	38.0	47.0	-
23	29.5	34.3	42.9	-	-
n	23	23	23	13	5
Mean	35.3	39.3	44.5	49.7	54.7
S.D.	3.3	3.0	2.5	2.0	1.8
Predicted VO_2 (A.C.S.M.)	35.5	39.1	42.7	46.3	49.9

Table 13. VO_2 (ml/kg.min) at 186 m/min.

Grade	0%	2.5%	5.0%
Subject			
1	44.8	-	-
2	43.0	46.7	52.0
3	42.6	46.0	52.0
4	42.6	-	-
5	44.9	46.3	-
6	39.8	-	-
7	38.5	-	-
8	43.9	-	-
9	40.0	47.0	51.2
10	39.1	41.4	47.1
11	40.5	42.7	-
12	43.0	47.3	51.0
13	38.0	41.2	48.0
14	45.0	48.9	53.4
15	40.0	-	-
16	41.0	-	-
17	38.0	42.7	-
18	41.1	-	-
19	39.4	43.1	-
20	40.3	45.0	52.0
21	42.9	47.6	-
22	35.5	39.5	-
23	36.0	41.9	-
n	23	15	8
Mean	40.9	44.5	50.8
S.D.	2.7	2.9	2.2
Predicted VO_2 (A.C.S.M.)	40.7	44.9	49.1

