Prediction of running economy based on observation

Thomas A. Raunig

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THE PREDICTION OF RUNNING ECONOMY
BASED ON OBSERVATION

by

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B.A., University of Montana, 1982

Presented in partial fulfillment of the requirements
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Date July 21, 1989
The study analyzed the ability of high school distance running coaches to predict the running economy of endurance athletes. Twelve athletes, ranging in age from 18 to 27 years were video taped individually for a 30 second interval while running at 268 meters per minute pace. Also, metabolic measurements were taken at 268 m.min⁻¹ and maximum oxygen uptake (VO₂ Max) was determined using a modified Balke test.

Fifteen high school distance running coaches with 3 to 30 years experience observed each runner on video twice. The coaches ranked the runners from 1 to 12 with 1 being the most economical runner. The coaches' rankings were correlated to the ranking of the actual metabolic measurements.

Coaches showed a significant (p<.05) ability to rank athletes as runners in proper order of testing performance in three of six metabolic measurements. Results for the Kendall correlation of coach rankings to the runners' rankings of oxygen uptakes at 268 m.min⁻¹ were r = .53 (p = .012); for percentage of maximum heart rate at 268 m.min⁻¹ an r of .42 (p = .037); and for the average RER value at 268 m.min⁻¹ coaches' rankings had an r of .36 (p = .050). With the Spearman-Rowe Correlation Coefficient coaches showed significant ability to rank the runners in two of the six areas. Percentage of maximum oxygen uptake at 268 m.min⁻¹, with a correlation of .53 (p = .048). Coaches' rankings correlated with the runners' rankings of oxygen uptake at 268 m.min⁻¹ with a correlation of .74 (p = .005). Thus, coaches showed some ability to predict athletes' running economy by observing video tapes of the athletes.
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CHAPTER ONE

INTRODUCTION

Distance running has many facets that are interrelated to form and effort. The work done in running can be divided into external work and internal work. External work involves that which is done against gravity, work producing velocity changes in a forward direction, and work producing lateral movement of the center of gravity. Internal work is made up of the effort involved in moving of limbs and head in relation to the body's center of gravity, along with the work done against muscle. Yet when looking at the different aspects of work the bottom line is that each component can affect each other (1).

Subcategories which play a role in the work of running can be broken down into individual aspects that affect external and internal work. External aspects can be wind resistance (2), surface (3), footwear (4), grade (5), and clothing (6). Internal work can possibly be affected by distribution of segmental mass in the body (7), distance of the insertions from joint centers of certain muscles, age, muscle fiber orientation, muscle fiber length (8), muscle viscosity (9), body temperature (10), cardiovascular fitness (11), and weight (12). It is evident from the above that distance running has a number of variables that can play a role in the work required to run. Yet it is possible
to measure the relative energy cost of running by measuring oxygen consumption (VO₂) (13). This allows comparisons to be made between individuals as to how much work they are doing at a given task.

When a runner's oxygen cost is measured in relation to their body weight at a particular running velocity, it is called running economy (14, 15). This measure enables researchers to determine individual differences in economy at specific workloads, but is of little help in deciding what causes one person to be more economical than another. Other measures that can be used to separate individual's ability to do work include maximum oxygen uptake (VO₂ max) (16), fractional utilization of the VO₂ max (17), maximal treadmill workload, anaerobic threshold (18), and lactate accumulation (19). All of these measures give an overall view of how much work is being done, but are specific to selective variables and thus do not account for all the variations in runners' work capacity.

Coaches, physiologists, runners, and biomechanists have looked to running technique for ways to improve performance by lowering one's energy cost while maintaining a given workload. This means the athlete would be more economical, and it is a logical way to improve performance. Since physiological changes have been shown to be limited somewhat by genetics. For example, improvements in maximum oxygen uptake have been reported to be limited to a 5 to 25 percent increase in most people (20). Running technique has a number of genetic factors involved in it
as well, and that raises questions as to how much benefit can be gained through changes in technique (21). Yet Costill (22) calls for more attention to be given technique with this statement:

In nearly every other sport, at least part of each training session is directed toward the improvement of skill. This is not the case in distance running. Few runners ever attempt to analyze or improve their running techniques. When we consider the fact that even a one percent decrease in the energy cost of running would improve a three hour marathoner's time by nearly two minutes, it is surprising that more attention isn’t given to this aspect of training.

Cavanagh (23) has come out on both sides of the issue with the following statements:

It is by no means axiomatic that athletes classified as skilled according to the criterion of running velocity exhibit the best form or style. Indeed the criteria for good style that are applied by coaches still rest on somewhat of an empirical base, since sport scientists have not yet produced an adequate theoretical model to allow the effects of parameter variation to be studied.

On another occasion he made this statement (24):

It is at the level of the elite athlete that considerations of improved economy are most relevant. Changes of even a small magnitude could have a major effect on performance ranking in endurance events.

Hyman (25) has come out with the following warning about technique changes:

In distance running the athlete must use his (her) energy as economically as possible. He (she) cannot afford to adopt changes in technique that increase his (her) speed, if in doing so they impose an intolerable increase in total energy expenditure. Hence, coaches who have advocated modifications in style on the basis of mechanical analysis of one aspect of work, have not been justified. They have been unable to predict the effect of the modification on the other sources of energy expenditure.

The experts are saying a lot of different things about one's chances of becoming more economical at running. But most agree
that economy is very important to distance running, particularly among groups with homogenous maximum oxygen uptakes. Conley (26) found that among an elite group of distance runners economy accounted for 65.4 percent of the variation in performance at a 10 kilometer race. Cavanagh (27) has pointed out that well-trained distance runners optimize their running form through using internal feedback. He theorized that they tend to minimize their energy cost by a kind of trial and error process. Some evidence to support this exists in Scrimgeour’s (28) findings that runners who trained over 100 kilometers a week were significantly faster than those training under 100 kilometers a week and all of the differences in performance were based on differences in economy. Those who go out and run more may have more chances to optimize their running form, but on the other hand, those who run more may be genetically more economical and thus more able to run a larger amount of miles. This situation is an example of how difficult it is to separate the physiological and mechanical aspects of running. Runners’ mechanics and their physiological capabilities are both the problem and the solution to optimizing performance.

Many coaches focus on the runners’ form, desiring to make their body movements more economical. Some coaches feel this is worthwhile and others don’t. Just which position is right is not known. Powell (29) has said:

So much of the writing in track and field is based solely on conjecture and opinion, it has been difficult to identify what is empirically believed and what has been scientifically founded and proved.
Lundin (30) advised coaches to leave running style alone unless gross deviations exist. Then on the other hand, Costill (31) is encouraging experimentation with running form. To add to the temptation, physiologists use graphs (Appendix A) that compare relative VO₂ to running velocity (32), to show that running economy can be a major factor. Coaches see the person with the much higher maximum oxygen uptake who is not running any faster than the economical person and start looking for ways to improve the runner's economy. Coaches can't be blamed for looking at ways to improve an athlete's economy, but with the lack of clear evidence it is difficult to give scientifically sound direction to long distance runners on improving form.

Statement of the Problem

Coaches are undecided on whether to act on changing running form. This is because just what is good running form may vary with the individual. Nonetheless, coaches do try to make changes, but no studies are available to say if these changes help. The lack of scientific evidence as to whether coaching distance runners to change form helps or not poses the question of what coaches can do to improve the economy of distance runners. By asking coaches to evaluate the economy of a group of runners, whose economy is known through taking metabolic measurements, the coach's ability to evaluate whether a runner is economical or not can be determined. Therefore, the purpose of this study is to determine the capability of coaches to assess
running economy by watching videos of runners with known physiological measurement of running economy.

**Hypothesis**

H:0

The variables of VO₂ at 268 meters per minute, average RER value at 268 m.min⁻¹, percentage of maximum heart rate at 268 m.min⁻¹ percentage of maximum oxygen uptake at 268 m.min⁻¹, and RER at VO₂ max will not vary significantly in runners when ranked and correlated against coaches' rankings of economy (p<.05).

**Scope Runners**

This study selected 12 college runners from a wide range of ability levels with an age range between 18 and 27 years. Participants varied in running training mileage from 0 to 114 kilometers (0-70 miles). Runners' heights ranged between 5'7" and 6'1", weight ranged from 59.0 to 77.2 kilograms, and percent body fat estimates varied between 5.0 and 14.0 percent. Subjects were tested for submaximum oxygen uptake at 268 meters per minute (10 miles per hour or 6 minute mile pace), maximum oxygen uptake, respiratory exchange ratio (RER) value at maximum VO₂, percentage of maximum heart rate, maximum heart rate, average heart rate at 268 m.min⁻¹, RER value at 268 m.min⁻¹, fractional utilization of maximum oxygen uptake at six minute pace, height, weight, and an estimation of percent body fat. Participants were required to fill out a questionnaire in which they listed their personal best running performances at distances of 1500, 3000, 5000, and 10,000 meters, and years of running experience. Subjects ran on both
the treadmill and track with oxygen analysis done only on the treadmill. Filming was done on a track with the same procedures followed for each subject.