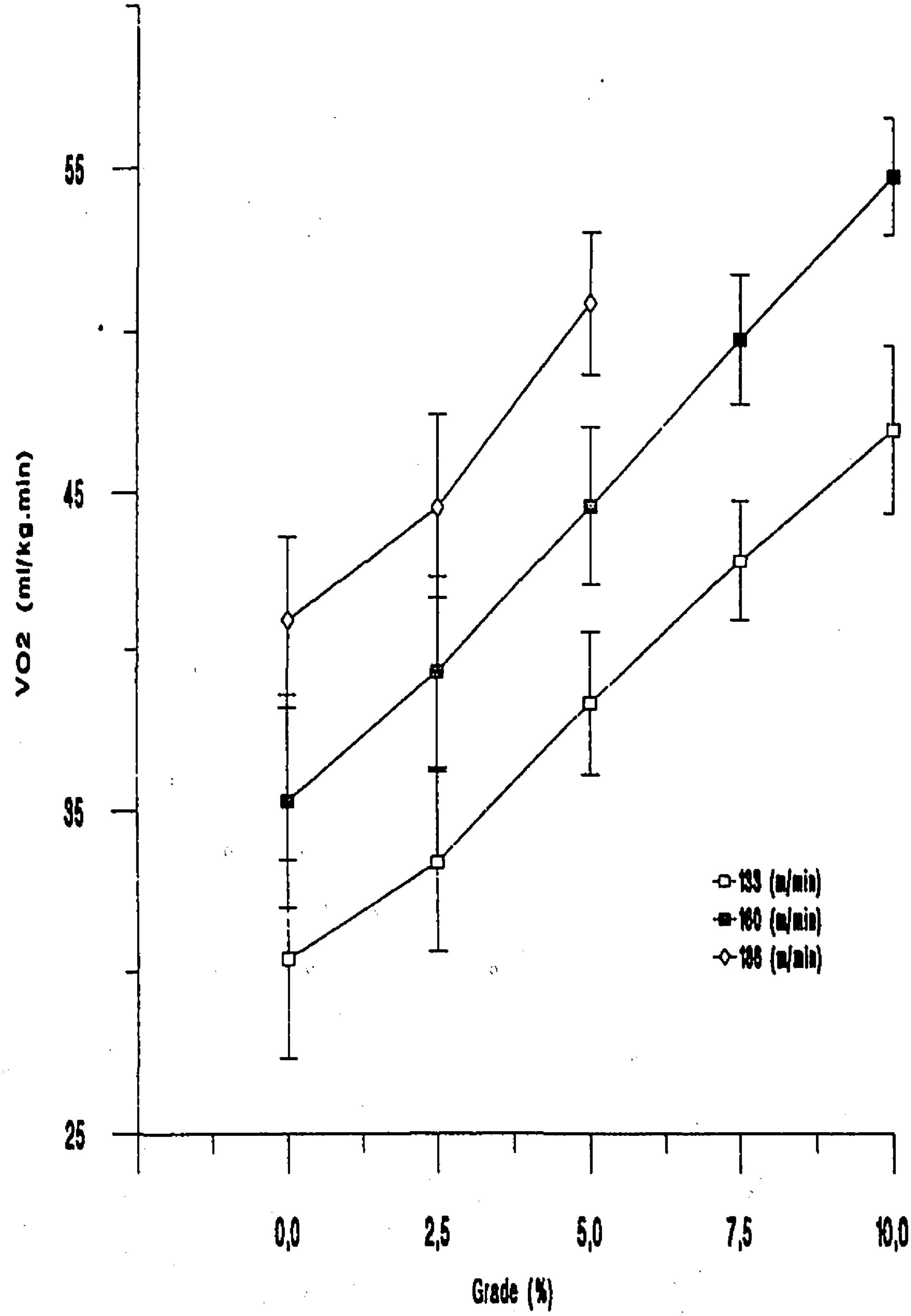

Figure 2 VO2 (ml/kg.min) versus grade at 133, 160, and 186 m/min

A stepwise regression analysis was performed using the data for each speed. The coefficients for the speed and grade, R, R^2, standard error of estimate (S.E.E.), and probability are compared in Table 14. These data are illustrated with the A.C.S.M. equation in Figure 3 (133 m/min), Figure 4 (160 m/min), and Figure 5 (186 m/min). The equations for the grade-VO_2 line at speeds of 133, 160, and 186 m/min were:

$VO_{2\text{ at 133 m/min}}$ (ml/kg.min) = 30.2 + 5.286(speed m/min) X grade(frac)

$VO_{2\text{ at 160 m/min}}$ (ml/kg.min) = 35.7 + 7.094(speed m/min) X grade(frac)

$VO_{2\text{ at 186 m/min}}$ (ml/kg.min) = 40.9 + 11.678(speed m/min) X grade(frac)

The constant was forced into each equation using the information from the horizontal running economy data. For example, when running at 133 m/min, the constant of 30.2 was obtained as follows:

VO_2 (ml/kg.min) = 3.5 + 0.201(speed)

VO_2 (ml/kg.min) = 3.5 + 0.201(133 m/min)

VO_2 (ml/kg.min) = 3.5 + 26.7

VO_2 (ml/kg.min) = 30.2

When running at 160 m/min, the constant was obtained as follows:

VO_2 (ml/kg.min) = 3.5 + 0.201(speed)

VO_2 (ml/kg.min) = 3.5 + 0.201(160 m/min)

VO_2 (ml/kg.min) = 3.5 + 32.2

VO_2 (ml/kg.min) = 35.7

When running at 186 m/min, the constant was obtained as follows:

VO_2 (ml/kg.min) = 3.5 + 0.201(speed)

VO_2 (ml/kg.min) = 3.5 + 0.201(186 m/min)

VO_2 (ml/kg.min) = 3.5 + 37.4

VO_2 (ml/kg.min) = 40.9

Table 14. Stepwise regression equations for speeds of 133, 160, and 186 m/min.

	Constant	Grade Coefficient	R	R^2	S.E.E.	Prob.
$VO_{2\ at\ 133\ m/min}$	3.5	5.286	.90	.803	15.74	0.001
$VO_{2\ at\ 160\ m/min}$	3.5	7.094	.86	.739	20.10	0.001
$VO_{2\ at\ 186\ m/min}$	3.5	11.678	.73	.530	28.08	0.001

At 0% and 2.5% grade, there was no significant difference between the measured VO_2 and the predicted VO_2 using the A.C.S.M. Guidelines equation. At 5.0% grade, the measured VO_2 was about 2 ml/kg.min higher than the predicted A.C.S.M. values. At 7.5% grade, the A.C.S.M. equation underpredicted the VO_2 by approximately 4 ml/kg.min. At 10% grade, at speeds of 133 and 160 m/min, the A.C.S.M. equation underpredicted the VO_2 by approximately 5 ml/kg.min. As grade increased, the difference between the measured and predicted values also increased. The results of this study clearly show that the slopes are considerably higher than the slope of the A.C.S.M. equation.

4.5 Prediction of VO_2 during grade running

A new equation was developed using stepwise regression analysis to predict VO_2 during grade running. Table 15 lists the statistical results of the new equation using data from three speeds (133, 160, and 186 m/min) and five grades (0%, 2.5%, 5.0%, 7.5%, and 10.0%). This equation accounted for 99.5% of the variance. The equation is:

$$VO_2\ (ml/kg.min) = 3.5 + 0.198\ speed(m/min) + 0.932\ grade(\%) + 0.006\ [speed(m/min) \times grade(frac)]$$

Table 15. Stepwise regression analysis to predict VO_2 during grade running.

Variable	Coeficient	Standard Error	Standard Coefficient	t	Prob.
Speed	0.198	0.002	0.809	118.0	0.001
Grade	0.932	0.319	0.125	2.9	0.004
Speed*Grade	0.006	0.002	0.113	2.6	0.011

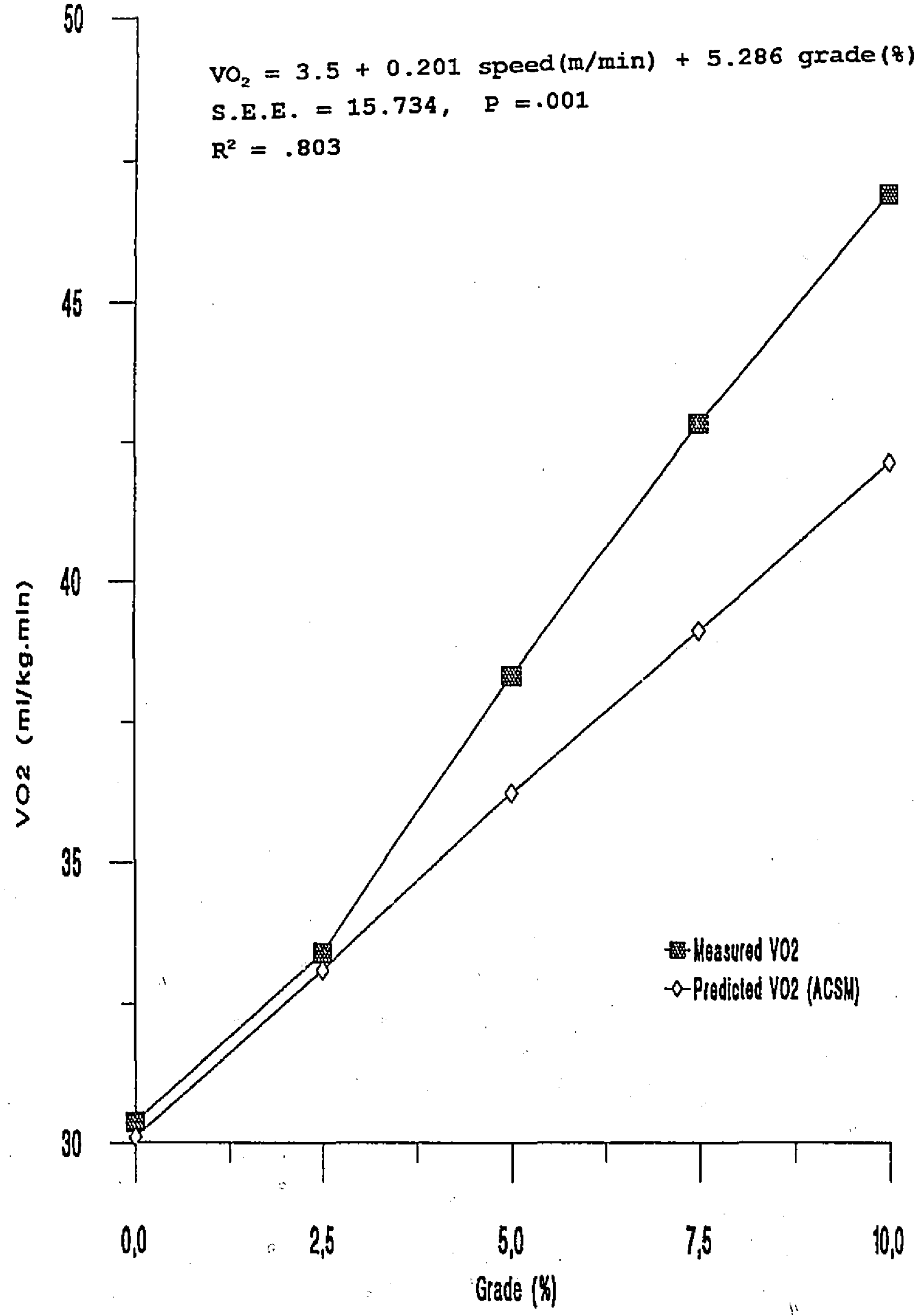

Figure 3 VO2 (ml/kg.min) versus percent grade at 133 m/min

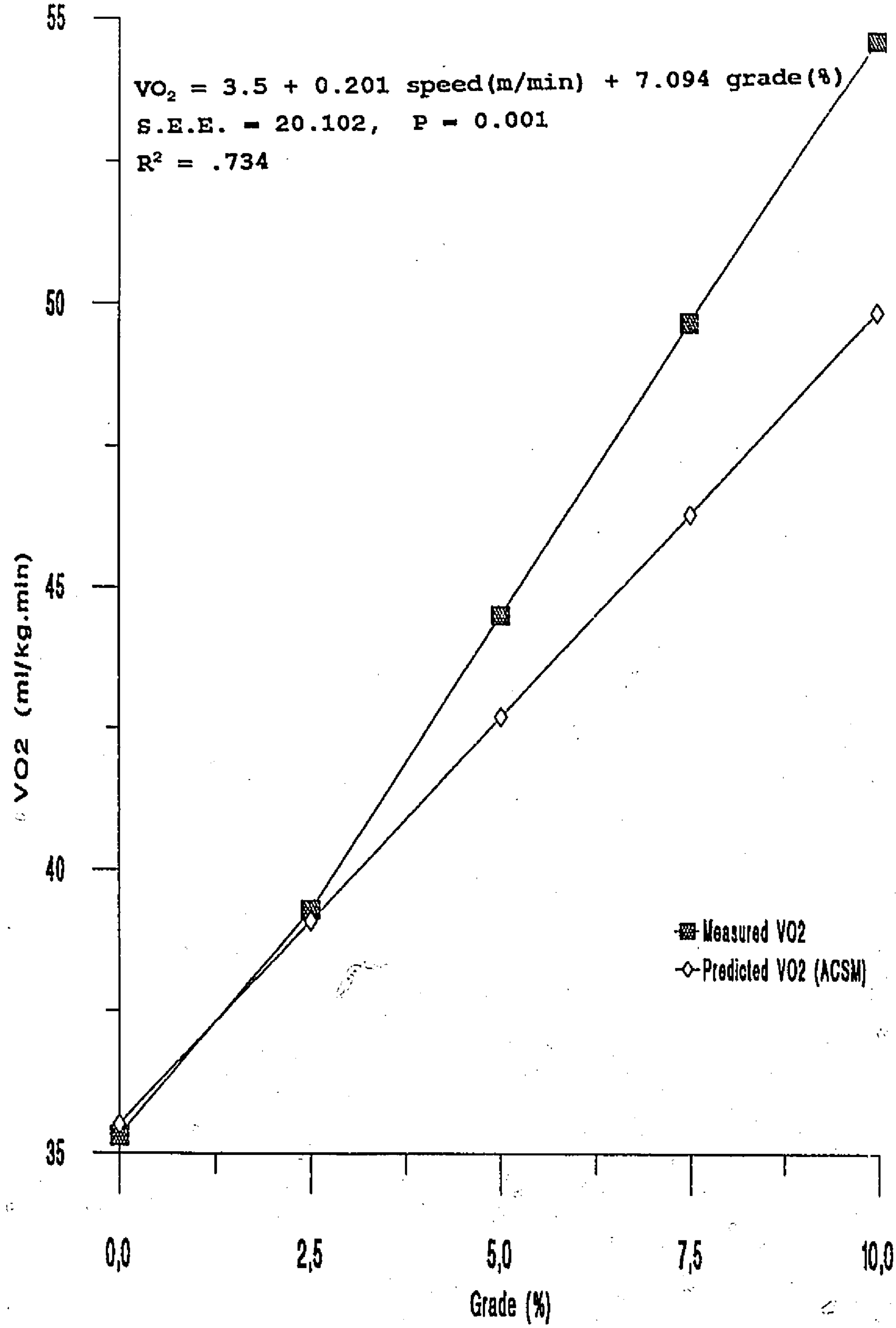

Figure 4 VO2 (ml/kg.min) versus percent grade at 160 m/min

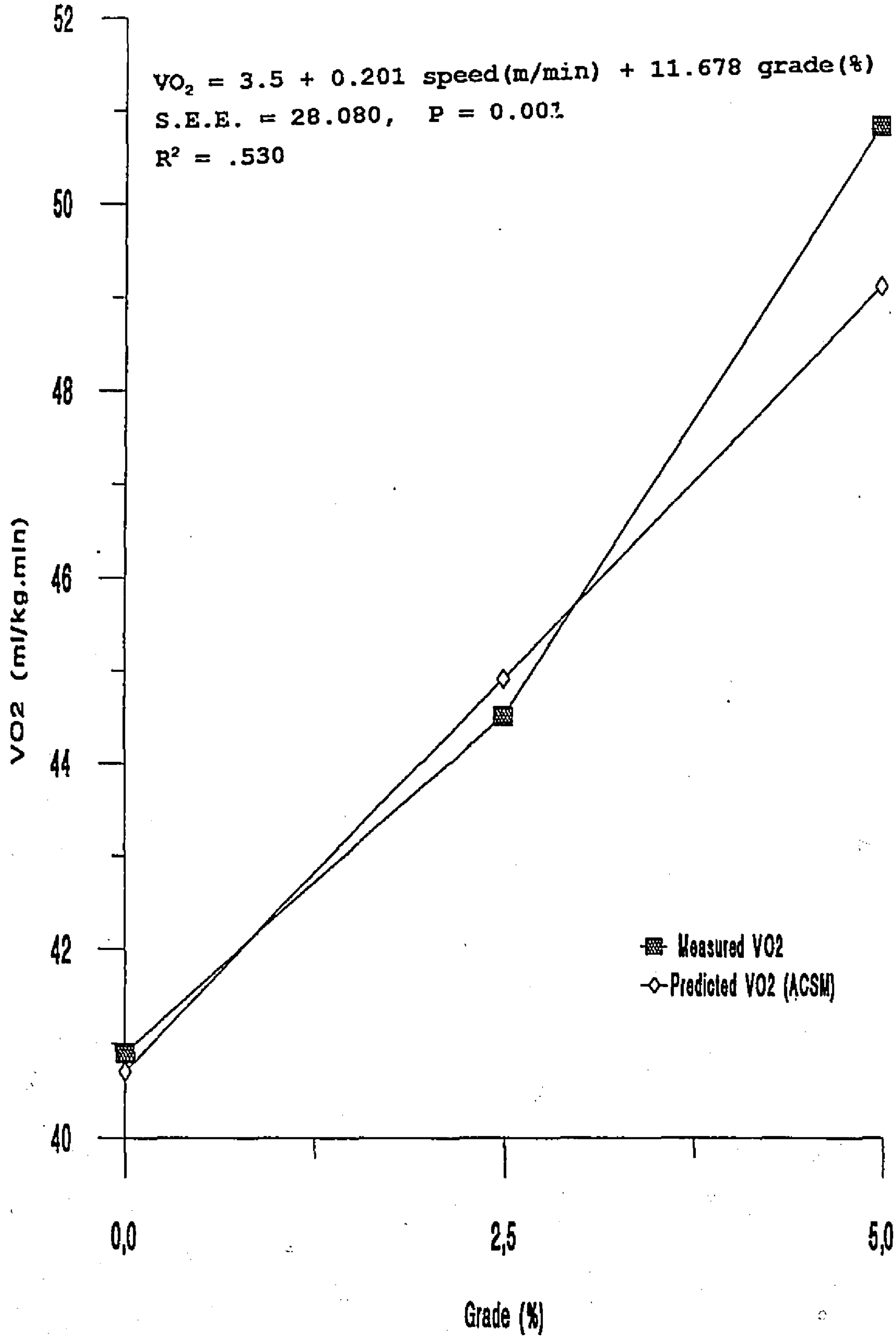

Figure 5 VO2 (ml/kg.min) versus percent grade at 186 m/min

4.6 Comparison of the new regression equation with the A.C.S.M. equation