Scope Coaches

Fifteen distance running coaches with a minimum of three years of coaching male runners were asked to observe all 12 runners on video tape. Each coach observed the "model" runners for two 30-second video segments. The order of observation was based upon one of three groupings. Random drawings for the order of observation were done to reduce the bias due to the order in which athletes appeared. Coaches were asked to write down comments as to what they saw as economical or uneconomical about the runner's form. Coaches were given a specific amount of time after the twelfth runner had been observed for making their rankings of economy.

Delimitations

1. Runners must be able to achieve 268 m.min\(^{-1}\) (6 minute mile pace) running pace to participate in the study.

2. Length of time allowed for viewing.

3. Two dimensions of the television screen instead of live observation.

Limitations

1. Coaches may know some of the runners they are observing.
2. Clothing could affect coaches' views of runners.
3. Variability in homogeneity within the three groups.

Variables

Runners' independent variables
1. percent body fat
2. age
3. height
4. weight
5. miles run a week

Runners' dependent variables
1. running economy of the individuals

Coaches' independent variables
1. coaching experience
2. beliefs about the practice of making running form changes

Coaches' dependent variables
1. predictions of the runners' economy

Definitions

Running Economy - The steady-state of oxygen consumption (ml.kg$^{-1}$.min$^{-1}$) for a standardized running speed (33).

Maximal Oxygen Consumption $\text{VO}_2\text{Max}$ - The point at which the oxygen consumption plateaus and shows no further increase with an increased workload (34).

Fractional Utilization of $\text{VO}_2\text{Max}$ - The percentage of maximum oxygen uptake required at a given workload (35).
Maximum Treadmill Workload - Running on a flat treadmill starting at eight kilometers an hour (5 mph) and increasing the speed at a rate of one kilometer per hour each minute until the runner must cease (36).

Efficiency of Running - The relationship between work done and energy expended, and minimizing or eliminating unwanted or counter productive movement of the muscles (37).

Anaerobic Threshold - The level of work or oxygen consumption just below that at which metabolic acidosis and associated changes in gas exchange occur (38, 39).
CHAPTER TWO

REVIEW OF THE LITERATURE

Coaches should look for methods to get the most out of their athletes, and this is true for distance running coaches as well. Brooks and Fahey (40) wrote about coaches being willing to explore new ways for improvement in athletic performance:

The scientist/coach observes and quantifies the factors affecting these performances and systematically varies them to achieve success.

They call for coaches to be innovative, but at the same time quantify what they see so that there is some basis for what they do. Very little research has been done to aid the coach in having the information necessary to try systematically varying their methods with any confidence. Thus coaches train their athletes the way they were trained and very little changes. Physiologists have studied top level athletes as a means to see what makes them better at running and possibly find ways to help other runners. But evidence points to heredity as the major factor in endurance performance, so truly being innovative may not be worth the trouble if you’re a high school coach with limited time and talent. Studies continue to come out reconfirming the need to have natural talent, and they are now breaking down the metabolic aspects among homogenous groups of runners (41). This enables researchers to determine strengths or
weaknesses that influence the variance in performance. Finding the mechanical, physiological, and psychological variables among runners, and what role they play in determining performance serves to help clarify the picture of predicting distance running ability.

**Mechanical Predictions**

Runners do alter their running mechanics over periods of time, and in some cases it does make them more economical, but these changes may be largely attributable to growth (42). Changes in running stride length have been longitudinally studied with high school and college runners. The results showed stride length to go down over a college career (43), whereas the high school runners showed no clear pattern (44). Finding the right stride length for younger runners has been given much of attention based on the idea that the athlete’s stride length may play a role in how much oxygen is consumed. Studies have had runners chop their strides, lengthen their strides, and freely choose strides. The results showed that the freely chosen stride length was significantly better (45, 46). Initially this would indicate that if freely choosing stride length is better, then the need to coach this aspect of running form would be negated. But since runners do change running form over time, coaches wonder about making changes in the present to gain immediate benefits rather than wait on the athletes.

Thus coaches still have an interest in stride length mechanics, and some advocate methods for checking to see if the
optimum stride is being used. Nelson (47) advocates a simple analysis of a runner’s stride length by having the athlete run 20 yards at speeds varying from a jog to all out sprint, with the coach counting the strides. Then using a chart based on the number of strides and the athlete’s size, it can be predicted whether the runner is choosing the proper stride length. McDavid (48) has shown that by averaging the athlete’s chopped strides and elongated strides a prediction can be made of the athlete’s freely chosen stride length. He has found a high correlation ($r = .975$) between freely chosen stride length and predicted natural stride length using this method. So should the athletes freely chosen stride length vary greatly from the predicted stride the coach may have grounds to suspect bad mechanics. Cavanagh and Williams (49) point out that by changing stride length the affected muscles are forced to work on different regions of their force-velocity curve, thus changes in efficiency can be expected. But it appears that in most cases these changes are not for the better.

In distance running the mechanics have a different purpose than in running a sprint. Although Armstrong, Costill, and Gehlsen (50) showed that sprinters and distance runners had only three significant differences in biomechanics, the two vary mostly in that sprinting can be wasteful of energy due to the event getting over so quickly. Coaches can change a sprinter’s stride length based on the idea that running speed equals stride length times stride rate (51). But coaches must also consider
whether such changes waste too much energy for the distance runner. Yet in another study, by Cavanagh, Pollock, and Landa (52), elite distance runners' only significant biomechanical advantage over good runners was that they took longer strides relative to their size. They also pointed out that good and elite runners had very similar running styles; however, some elite runners were reported to have worse styles than many good runners (53). So should a coach work to lengthen an athlete's stride, work to shorten the stride, or leave it alone? Cavanagh (54) has made this statement about stride length:

Stride length is not a critical determinant of physiological efficient running.

Running can be subdivided into functional processes. Schuder (55) analyzed various running forms and determined that it consisted of six aspects:

Foot Plant - Land behind the ball of the foot and push off the back foot.

Knee Lift - Knee forward and high enough to allow the leg through.

Center of Gravity - Keep the body weight over the lead leg to maintain forward momentum.

Arm Swing - Have a vertical forearm movement.

Head and Shoulders - Keep them relaxed.

Rhythm - Have a gentle bounce to your run.

Yet even a simple description of running like the one above is subject to question based on the evidence of others. For example, Hinrichs, Cavanagh, and Williams (56) showed that there is no apparent advantage to the style of swinging the arms
directly forward (vertical), as opposed to the cross over style most distance runners use. The question of what will help or hurt a runner's economy from this perspective remains open. The old rule of not making any changes in style unless there is gross deviations in form remains prevalent (57).

**Muscle Variables**

One can take a coaching viewpoint slightly different than asking the athlete to make changes in mechanics, yet still try to alter an athlete's running form. This is attempted through certain types of training designed to improve the properties of the muscle that help make our bodies more economical. Though not fully understood, it appears that the muscles, bones, and tendons improve efficiency while doing positive and negative work, plus in their elastic storage capabilities. These processes play a major role in the muscular efficiency of the body, and are the primary reason why the metabolic efficiency and many other activities are higher than what is known for the highest efficiency of transformation of chemical energy into mechanical work (58). Positive and negative work are concentric and eccentric contractions respectfully, with positive work involving a contracting of the muscle, and negative work requiring a stretching of the muscle. Negative work requires far less energy with the possible reason being that during eccentric contractions the muscle cross-bridges are forcibly detached and reattached without splitting more ATP (59).
Elastic recoil requires a shortening of the muscle preceded by an active pre-stretch; this allows more tension at a given length (60). The benefits of elastic storage for running were demonstrated by Bosco et al. (61), where they took a ratio between efficiency between muscular work performed during pre-stretch jumps and the corresponding value found in jumps with no pre-stretch. The ratio showed a significant inverse relationship with energy expenditure during running, \( r = -0.66, n = 13, p<0.01 \). With the above evidence coaches can work to improve runners' economy by using drills which involve a pre-stretch of the muscle followed by contraction. Bosco and Komi (62) point out that the amount of utilization of elastic energy could be genetically predetermined to a large extent, so improvement in this area could vary greatly among individuals.

Further evidence of the importance of muscular elastic properties was supplied by Thorstensson (63) in a study on children's running economy. He found children to become more economical when external loads were added to their bodies. Loading doesn't appear to significantly help adults' running economy, but in children it seemingly helps the use of elastic components during lengthening of an activated muscle. Evidence like this helps show the great importance of muscles, tendons, bones, and joints elastic properties during exercises that involve a pre-stretch of the muscle. In addition, these properties come into the picture when aging is looked at as a factor in performance. Children tend to have high maximum
oxygen uptakes but low economy, adults have higher economy until flexibility is lost through the aging process (64). Maximal VO\textsubscript{2}, maximal heart rate, stroke volume, maximal pulmonary ventilation, and muscular strength all decrease as a person ages (65) and eventually takes its toll on performance.