For the 23 subjects, oxygen uptake was measured for 245 tests using three speeds (133, 160, and 186 m/min) and five grades (0%, 2.5%, 5.0%, 7.5%, and 10.0%). The measured VO_2 was correlated (Pearson r) with the predicted VO_2 using the A.C.S.M. Guidelines equation and the predicted VO_2 using the new regression equation developed in this study. The Pearson r was 0.885 using the A.C.S.M. equation and 0.998 using the new regression equation. The additional variation explained by the new regression equation warrant using this equation instead of the A.C.S.M. Guidelines equation.

Chapter V

Discussion

This chapter is divided into the following sections:

5.1 Subject characteristics

5.2 Maximal oxygen consumption (VO_2max)

5.3 Horizontal running economy

5.4 Grade running economy

5.1 Subject characteristics

Table 16 compares the physical characteristics of the subjects in this study with mean values for trained runners. The mean weight of the subjects in this study was approximately 6 to 10 kg heavier than the runners shown in Table 16. Since their height was similar to other trained runners, the weight difference is attributed to a higher body fat mass and/or a higher muscle mass.

5.2 Maximal oxygen consumption (VO_2max)

VO_2max values for subjects in this study were compared to values reported in the literature (Table 17). The values for the subjects in this study were not as high as those reported for other trained runners. This could be partly explained because of the higher mass of the subjects in this study and partly because some of the subjects were not as highly trained as the reference subjects cited in Table 16.