Muscle fiber types distribution has been shown to play a role in the economy of distance runners and their performances. Evidence shows a significant relationship between the percent of slow twitch fibers a person possesses and their best six mile time. Slow twitch fiber percentages are able to help predict whether a runner is an elite athlete or a good athlete, although they are not able to distinguish who will perform better among a homogenous group (66). It seems that muscle fiber composition is tied to the onset of blood lactate accumulation at submaximal running speeds (67), and a positive relationship exists between the percentage of fast twitch fibers and energy costs. It has been shown that when comparing the mechanical efficiency of sprinters to distance runners that when the sprinters were forced to run slow they show only 47 percent efficiency. The distance runners were 72 percent efficient at slow speeds. When running slows, the fast twitch fibers detach and lose their elastic potential, unlike the slow twitch fibers (68). Clearly, muscle fiber composition plays an important role in the economy of runners, but finding out exact muscle fiber composition is not something that is practiced by most coaches. This is due to the need of a muscle biopsy in order to determine muscle fiber
composition. As a method to assess potential, it is useful knowledge; but for predicting a particular performance, it would be of little help.

**Metabolic Variables**

Blood lactate accumulation has been shown in some studies to correlate best among all the variables at predicting performance (69). The accumulation of blood lactate is tied to the ability to use a large percent of one’s maximum oxygen uptake (70); thus it is tied in with all the metabolic variables. Robinson (71) gives a perspective of blood lactates roles and possible roles in exercise:

Fatigue associated with increased lactic acid in both muscles and the extracellular fluid, not only reduces the power of the muscles and slows the runner’s pace, but may well increase the energy cost of running at a given speed by upsetting neuromuscular coordination and/or by causing such changes in the muscle as contracture and increased viscosity.

The use of 4 millimeters lactate as the point of having reached the anaerobic threshold points to how closely blood lactate is related to understanding the physiological variables that make up a runner’s performance capability. The aerobic threshold is considered to be at 2 millimeters of blood lactate (72), but has received less attention as a physiological predictor. One’s anaerobic threshold is also considered the point at which the ventilatory equivalent for oxygen consumption \( \frac{VE}{VO_2} \), \( VE \), and \( FEO_2 \) experience a non-linear increase, followed by the \( VECO_2 \) experiencing a non-linear increase while the \( FECO_2 \) doesn’t fall (73). The anaerobic threshold is considered a
valuable point to measure when evaluating a person's capacity to perform submaximal work. This is because when the body goes beyond the steady state and work rises exponentially, the amount of time left that the body can function at a high level is limited. Those who are able to do a lot of work before reaching the anaerobic threshold can generally perform well as long as they have a fairly high maximum oxygen uptake.

Fractional utilization of maximum oxygen uptake is another valuable determinant of metabolic capability. Fractional utilization at a given workload indicates what percentage of the maximum oxygen uptake is being used at a given workload. Costill, Thomason, and Roberts (74) found fractional utilization at 268 m.min\(^{-1}\) to be highly correlated to performance in distance runners. This measurement is closely tied with running economy at submaximum speeds, since one's economy is simply taken and divided by their maximum oxygen uptake to get the fractional utilization. Conley (75) found among women subjects a .65 correlation of fractional utilization to racing performance when testing them at submaximal speeds. This proved to be less of a correlation than that found for the anaerobic threshold (r = .74) but similar to the max VO\(_2\) (r = .66). Economy and relative body fat both failed to show significant relationships to performance in this study. Economy in other studies by Conley (76) has been shown to have correlations to performance, r = .83 at 241 m.min\(^{-1}\), r = .82 at 268 m.min\(^{-1}\), and r = .79 at 295 m.min\(^{-1}\). Evidence on the importance of submaximal economy does vary; but when it is
looked at as part of one's fractional utilization of max, it is clearly a good predictor.

Maximum oxygen uptake as a determinant of athletic performance is considered good at separating ability groups, but not an accurate assessment of performance among homogenous groups. It may also be an insensitive method for determining the overall response of a body to training. This was evidenced in a study where athletes showed no increases in max VO₂ over a time period but performances improved (77). However, in a study on elite Irish distance runners, max VO₂ changes were the primary physiological adaptation, with running economy and ventilatory threshold dependent on changes in the max VO₂ (78). Yet another study showed the relationship between VO₂ max and racing performance to have a correlation of -.12 (79) among a group of elite distance runners. The key difference between all the various findings are that some are looking at physiologic changes, and others are looking at physiologic factors to predict performance. Differences exist between the two types of findings when they are looked at jointly, as well as when they are compared against the same types of studies. But when ability levels of runners are examined, maximum oxygen uptake can separate groups. It can also serve to assess gains in fitness among those not yet at a high level of training and long term changes among those who are training seriously over long periods.
Mitochondrial changes are very dramatic when endurance training is done, and they are one reason why max VO\textsubscript{2} changes are considered to be somewhat insensitive. One study found the muscle mitochondrial capacity to increase 130 percent, while the max VO\textsubscript{2} increased 19 percent. Muscle mitochondrial capacity, also called muscle respiratory capacity, was shown to correlate .92 with running endurance capacity in animals (80). Training clearly increases the muscle respiratory capacity, but it is also causally related to substrate utilization during submaximal exercise. Thus glycogen and fat usage are related to mitochondrial content and the end result is that a high mitochondrial content serves to spare glycogen in the muscles and liver (81). This would tend to indicate that mitochondrial content is key to economical running. Brooks and Fahey (82) have this belief about the role of muscular mitochondria and the role of one’s maximum oxygen uptake:

Taken together, these results strongly suggest that VO\textsubscript{2} max is a function of oxygen transport (a cardiovascular parameter) where as endurance is more dependent on muscle mitochondrial capacity. The maximal ability of mitochondria in muscle to consume oxygen is apparently several times greater than the ability of circulation to supply oxygen. Hence, VO\textsubscript{2} max is probably limited by arterial oxygen transport.

Based on the high correlation between muscle mitochondrial content and running endurance one might feel that the issue of which physiological variable is the best indicator of running performance is settled. Indeed one study using five variables nearly achieved the accuracy in discriminating between ability levels that mitochondrial content did. That study used fat
weight, lean weight, submax VO₂, lactic acid, and max VO₂ to arrive at a 79.5 percent discriminatory power (83), meaning that nearly 80 percent of the facets involved in endurance performance were accounted for by these five variables. Predicting performance, or using the physiologic variables that make up an effort to predict performance, serve little use unless a coach or athlete is made aware of the person’s strengths or weaknesses. Cost usually prevents the discovery of an athlete’s physiologic capabilities, so the primary determinant of ability is the athlete’s performance. Performance fails to show specific physiological faults in the athlete, but training practices try to work all the areas so that most of the athlete’s training needs are covered.

Physiologists have begun to simply use all out running as their kind of race assessment. The results of these all out runs have been good predictors of performance, as would be expected. Scrimgeour et al. (84) showed maximal horizontal treadmill running speed to be a better predictor of running performance than maximum oxygen uptake, r = .72 for all-out treadmill run to r = .54 for the max VO₂. In another study it was shown that the velocity reached at VO₂ max when correlated to 10 kilometer running had a closer relationship than max VO₂ to 10 kilometer times (85). So it seems that physiologists are moving back toward tests that are much more like actual races to predict performance. Noakes (86) has this to say about performance prediction:
Basically we have found that the VO2 max and running economy are not the factors determining performance, rather it is the maximum workload an athlete can achieve on a treadmill.

Body temperature and the body's ability to dissipate heat is yet another factor which influences performance. Temperature plays a role in the rate at which biochemical reactions take place, and heat is the major waste product of exercise. Individuals will vary in their ability to cool themselves and this can be a major factor in performance. The basal metabolic rate in humans is closely tied to body temperature. The BMR will rise 13 percent for every one degree celsius rise in humans with a fever temperature (87). Individuals range widely in heat tolerance due to the hypothalamus having set points at which it starts increasing heat loss from the body (88). Because heat plays such a key role in the biochemical reactions within muscles, particularly the oxidative phosphorylation process in the mitochondria (89), it must be considered an important variable in running performance. Water is of course critical to heat regulation in the body, comprising 80 percent of blood's composition, the blood serves to transport products to and from body tissue to help maintain balance (90).