5.3 Horizontal running economy

The horizontal running economy of the subjects in this study were compared to reported values for other trained runners (Table 17). The subjects in this study had similar oxygen consumption as predicted by the A.C.S.M. Guidelines equation for treadmill running. This indicates that these subjects have similar economy as the average person. The subjects in this study consumed approximately 5-7 ml/kg.min more oxygen than the trained runners reported in Table 17.

From horizontal running economy data, the slope of the speed-VO_2 line in this study was found to be 0.201 ml/kg.m when the Y-intercept is forced into the equation to reflect the resting VO_2 component of 3.5 ml/kg.min. This is similar to the slope of the A.C.S.M. Guidelines equation (0.200 ml/kg.m).

Table 16. Physical characteristics of trained female runners.

Reference	n	Weight (kg)	Height (cm)
Bransford & Howly (1977)	10	53.7	166.4
Conley et al. (1981)	11	49.3	159.7
Daniels et al. (1977)	10	52.1	166.2
Daniels et al. (1986)	30	52.5	166.0
Daniels & Daniels (1992)	20	52.2	166.0
A.C.S.M. (1991)	?	?	?
Present study	23	59.5	164.7

Table 17. VO_2 (ml/kg.min) of trained female runners.

Reference	n	VO_2max	VO_2 at 161 m/min	VO_2 at 188 m/min
Bransford & Howly (1977)	10	48.8	32.8	37.7
Conley et al. (1981)	11	53.0	30.6	34.6
Daniels et al. (1977)	10	59.6	28.7	34.4
Daniels et al. (1986)	20	67.0	26.5	33.0
Daniels & Daniels (1992)	20	66.2	26.5	32.3
A.C.S.M. (1991)	?	?	35.5	40.7
Present study	23	53.5	35.3*	40.6*

* The present study used treadmill speeds of 160 and 186 m/min due to the limitations over the control of speed.

5.4 Grade running economy

Few studies have examined grade treadmill running economy, hence there is no standardized protocols specifying appropriate combinations of speed and grade. This study used three speeds (133, 160, and 186 m/min) and five grades (0%, 2.5%, 5.0%, 7.5%, and 10.0%). Other reports of the oxygen cost of grade running have used grades of +5.7% (Bassett et al., 1985), +7.5% and -5.0% (Breiner, 1987), +6.0% (Costill et al., 1974; Gregor and Costill, 1973; Kollias et al., 1967); +2.0%, +4.0%, +6.0%, and 10.0% (Hinch and Moroz, 1981), -20.0 to +15.0% (Margaria et al., 1963); +5.0%, +10.0%, and +15.0% (Montgomery et al., 1987); 3.0%, 6.0%, and 9.0% (McGruer and Montgomery, 1989); -10.0 to +10.0% (Nelson and Osterhoudt, 1971); and +5.0% (Stabb et al, 1988).