Glycogen levels in the muscle are yet another important variable in performance. Though tied to mitochondrial content and fiber type (91, 92) in determining performance, it is still absolutely essential to performing well in distance running. Glycogen levels are depleted during strenuous efforts and if not adequately resupplied the low levels will lead to a state of
physical staleness. In a study where exhaustive runs were performed it took 46 hours to restore muscle glycogen to pre-workout levels (93). So adequate glycogen supplies in the muscle are tied to distance running performance since carbohydrates are a more efficient source of energy than fats (94). The role of energy supply in the metabolic processes involves oxygen, water, glycogen, fats, and protein, with the goal being to convert those metabolic substrates into high energy phosphates, this takes place at an efficiency of about 60 percent. This process is followed by the phosphates being converted into tension. It is called contraction coupling and has an efficiency of about 49 percent (95). Humans, of course, vary in efficiency a great deal and the above numbers don't account for all the ways people vary in how much work is getting done while converting the energy.

**Anthropometric Variables**

The body's general structure has been shown in very basic terms to play a role in how economical a person is. Seltzer (96) found that those with more linear body builds and shorter extremities tended to use more oxygen per-kilogram of body weight. He found lateral body builds to be more economical at rest than the linear built person as well. This seems odd in some ways, but economy is only one of many factors in making up one's physiological capacity and performance. Other isolated examples related to anthropometric measurements not fitting the expected norm have been found. Astrand (97) showed that total
lean body mass is independent of economy, and Conley (98) found no significant relationship between running performance and relative body fat among female road racers. Height was shown in another study to have a major influence over 10,000 meter run success; stride length and max VO₂ were the other major factors found in the study (99). Stride length and leg length have been shown to have a significant relationship for elite runners ($r = .67$), but not for good runners ($r = .10$) (100). This would seem to indicate that having long legs and being able to take long strides is an important factor in being an elite distance runner. Once again the facts fail to predict performance as the limited variables produce an incomplete picture. Body fat can obviously separate groups of fit people from clearly less fit groups, as it goes down with training (101). But to distinguish performance among a homogenous group it is of little help. The anthropometric factor of human body size increasing over the years has played a key role in athletic improvements, but findings indicate little about the role of sizes in an event where individuals are well matched (102).

Summary

Lamb (103) is able to summarize the basis of economical running with the statement:

It appears that the best endurance athletes learn to use the smallest possible muscle mass (for the smallest oxygen demand) to accomplish their performances.

All the many physiologic variables that go into the makeup of an endurance performance play a role in causing those demands
to be what they are. Age, lactate accumulation, max VO\textsubscript{2},
economy, anaerobic threshold, muscle fiber orientation,
temperature, percent body fat, weight, height, fitness, and even
a psychological component exist (104). No matter what a
distance runner sees as his/her weak point, performance is still
a combination of factors. Coaches have the job of taking what an
athlete is endowed with and working to enhance performance within
those limitations. Coaches that are aware of the proper methods
for training an athlete in terms of the cardiovascular, muscular,
and psychological have nowhere else to look to except
mechanically. Whether this is possible to do with suggestions
and practice alone is not clear.
CHAPTER THREE

METHODS

Initially a pilot study was conducted to aid in determining a proper length of time for coaches to observe the athletes on video. The study consisted of one runner who was video taped while running on the track. Taping was done for time segments of 30 seconds, 45 seconds, 60 seconds, 75 seconds, and 90 seconds. One location was used to film the runner. The angle selected allowed front, side and back views of the athlete as he ran around the track at a $268 \text{ m.min}^{-1}$ pace. The video tape was taken to three different coaches for observation. The order in which each coach saw the five time segments of film went from the shortest to longest segment. The coaches rated the segments from most preferred to least preferred to give a proper assessment of the runner's form. A consensus on the minimal but adequate time was determined to be 30 seconds. Two observations of 30 seconds in length were judged adequate.

Subjects

Twelve runners were selected to represent three diverse performance abilities. Four runners were among the top five runners at their university. Four were serious runners, but not highly competitive in their distance running performances. The
final subjects were cyclists who do not train for running but are within the fitness parameters outlined in the scope. Coaches were sampled on the basis of their availability; the only prerequisite being that they had coached male distance runners a minimum of three years. The exact format for sampling coaches follows.

**Procedures for Runners**

Athletes were filmed on March 15, 1988 at Dornblaser Field in Missoula, Montana. Before starting the video taping all athletes filled out an informed consent form (Appendix B), along with a questionnaire of their running performances (Appendix C). Athletes ran at a 268 m.min\(^{-1}\) pace around the track. Pace was monitored with a time check every 50 meters and verbal commands to the subject to adjust the pace were given if it was not on. Once the proper pace was reached, the time segments were filmed with a camera mounted on a tripod and set on automatic focus to standardize the view of each runner.

In the time period following the filming, athletes practiced running on a treadmill for at least 30 minutes to become familiar with treadmill running. Once the runners completed their practice, they were then given a submaximal test. Treadmill testing took place over a ten-day period from April 1 to April 9, 1988. Body composition testing was conducted after completion of the submaximal test on April 13.
Body Composition Procedures

a. Subject’s weight, age, sex, and number of hours since their last meal was determined.

b. The subject was then familiarized with the hydrostatic weighing procedure. This involved a reminder to exhale completely while under the water; to hold as still as possible so an accurate reading could be determined on the scale; and to not touch the bottom or sides of the tank while being weighed.

c. Hydrostatic weighing began with the subject entering the weighing tank and making sure they were completely wet before weighing. A weight belt was then fitted around the subject’s waist and the weighing trials began. A minimum of five trials were performed. Results were calculated using the Fat City Body Composition Program, and the estimation of body composition derived.

Treadmill Protocol

The treadmill protocol is as follows:

a. The subject weighed in and then prepared for EKG testing. A resting EKG was taken. Blood pressure was taken from a sitting position.

b. The runner was filled with an O₂ collection mask. Resting O₂ consumption was measured for three minutes.

c. With the treadmill set at 80.4 m.min⁻¹, the runner walked for two minutes.
d. After the two minute warm-up stage, the treadmill was set at 160.8 for three minutes.
e. Running pace was increased to 268 m.min⁻¹ and this phase lasted five minutes.
f. Pace was dropped to 80.4 m.min⁻¹ for three minutes.
g. Subject sat for seven minutes on stool.
h. Walking was resumed at 80.4 m.min⁻¹ for three minutes.
i. The Maximum Oxygen Uptake test began with four minutes at 214.4 m.min⁻¹. Pace was kept constant throughout the entire test, but grade was increased 2.5 percent each minute after the initial four minutes. Upon test termination, the grade was reduced to zero.
j. Subject walked at 80.4 m.min⁻¹ for three minutes.

Procedures for Coaches

Distance coaches who would be attending the Montana State University High School Indoor Track Meet were sent a letter (Appendix D) approximately one month before the meet requesting them to fill out a questionnaire (Appendix E). Those who returned the questionnaire and had more than three years of distance coaching experience were contacted as to the evaluation protocol for rating the runners. Five coaches rated the runners at the indoor meet on March 19. Ten more high school distance coaches were contacted and had personal viewings of the videos during April 1988.

For the viewing of the taped runners, coaches were randomly placed into one of the three groups. Each coach was given the
same instructions (Appendix F). They were given a sheet of paper to record comments regarding the runner's form. Thirty seconds was allowed for this after each runner. After viewing the 12 runners, the coaches ranked the runners on how economical they appeared. No comments were allowed during any part of the procedure, although questions were permitted during the instructions.

**Analysis of Data**

Statistical analysis was threefold and used the SPSS-X statistical program. The Spearman-Rowe and Kendall Nonparametric Correlation Coefficients were used to compare the coaches' predictions to the actual metabolic measurements of running economy. Then a One-Way Analysis of Variance was done between the measurements taken to assess what key factors might separate the runners. Measurements figured in the one-way variance were max VO₂ at 268 m.min⁻¹, maximum oxygen uptake, age, weight, height, percent body fat, percentage of maximum heart rate at 268 m.min⁻¹, RER value at maximum VO₂, average RER value at 268 m.min⁻¹, percentage of maximum heart rate at 268 m.min⁻¹, and blood pressure.
CHAPTER FOUR

RESULTS AND DISCUSSION

Results

The variables age, percent body fat, weight, systolic blood pressure, diastolic blood pressure, and height were determined to analyze homogeneity among groups. Table I illustrates the findings from the variables for Groups 1, 2, and 3. The only variable in Table I which showed a lack of homogeneity among the three groups was percent body fat. All of the other variables did not differ significantly, thus indicating homogeneity in the descriptive variables. Individual differences among the population in Table I can be found in Appendix G. A bar graph illustrating the group differences in percent body fat can be found in Appendix A.

Table I. Group Mean Descriptive Results

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>%Fat</th>
<th>Wt</th>
<th>SBP</th>
<th>DBP</th>
<th>Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 Mean</td>
<td>21.88</td>
<td>3.90</td>
<td>138.23</td>
<td>120.75</td>
<td>79.00</td>
<td>68.63</td>
</tr>
<tr>
<td>Group 2 Mean</td>
<td>21.80</td>
<td>9.40</td>
<td>157.68</td>
<td>122.00</td>
<td>75.00</td>
<td>70.80</td>
</tr>
<tr>
<td>Group 3 Mean</td>
<td>23.85</td>
<td>11.88</td>
<td>153.98</td>
<td>121.00</td>
<td>79.50</td>
<td>70.13</td>
</tr>
</tbody>
</table>
Because it was desirable for the findings in Table I to be homogeneous, the variation in body fat can be looked at as a problem. However, only Group 1 varied significantly from the other two with a percent of 3.90 compared to 9.40 and 11.88 percent for the other two groups.

Metabolic measurements taken to determine group similarity were percent maximum oxygen uptake (%VO₂ Max), percent of maximum heart rate (%Max HR), maximum oxygen uptake (Max VO₂), oxygen uptake at 268 m.min⁻¹ (VO₂ @268 m.min⁻¹), respiratory exchange ratio at maximum oxygen uptake (RER@ Max), average percent respiratory exchange ratio at 268 m.min⁻¹ (Avg %RER), and maximum heart rate (Max HR).

The three groups of runners (Group 1, elite runners; Group 2, runners; Group 3, cyclists) showed significant differences between each other in several areas. Areas where the groups differed were in VO₂ @ 268 m.min⁻¹, and %Max HR as evidenced in Table II. Areas that failed to show significant differences in Table II were %VO₂ Max, Max VO₂, and Max HR. While three of the areas failed to produce significant differences between the groups, percentage of maximum oxygen uptake at 268 m.min⁻¹ was the major factor in determining metabolic economy. Maximum oxygen uptake, and maximum heart rate were all either controlled variables or not factors in determining economy among a population which fit within the controlled variables. Among groups as homogenous as the three in this study, max O₂ uptake
failed to distinguish differences, even with very different performance abilities among the participants.

Table II. Group Mean Metabolic and Ranking Results

<table>
<thead>
<tr>
<th></th>
<th>%VO₂ Max</th>
<th>%Max HR</th>
<th>Max VO₂</th>
<th>%Max %VO₂</th>
<th>M.Min⁻¹</th>
<th>@268 M.Min⁻¹</th>
<th>RER@Max</th>
<th>Avg %RER</th>
<th>Rank% V0₂Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1 Mean</strong></td>
<td>0.77</td>
<td>0.81</td>
<td>73.08</td>
<td>56.28</td>
<td>1.17</td>
<td>0.92</td>
<td>3.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Group 2 Mean</strong></td>
<td>0.85</td>
<td>0.90</td>
<td>69.25</td>
<td>58.36</td>
<td>1.18</td>
<td>1.01</td>
<td>7.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Group 3 Mean</strong></td>
<td>0.87</td>
<td>0.89</td>
<td>69.35</td>
<td>64.00</td>
<td>1.12</td>
<td>1.04</td>
<td>7.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The athletes' percent of maximum heart rate at 268 m.min⁻¹ showed significant differences between Group 1 with Groups 2 and 3 of (p<.001). Group 1 had a mean of 80.51 percent, Group 2 had a mean 90.47 percent and Group 3’s mean was 89.68 percent. Oxygen uptake at 268 m.min⁻¹ showed significant differences
(p<.01) between Groups 1 and 2 with Group 3. Group 1's mean was 56.28, Group 2's was 58.40, and Group 3 had a mean of 64.20. The average RER value at 268 m.min⁻¹ was significantly different between Groups 1 and 3 (p<.05). The mean of Group 1's RER value at 268 m.min⁻¹ was .92, Group 2, 1.01, and Group 3, 1.04. Bar graphs depicting group differences in coaches' rankings and metabolic areas can be found in Appendix A. Individual metabolic differences can be found in Appendix G.

Coaches' rankings of the groups varied significantly with a probability of p<.005, between Groups 2 and 3 and 1 and 3. Table III compares the actual data to the coaches' rankings in order to further examine the coaches' ability to predict economy. The mean ranking for Group 1 was five, Group 2 was four, and Group 3's mean ranking was 10.50. A rank of 2.5 for Group 1 would have fit the expected pattern since Group 1 is the group of superior runners. So the elite runners were underrated by the coaches. Six and one-half would have been the expected ranking for Group 2, thus they were overrated. Group 3 was rated exactly where they were expected to be. It is important to note that the coaches were able to select non-runners accurately, but they did not distinguish between elite and average runners. Coaches have the ability to distinguish runners' economy from this data, yet questions remain on how great the differences must be in ability or practice time for the coaches to distinguish among those who actually train for running.
Table III. Coaches' Rankings Compared To Actual Data

1. Percentage of Maximum Oxygen Uptake at 268 M.Min$^{-1}$

<table>
<thead>
<tr>
<th>Group 1 Rank</th>
<th>Group 2 Rank</th>
<th>Group 3 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>.77</td>
<td>.85</td>
<td>.87</td>
</tr>
</tbody>
</table>

2. Percentage of Maximum Heart Rate at 268 M.Min$^{-1}$

<table>
<thead>
<tr>
<th>Group 1 Rank</th>
<th>Group 2 Rank</th>
<th>Group 3 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>.81</td>
<td>.90</td>
<td>.90</td>
</tr>
</tbody>
</table>

3. Maximum Oxygen Uptake

<table>
<thead>
<tr>
<th>Group 1 Rank</th>
<th>Group 2 Rank</th>
<th>Group 3 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>73.08</td>
<td>69.25</td>
<td>69.35</td>
</tr>
</tbody>
</table>

4. Oxygen Uptake at 268 M.Min$^{-1}$

<table>
<thead>
<tr>
<th>Group 1 Rank</th>
<th>Group 2 Rank</th>
<th>Group 3 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>56.28</td>
<td>58.36</td>
<td>59.95</td>
</tr>
</tbody>
</table>

5. Respiratory Exchange Ratio Value at Maximum Oxygen Uptake

<table>
<thead>
<tr>
<th>Group 1 Rank</th>
<th>Group 2 Rank</th>
<th>Group 3 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.17</td>
<td>1.12</td>
<td>1.12</td>
</tr>
</tbody>
</table>

6. Average Respiratory Exchange Ratio Value at 268 M.Min$^{-1}$

<table>
<thead>
<tr>
<th>Group 1 Rank</th>
<th>Group 2 Rank</th>
<th>Group 3 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>.92</td>
<td>1.01</td>
<td>1.12</td>
</tr>
</tbody>
</table>

* p<.05 with Groups 2 and 3
Table IV. Correlations and Levels of Significance for Metabolic Data

1. Percentage of Maximum Oxygen Uptake at 268 M.Min⁻¹
   Kendall    Spearman
   \( r = .4182 \) sig. .037  \( r = .5273 \) sig. .048

2. Percentage of Maximum Heart Rate at 268 M.Min⁻¹
   Kendall    Spearman
   \( r = .2000 \) sig. .196  \( r = .1909 \) sig. .287

3. Maximum Oxygen Uptake
   Kendall    Spearman
   \( r = .2121 \) sig. .169*  \( r = .3147 \) sig. 160

4. Oxygen Uptake at 268 M.Min⁻¹
   Kendall    Spearman
   \( r = .5273 \) sig. .012  \( r = .7364 \) sig. .005

5. Respiratory Exchange Ratio Value at Maximum Oxygen Uptake
   Kendall    Spearman
   \( r = -.2273 \) sig. .293  \( r = -.2727 \) sig. .293

6. Average Respiratory Exchange Ratio Value at 268 M.Min⁻¹
   Kendall    Spearman
   \( r = .3636 \) sig. .050*  \( r = .4545 \) sig. .069

* \( p \leq .05 \) with Kendall with Group 3
Rankings of six metabolic measurements were correlated to the coaches' rankings of the runners they watched on video tape, as evidenced in Table IV. The 15 track coaches were able to rank the runners in proper order of testing performance in three of the six metabolic measurements correlated with the Kendall Correlation Coefficient. They showed significant (p<.05) ability on two of the six areas on the Spearman-Rowe Correlation Coefficient. The Kendall results showed a $r$ of .42 ranking of runners by their percentage of maximum oxygen uptake at 268 m.min$^{-1}$. The runners' ranking of oxygen uptake at 268 m.min$^{-1}$ had a $r$ of .53 to the coaches' predictions. Coaches' rankings had a $r$ of .36 with the average RER value rankings of the athletes at 268 m.min$^{-1}$.

The Spearman-Rowe Correlation Coefficient showed significant results with the coaches' rankings of the runners as to their percentage of maximum oxygen uptake at 268 m.min$^{-1}$. The correlation was .53. The coaches' rankings correlated with the runners' rankings of oxygen uptake at 268 m.min$^{-1}$ and a correlation of .74.

Discussion

Significant difference did not exist among the three groups of athletes in maximum oxygen uptake. The mean maximum oxygen uptake for all groups was 70.56 ml.kg$^{-1}$.min$^{-1}$ with a standard deviation of 5.65 ml.kg.min. Group 1 had the highest max VO$_2$ at 73.08 and Groups 2 and 3 had 69.25 and 69.35 respectively. These
levels are very high and thus it can be concluded that the athletes in the study were very fit.