Several studies have presented data that reveals that the A.C.S.M. Guidelines equation under-predicts VO_2 during grade running. In the investigation by Montgomery et al. (1987), 18 male runners performed treadmill exercise at 0, 5.0, 10.0, and 15% grade with the speed ranging from 128.6 to 215.3 m/min. At a speed of 128.6 m/min and a grade of 15%, the difference between the VO_2 predicted by the A.C.S.M. equation and the measured oxygen consumption was 3.4 ml/kg.min. The A.C.S.M. equation predicted the VO_2 to be 46.6 ml/kg.min while the VO_2 was 50.0 ml/kg.min. In the investigation by McGruer and Montgomery (1988), 15 male runners performed treadmill exercise at 0, 3.0, 6.0, and

9.0% grade at a speed of 188 m/min. The difference between the VO_2 predicted by the A.C.S.M. equation and the measured oxygen consumption was 2.1 ml/kg.min. The A.C.S.M. equation predicted the VO_2 to be 56.3 ml/kg.min while the VO_2 was 58.4 ml/kg.min.

The A.C.S.M. Guidelines equation to predict the oxygen cost of treadmill running is as follows:

$$VO_2 = 3.5 + 0.2\ \text{speed(m/min)} + 0.9\ [\text{speed(m/min)} \times \text{grade(frac)}]$$

This equation includes an interaction factor but no main effect for grade.

When comparing the A.C.S.M. Guidelines equation with the new equation, it was observed that: (1) the Pearson r was 0.885 using the A.C.S.M. equation and 0.998 using the new regression equation. The new equation explained 99.5% of the variance (R^2) as compared to the A.C.S.M. Guidelines equation which explained 78.0% of the variance (R^2). It is recommended that the A.C.S.M. modify the equation in the book "Guidelines for Exercise Testing and Prescription" by adopting the equation proposed in this investigation.

Chapter VI

Summary, Conclusions, and Recommendations

This chapter is divided into the following sections:

6.1 Summary

6.2 Conclusions

6.3 Recommendations

6.1 Summary

Previous studies have correlated horizontal running speed and VO_2 consumption. Few studies have correlated grade running and VO_2 consumption. The purpose of this study was to examine the grade-VO_2 relationship of running and compare it to the A.C.S.M. Guidelines equation for predicting the oxygen cost of grade running.

The subjects in this study were 23 trained female runners. Subjects participated in: (1) a VO_2max test, (2) five 6 minute running economy tests at 133 m/min, (3) five 6 minute running economy tests at 160 m/min, and (4) three 6 minute running economy tests at 186 m/min. The running economy tests at 133 and 160 m/min were performed at the following grades: 0%, 2.5%, 5.0%, 7.5%, and 10.0%. The running economy tests at 186 m/min were performed at 0%, 2.5%, and 5.0% grade. In general, if the combination of speed and grade resulted in a VO_2 above 90% of the subject's VO_2max or an R value in excess of 1.00, then the results were not included in the calculations.

The first hypothesis stated that there is a linear relationship between VO_2 and horizontal velocity of running with a slope of 0.20 ml/kg.m. The results from this study predicted from the following regression equation: VO_2 (ml/kg.min) = 3.5 + 0.201 speed(m/min). The r for this equation was 0.996.

The second hypothesis stated that there is a linear relationship between VO_2 and percent grade when running on a treadmill. The results from this study predicted $VO_{2\ at\ 133\ m/min}$ from the following regression equation: $VO_{2\ at\ 133\ m/min}$ = 3.5 + 0.201 speed(m/min) + 5.286 grade(%). $VO_{2\ at\ 160\ m/min}$ was predicted from the following regression equation: $VO_{2\ at\ 160\ m/min}$ = 3.5 + 0.201 speed(m/min) + 7.094 grade(%). $VO_{2\ at\ 186\ m/min}$ was predicted from the following regression equation: $VO_{2\ at\ 186\ m/min}$ = 3.5 + 0.201 speed(m/min) + 11.678 grade(%). The r for the regression equations at speeds of 133, 160, and 186 m/min were 0.896, 0.859, and 0.728, respectively.