The fact that all the subjects had good aerobic capability indicates that the subjects were not biased by some groups having far less aerobic ability than others. Maximum heart rate and the blood pressures not being significant further points to all three groups' homogeneity. Finding age and weight not to be significantly different between the groups is important in view of the fact that coaches watching the video could have been affected by a person being young, old or heavy. All the athletes were dressed in running shoes and had tights or shorts on. No caps, sweat pants, gloves or headbands were worn. Shirts varied from short sleeved to long sleeved tops with the fit varying from skin tight to quite loose. The role of clothing was never mentioned by any of the coaches as a possible giveaway in ability of the runners.

The RER value at maximum oxygen uptake's inability to show significant differences in the three groups is to be expected among a fit population. Particularly since the increasing grade on a treadmill required in a maximum oxygen uptake test is foreign to both the runners and cyclists. This common ground between groups and the fact that the only RER value used was taken at each individual's point of maximum oxygen uptake makes this finding reasonable. The percent of maximum oxygen uptake used at 268 m.min$^{-1}$ proved to not be significant between the three groups. This would indicate that the three groups were not different enough. This may make the coaches' job of
distinguishing the runners, based on how economical the runners are, more difficult.

Significant differences among the groups show that each group was different enough from the other that coaches would have a chance of finding differences in the runners. Percent body fat showed that Group 1 was significantly (p<.05) different than Groups 2 and 3. Yet in looking at the coaches' average rankings they put Group 2 ahead of 1. This would suggest that coaches didn't assess percent body fat when ranking the runners. The fact that Group 3 had an average ranking of 10.5 from the coaches, but was not significantly different in body fat than Group 2, further indicates that the coaches looked for efficiency at 268 m.min⁻¹ in the runner's form rather than how heavy the runner appeared. Group 2 not being significantly different from Group 1 in oxygen uptake at 268 m.min⁻¹ supports findings that body fat is not a significant factor in economy of running (105).

The athletes' percentages of maximum heart rate at 268 m.min⁻¹ pointed to Group 1's differences from both 2 and 3, with Group 1 being significantly different while 2 and 3 were not different from each other; yet the coaches ranked Group 2 (the runners) higher than Group 1 (elite) on the average. Oxygen uptakes at 268 m.min⁻¹ differed from the heart rate findings in that the middle group (2) was sided toward Group 1 in this case. Group 2 was not significantly different from Group 1 but both were significantly different from Group 3 (the cyclists). Findings from averaging the RER values at 268 m.min⁻¹ produced a
significant difference between Groups 1 and 3 but not between Groups 1 and 2, putting 2 in the middle, not significantly different than Groups 1 or 3.

Correlations of the coaches' predictions to the metabolic measurement rankings found the coaches to have significant ability to rank runners in an area that lacked significant difference between the groups. That area was the percentage of maximum oxygen uptake used at 268 m.min\(^{-1}\), both the Kendall and Spearman-Rowe Coefficients found significance in this variable. Only on the Kendall Correlation did a significant relationship exist between the average RER value at 268 m.min\(^{-1}\) and the coaches' rankings. This variable did have significant differences between Groups 1 and 3 though. Oxygen uptake at 268 m.min\(^{-1}\) was the only variable whose rankings had a significant correlation to the coaches' predictions on both the Kendall and Spearman-Rowe tests, as well as showing significant differences among some of the groups.

Oxygen uptake at 268 m.min\(^{-1}\) separated Groups 1 and 2 from Group 3 and had the highest correlation to the coaches' predictions \(r\) of .53 for the Kendall test and \(r\) of .74 for the Spearman-Rowe test. This variable served to distinguish a group of highly skilled cyclists from two groups of runners who differed greatly in achievement but only mildly physiologically shows the need for specificity of training. This lack of specific training did not show up as strongly when energy sources were investigated (RER values) or when oxygen uptake was
computed as a percent of maximum oxygen uptake. Yet coaches noticed something different in the cyclists. The accuracy of oxygen uptake at $268 \text{ m.min}^{-1}$ was aided by all three groups having high maximum oxygen uptakes. Had one group been very different in maximum oxygen uptakes then the results may have been quite different.

The coaches did well on the average for predicting which runners were most economical. The difficulty of merely watching a video to predict how economical a runner is cannot be overlooked. Some coaches made mention of how sound is important in determining how hard a runner is working at a given pace. The sound of feet hitting the track and a runner’s breathing were mentioned as useful for a coach in determining how a runner is doing. But evidence exists to indicate that if the groups differed to a greater extent the coaches would have done better. This can be seen in the fact that Group 1 (the elite runners) were significantly different from Group 3 (the cyclists) in three of the six actual metabolic measurements that were correlated with the coaches’ predictions. The coaches ranked the cyclists on the average in the 10.5 position among the athletes.

Group 1 varied significantly from Group 2’s runners in one metabolic measurement that was correlated with the coaches’ rankings; that was in percent of maximum heart rate at $268 \text{ m.min}^{-1}$. Group 1, however, on the average, did record the best measurements in every metabolic area. The differences between Groups 1 and 2 were not great enough to be significant in most
cases, but the elite group clearly proved superior to Group 1. The coaches' low rankings of the cyclists, and the fact that they were ranked far below Groups 1 and 2, shows an ability for the coaches to discriminate. The fact that the runners (Group 2) were significantly different from Group 3 in only one metabolic measurement, yet were ranked even higher than Group 1 by the coaches, indicates it is a limited ability to predict. This would be more clearly understood if the elite runners (Group 1) had varied in more areas than the runners (Group 2). Performance background indicates that there are large differences between Groups 1 and 2 in running times and between 1 and 2's experience compared to Group 3's experience, but the metabolic differences are less clear as indicated in Table V.

Table V. Description of Subjects' Running Background

<table>
<thead>
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<th>3000 Best</th>
<th>5000 Best</th>
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<td>14:50.5</td>
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<tr>
<td>Group 2 (Runners)</td>
<td>7.7</td>
<td>4:10.5</td>
<td>9:22</td>
<td>16:07</td>
</tr>
<tr>
<td>Group 3 (Cyclists)</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The coaches had an average of 13.6 years of experience in coaching distance runners, which far exceeded the limitation set of three years' experience. The coaches' comments dealt more on
the arm carriage than with any other area. Comments were made on
the amount of bounce in the stride, stride length, foot strike
and toe off, relaxation, shoulder carriage, body motion being
excessive, forward lean of the body being excessive, and head
motion being excessive. General comments about the athletes also
were made, such as the person plodding rather than running
smooth, and the athlete appearing rough. Comments on the arms
included: too high of arm carriage, too low of arm carriage, too
tight of arm action, excessive cross body arm movement, arms too
far away from the body, elbows out, and one arm being carried
different than another. In light of Hinrichs’ (106) findings
using 3-D cinematography, that there is no apparent advantage in
using the classic straight forward arm carriage, as opposed to
the crossover style of arm carriage, perhaps the arms were looked
at too closely by the coaches.

The number of years’ coaching experience, and the ability
to distinguish the groups that proved more efficient than others,
did not relate as shown in Table VI. The eight coaches with 10
years or less experience ranked Group 1 on the average 4.7; those
with over 10 years ranked Group 1 at 5.9. Those with 10 years or
under ranked Group 2 at 4.9 and those over 10 years ranked Group
2 at 4.1. Those with 10 years or under ranked Group 3 at 9.2;
those with over 10 years ranked Group 3 at 9.7. This data, along
with looking at the ranges of coaches’ average rankings for each
group brings out the differences in the rankings among the
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<td>7.75</td>
<td>6.50</td>
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<td>2.50</td>
<td>6.00</td>
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<tr>
<td>II</td>
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<td>4.25</td>
<td>4.75</td>
<td>3.25</td>
<td>7.25</td>
<td>3.50</td>
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<td>4.00</td>
</tr>
<tr>
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<td>7.50</td>
<td>8.25</td>
<td>9.75</td>
<td>9.75</td>
<td>10.00</td>
<td>10.00</td>
<td>10.50</td>
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</tbody>
</table>

individual coaches. Group 1’s range 4.00, Group 2’s 3.75, Group 3’s 4.25. This wide range of scores on a scale of 1-12 helps indicate the difficulty in ranking the runners’ economy.
CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study's purpose was to investigate the ability of 15 high school track coaches to predict the economy of 12 runners. The coaches observed each runner on video tape for two 30-second segments and then ranking the runners from 1 to 12 with 1 being the most economical. The coaches' predictions were then correlated to actual metabolic measurements taken on the runners while running at the same pace as they were running in the video shown to the coaches. Measurements taken were: Maximum Oxygen Uptake, Maximum Heart Rate, Percentage of Maximum Oxygen Uptake at 268 m.min⁻¹, Percentage of Maximum Heart Rate at 268 m.min⁻¹, Oxygen Uptake at 268 m.min⁻¹, RER Value at Maximum Oxygen Uptake, Average RER Value at 268 m.min⁻¹, Percent Body Fat, Blood Pressures, Weight, and Height. The SPSS-X statistics program was used to analyze the data. A one-way analysis of variance was done using the Tukey-HSD Procedure, at p<.05. The differences were analyzed using both the Spearman-Rowe and Kendall tests.

Conclusions

Coaches demonstrated a moderate ability to predict the economy of runners from watching video tapes of the athletes. There were five measures of economy that were correlated to the
coaches' predictions: 1) percentage of maximum heart rate, 2) oxygen uptake at 268 m.min\(^{-1}\), 3) percentage of max \(\text{VO}_2\) at 268 m.min\(^{-1}\), 4) RER value at \(\text{max} \ \text{VO}_2\), and 5) average RER value at 268 m.min\(^{-1}\). Of the five areas, three showed significant ability to predict by the coaches on the Kendall and two on the Spearman-Rowe. They were percentage of max at 268 m.min\(^{-1}\), oxygen uptake at 268 m.min\(^{-1}\) and average RER value at 268 m.min\(^{-1}\) on the Kendall, with the percent of max \(\text{VO}_2\) and \(O_2\) uptake at 268 m.min\(^{-1}\) being significant on the Spearman-Rowe.

Percent of maximum heart rate at 268 m.min\(^{-1}\) showed an ability to separate two groups from each other, as did oxygen uptake at 268 m.min\(^{-1}\). No measurement taken was able to significantly separate all three groups. Since percent of maximum heart rate showed no significant correlations to the coaches' predictions, it seems that oxygen uptake at 268 m.min\(^{-1}\) was the most useful measurement used in the study. It was able to distinguish the cyclists from the two groups of runners and had the highest correlation to the coaches' rankings.

Oxygen uptake at a given pace is considered the definition of economy (107), and that pace was 268 m.min\(^{-1}\) for this study. Oxygen uptake at 268 m.min\(^{-1}\) had a correlation to the coaches' rankings of \(r = .53\) on the Kendall and \(r = .74\) on the Spearman-Rowe. The importance of the coaches' ability to predict when this measure was looked at must be emphasized.

The coaches' one shortcoming in predicting the economy of the runners was in that they ranked Group 2 ahead of Group 1,
although they were highly successful at distinguishing the non-runners. The fact that Group 1 had an oxygen uptake at 268 m.m.min$^{-1}$ of 56.28 ml.kg$^{-1}.min^{-1}$ and Group 2 required an average of 58.36 ml.kg$^{-1}.min^{-1}$ makes it understandable that the coaches would have trouble distinguishing Group 1 from Group 2. Group 1 were highly achieved runners yet they differed very little physiologically, and the coaches' rankings reflected this. The fact that the cyclists (Group 3) were ranked so low by the coaches may show that the coaches could see a lack of practice at running on the cyclists' part.

Cavanagh (108) has made mention of runners optimizing their movements through practice; meaning that those who run seem to become more economical with time and training. The cyclists do not run for practice and this is reflected in their high oxygen cost at 268 m.min$^{-1}$, 64.20 ml.kg$^{-1}.min^{-1}$. The coaches were able to distinguish the cyclists as being less economical and this allowed them to have a significant ability to predict the athletes' economy.

When looking at just the metabolic findings of this study, it can be noted that some of the findings support others' results. For example, Conley and Krahenbuhl concluded in a 1980 study that among highly trained runners of comparable ability and similar VO$_2$ max, running economy accounts for a large and significant amount of the variation observed in performance on a 10 kilometer race (109). Their findings are in agreement with this study, as those with the fastest 10 kilometer times were
also the most economical at 268 m.min$^{-1}$, as can be noted from the oxygen uptake values at 268 m.min$^{-1}$ and the average times noted in Table V. In another example, Costill showed that fractional utilization of aerobic capacity at submaximal speeds, or as it was termed in this study, percentage of max VO$_2$ at 268 m.min$^{-1}$, is highly related to running performance among runners with a wide range of abilities and max VO$_2$ (110). In this study, fractional utilization clearly distinguished the elite group from the other two, as evidenced in Table III. Group 1 was eight percent better than Group 2 and 10 percent better than Group 3.

So the metabolic data dealing most closely with economy in this study (percentage of max VO$_2$ at 268 m.min$^{-1}$ and fractional utilization) supports Conley and Costill’s findings. In addition, the finding that max VO$_2$ results between the three groups were not significantly different agrees with Conley’s finding a max VO$_2$ to 10 kilometer run relationship of r = 0.12 (111). Thus, it is not odd for the clearly faster runners to have max VO$_2$ results which are not significantly different from slower runners who are fit.

**Recommendations**

The lack of clear physiological differences between groups I and II can be viewed as a shortcoming in this study. For future work the groups should show greater physiological differences so that the coaches will be able to view runners distinctly different in economy. The fact that the runners were very different in ability to run fast was not enough. It could be
recommended for a future study to use a third group of actual runners, rather than non-runners. This would be more difficult for the coaches, but would shed further light on the ability of coaches to judge the economy of the runners. In this study, the non-runners were almost giveaways.

Other recommendations for studies of this kind were given by the participating coaches. Some felt sound was a tool they used in judging the economy of a runner. They listened for pounding or slapping of the feet and labored breathing. A split screen camera, with rear and lateral views, to aid the coaches' viewing ability was suggested. More viewing angles and more time were also recommended. The average high school coach in everyday practice may not use the extra views; and a pilot study indicated that the two 30-second viewing periods in this study were adequate for merely ranking the athletes. However, it would be useful for a future study to use more camera angles, as well as sound, to see if a significantly higher ability to predict occurs.

Using people other than high school track coaches would be another area to explore in the future. Having runners of different abilities or college coaches predict the economy of groups could be used in the same type of study. However, keeping the ability of the runners from those predicting economy is important. Caution should be used in selecting all participants to insure that the viewers focus only on the runners' economy.
NOTES


6 Hyman, 1676.


8 Cavanagh and Kram, 326.

9 Hyman, 1676.


13 Hyman, 1671.


22 "In nearly every other sport, at least part of each training session is directed toward the improvement of skill. This is not the case in distance running. Few runners ever attempt to analyze or improve their running techniques. When we consider the fact that even a one percent decrease in the energy cost of running would improve a three hour marathoner’s time by nearly two minutes, it is surprising that more attention isn’t given to this aspect of training." (Costill, *Inside Running: The Basics of Sport Physiology*, 54).

23 "It is by no means axiomatic that athletes classified as skilled according to the criterion of running velocity exhibit the best form or style. Indeed the criteria for good style that are applied by coaches still rest on somewhat of an empirical base, since sport scientists have not yet produced an adequate theoretical model to allow the effects of parameter variation to be studied." (Peter Cavanagh, et al., "A Biomechanical Comparison of Elite and Good Distance Runners, "*Annals New York Academy of Sciences,"* 301 (1977): 328).

24 "it is at the level of the elite athlete that considerations of improved economy are most relevant. Changes of even a small magnitude could have a major effect on performance ranking in endurance events.," (Cavanagh and Kram, 326).

25 "In distance running the athlete must use his (her) energy as economically as possible. He (she) cannot afford to adopt changes in technique that increase his (her) speed, if in doing so they impose an intolerable increase in total energy expenditure. Hence, coaches who have advocated modifications in
style on the basis of mechanical analysis of one aspect of work, have not been justified. They have been unable to predict the effect of the modification on the other sources of energy expenditure." (Hyman, 1676).

26 Conley and Krahenbuhl, 357.

27 Cavanagh and Kram, 331.

28 Scrimgeour et al., 202.


30 Phil Lundin, "Distance Running Technique: Application of Research to Coaching," Track and Field Quarterly Review 86, no. 3 (1986): 29.

31 Costil, 54.


33 Conley and Krahenbuhl, 357.


35 Costill and Thomason, 248.

36 Scrimgeour et al., 203.


44 Lundin, 28.


47 Nelson, 31.


49 Cavanagh and Williams, 30.


51 Nelson, 29.

52 Cavanagh et al., "A Biomechanical Comparison of Elite and Good Distance Runners," 331.

53 Cavanagh et al., "A Biomechanical Comparison of Elite and Good Distance Runners," 342.

54 Cavanagh and Williams, 35.


57 Lundin, 29.

59 Cavanagh and Kram, 328.

60 Cavanagh and Kram, 327.

61 C. Bosco et al, 116.

62 Bosco and Komi, 114.


64 Daniels, "A Physiologist's View of Running Economy," 334.

65 Astrand and Rodahl, 337.


67 Sjodin and Schele, 61.

68 Bosco, 138.

69 Sjodin and Schele, 62.

70 Costill et al., 253.

71 "Fatigue associated with increased lactic acid in both the muscles and the extracellular fluid, not only reduces the power of the muscles and slows the runner's pace, but may well increase the energy cost of running at a given speed by upsetting neuromuscular coordination and/or by causing such changes in the muscle as contracture and increased viscosity." (D.L. Robinson et al., "Influence of Fatigue on the Efficiency of Men During Exhaustive Runs," Journal of Applied Physiology 12 (1958): 198).