The third hypothesis stated that the vertical component to predict the oxygen cost of grade running is better described with an equation containing a grade component. A stepwise regression equation using the variables speed, grade, and speed X grade was performed to predict the oxygen cost of grade running. The following equation was established:

$$VO_2\ (ml/kg.min) = 3.5 + 0.198\ speed(m/min) + 0.932\ grade(\%) + 0.006\ [speed(m/min) \times grade(\%)]$$

The R^2 for this equation was 99.5%.

The fourth hypothesis stated that there will be a significant difference between the predicted VO_2 for grade running from the A.C.S.M. Guidelines equation and the value predicted by the new equation. The Pearson r was 0.885 using the A.C.S.M. Guidelines equation and 0.998 using the new regression equation. The new equation explained 99.5% of the variance (R^2) as compared to the A.C.S.M. Guidelines equation which explained 78.0% of the variance (R^2).

6.2 Conclusions

Within the limitations and delimitations of the study, the following conclusions can be drawn:

1. There is a linear relationship between VO_2 and horizontal velocity with a slope of 0.20 ml/kg.m.

2. There is a linear relationship between VO_2 and percent grade when running on a treadmill. At a speed of 133 m/min, the correlation between grade and VO_2 is 0.900. At a speed of 160 m/min, the correlation between grade and VO_2 is

0.859. At a speed of 186 m/min, the correlation between grade and VO_2 is 0.728.

3. Inclusion of a grade component in the regression analysis equation increases the accuracy for predicting the oxygen cost of grade running. VO_2 consumption for grade running is predicted with increased accuracy using the new regression equation.

4. The new equation to predict the oxygen cost of grade running explains 99.5% of the variance compared to 78.0% of the variance that was explained by the A.C.S.M. Guidelines equation.

6.3 Recommendations

The following recommendations are proposed for future investigations:

1. Future studies should investigate the running economy on different grades at various speeds. The economy of horizontal running has been well researched, but economy of grades running is not well established.

2. Future studies should use a broader sample of subjects that includes untrained subjects, trained runners, and highly trained runners with a range in VO_2max values.

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Appendix A

Consent For Exercise Testing

I, ____ (print name) authorize Dr. David Montgomery and Georgia Tzavellas to administer the exercise tests outlined below. I understand that I may discontinue the testing if at any time I experience unusual discomfort. I understand that the staff conducting the tests will ask me to discontinue the tests if any indication of abnormal response to the tests become apparent. I understand that I will perform the tests as listed below and I have the opportunity to question and discuss the exact procedure that will be followed.

Tests to be performed:

Session 1:

Aerobic endurance - you will run on a treadmill between 10-16 minutes. The test will begin at 160 m/min and 0% grade for the first two minutes. For the following two minutes, the speed will be increased to 176 m/min with the grade remaining at 0%. For the next two minutes, the speed will be increased to 186 m/min with the grade remaining at 0%. After this stage, the speed will remain at 186 m/min and the grade will be increased by 2% every 2 minutes until volitional exhaustion.

Sessions 2, 3, and 4:

You will run four-five running economy tests (RE) per testing session. Each RE test will last six minutes. The following speeds will be used: 133, 160, and 186 m/min. The tests at 133 and 160 m/min will include five grades: 0%, 2.5%, 5.0%, 7.5%, and 10%. The tests at 186 m/min will be conducted at 0%, 2.5%, and 5.0% grade.

Between each speed and grade combination, there will be a minimum recovery period of five minutes. You will continue the next RE test after five minutes of recovery or when your heart rate is 120 beats per minute or below.

Each subject will participate in all speed and grade combinations. These 13 combinations will be conducted in random order.

I acknowledge that I have read this form and I understand the test procedures to be performed and the inherent risk and I consent to participate. I understand that the data will be released only to principal investigators.

SIGNATURE OF SUBJECT: ______________________ DATE: ______________