73 Brandon and Boileau, 158.

74 Costill et al., 248.

76 Conley and Krahenbuhl, 357.


79 Conley and Krahenbuhl, 357.

80 Brooks and Fahey, 714.


82 Brooks and Fahey, 716.

83 Michael Pollock et al., "Discriminant Analysis of Physiological Differences Between Good and Elite Distance Runners," Research Quarterly For Exercise and Sport 51 (1980): 530.

84 Scrimgeour, 202


86 "Basically we have found that the VO2 max and running economy are not the factor determining performance, rather it is the maximum workload an athlete can achieve on the treadmill." (Timothy Noakes, letter to author, 27 July, 1987.).

87 Brooks and Fahey, 199.

88 Brooks and Fahey, 453.

89 Brooks and Fahey, 200.


91 Moore et al., 1724.
92 Fink et al., 326.


94 Astrand, 316.


97 Astrand, 314.

98 Conley et al., "Physiological Correlates of Female Road Racing Performance," 441.

99 Brandon and Boileau, 160.

100 Cavanagh et al., "A Biomechanical Comparison of Elite and Good Distance Runners," 333.

101 Astrand and Rodahl, 409.

102 Astrand and Rodahl, 336.

103 "It appears that the best endurance athletes learn to use the smallest possible muscle mass (for the smallest oxygen demand) to accomplish their performances." (D.R. Lamb, Physiology of Exercise: Responses and Adaptations (New York: MacMillan Pub., 1984), 176).


105 Schuder, 37.

106 Hinrichs, S11.

107 Daniels, 345.

108 Cavanagh et al., 33.

109 Conley and Krahenbuhl, 351.

110 Costilill et al., 349.

111 Conley and Krahenbuhl, 358.
BIBLIOGRAPHY


---. "Human Physical Fitness With Special Reference to Sex and Age." Physiological Reviews 36 (1956): 307-331.


Averages of Group Results

RER Value at Max VO₂

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<td>Value</td>
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Max Heart Rate

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<tbody>
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Percent Body Fat

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<td>12</td>
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Coaches Average Ranking

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<tbody>
<tr>
<td>Ranking</td>
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<td>3</td>
<td>7</td>
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</tbody>
</table>
Averages of Group Results

Max \( \text{VO}_2 \)

\[ \begin{array}{ccc}
1 & 2 & 3 \\
\end{array} \]

\[ \begin{array}{ccc}
70 & 60 & 60 \\
\end{array} \]

\( \text{VO}_2 \) at 268 meters per minute

\[ \begin{array}{ccc}
1 & 2 & 3 \\
\end{array} \]

\[ \begin{array}{ccc}
70 & 60 & 70 \\
\end{array} \]

Percent of Max Heart Rate at 268 meters per minute

\[ \begin{array}{ccc}
1 & 2 & 3 \\
\end{array} \]

\[ \begin{array}{ccc}
1.0 & 0.8 & 0.8 \\
\end{array} \]

Average RER Value at 268 meters per minute

\[ \begin{array}{ccc}
1 & 2 & 3 \\
\end{array} \]

\[ \begin{array}{ccc}
1.2 & 1.0 & 1.0 \\
\end{array} \]
APPENDIX B

Informed Consent

1. Explanation of the Exercise Test

You will be asked to perform a series of runs on a track and treadmill, as well as have your body fat determined using underwater weighing. The track run will involve the filming of you, and this film will be shown to a group of track coaches for analysis of your running form. You will be asked to run six minutes per-mile pace for one half mile around the track and go for four minutes on the treadmill. The final running test will involve a maximum oxygen uptake test to determine your fitness; this will require you to run to near complete fatigue. We will stop the test at any time, should you feel it is necessary. A gradual increase in intensity will take place during the maximum oxygen uptake test, so you won't be asked to exert yourself a great deal throughout the entire test. The two runs at six minutes per-mile pace and the maximum oxygen uptake test will allow you five minutes of warm-up running at your chosen pace, followed by a five minute stretching period before starting the test. The two runs at six minute pace will also be an effort which will be difficult for those not training seriously for running. Because you will be asked to run this pace for four minutes, do not consent to this test should you not be capable of running the pace.

2. Risks and Discomforts

There exists the possibility of certain changes taking place during the test. Elevation in blood pressure, fainting, disorder of heart beat, and in rare instances heart attack or death. Every effort will be made to minimize the risk of injury, but working to fatigue on the maximum oxygen test is necessary.

3. Benefits to be Expected

The results obtained from your test will benefit the study of running form and enhance your knowledge of how fit you are.

4. Procedures to Aid Subject in the Testing

It is recommended that you not eat food within one hour of doing any of the three runs. It is recommended that you keep an adequate water intake going into the test; do not go into any of
the tests thirsty. The underwater weighing test requires you to fast for eight hours before the test. This test will be done in the morning to make the fasting easier. If you are on any medication, please inform the test administrator so that clearance from your doctor can be obtained before testing. If you consume any alcohol or use any illegal drugs the day you are to be tested, please do not participate in the tests. The testing can be delayed or cancelled by you at any time.

5. Inquiries

Any questions about procedures used in the test, or in the result of your test, will gladly be answered. If you have any doubts or questions, please ask for further explanations.

6. Freedom of Consent

Your permission to perform this exercise test is voluntary. You are free to deny consent at any time if you so desire.

7. I have read this form and I understand the test procedures that I will perform. I can run for four minutes at six minutes per-mile pace and consent to participate in this test.

Signature of Participant ________________________________

Date ________________

Witness ________________________________

Questions: ________________________________

Response: ________________________________

Physician Signature (Optional) ________________________________
Runner's Questionnaire

Name ____________________________  Age ________

Number of years running experience ________

Height ________  Weight ________

Personal Best Running Performances (if any):

1500 meters ________

3000 meters ________

5000 meters ________

10,000 meters ________
APPENDIX D

Thomas A. Raunig
Graduate Assistant Track Coach
Montana State University
Bozeman, MT 59715
Phone (406) 994-4299

Head Cross Country Coach
High School
Town

Dear Coach:

Enclosed you will find a brief questionnaire for the coaches who handle distance runners. I am conducting a study on distance runners' economy, it is an attempt to shed further light on the coach's role in helping distance runners become more efficient. The study will require that a video tape of twelve runners be watched, and any things that the coach notices in the runners' form that appear efficient or inefficient be written down. Then, after all twelve runners have been observed, coaches are asked to rank the runners from 1 to 12 in how economical they appear.

The study will be conducted the weekend of the MSU Indoor Track Meet, which your team is slated to attend. If your coaches are willing to participate we can arrange the viewing time upon receipt of the questionnaire. It would be much appreciated if the distance coaches at your school would be willing to participate in the study. I would be glad to let you know how our results come out once the study is completed. Enclosed is a self-addressed stamped envelope to return your questionnaire in.

Sincerely,

Thomas A. Raunig
APPENDIX E

Coach's Questionnaire

Name ________________________________

Number of years coaching distance runners ______

Would you be willing to observe a video of twelve separate runners and then comment on their running form, as well as rank them in terms of how economical their running form appears to be? (Circle one.) Yes No
APPENDIX F

Instructions for Coaches

1. Thank you for participating in my study; we will be as brief as possible in conducting the study. This will be done by allowing the same amount of time for the viewing of each runner. So it is very important that you watch carefully and treat each runner with equal importance.

2. Time will be limited to 30 seconds for commenting on each runner's form; no talking will be allowed during these breaks. Following the viewing you will have ten minutes to rank the twelve runners from 1 to 12 with 12 being the least economical appearing runner.

3. Are there any questions? No questions will be answered that pertain to what the coaches should be looking for. They will just be asked to look for what appears to be economical or uneconomical about the runner's form, and to rank the runners. Questions to clarify the viewing procedures will be answered, and coaches will be invited to ask any questions after the procedure is fully completed.
### Appendix G

#### Individual Metabolic and Ranking Results

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<th>Name</th>
<th>Age</th>
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<th>Wt</th>
<th>BMI</th>
<th>DLS</th>
<th>IQ</th>
<th>VO2</th>
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<th>R20</th>
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<td>3.00</td>
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<td>96.0</td>
<td>69.5</td>
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#### Mean

- **Standard Dev:**
  - **Minimum:** 0.36
  - **Maximum:** 0.40
  - **Range:** 0.10

#### Individual Results

<table>
<thead>
<tr>
<th>Name</th>
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#### Mean

- **Standard Dev:**
  - **Minimum:** 0.36
  - **Maximum:** 0.40
  - **Range:** 0.10

### Table: Results for All Individuals

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