Correlates of Running Performance in Middle School Cross-Country Runners

An Honors 499 Thesis

by

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I am very fortunate to have had the opportunity to work with Dr. Mahon as an undergraduate fellow and while working on this project. I have learned more under his direction than in most educational classes.

Thanks also to Chris Cheatham for his assistance with data collection and to Bill Fink for performing the blood sample analysis.
In loving memory of Sue Bertoldi.
(1953 - 1997)

You are in inspiration!
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ABSTRACT

The purpose of this study was to assess the relationship of body fatness (BF), aerobic and anaerobic ability on 3-km running performance in 7 (3 male, 4 female) middle-school runners (13.7 ± 0.7 years). Running economy (RE) at 5, 6, and 7 mph and VO2max were measured during an exercise test on a treadmill. On another day, two 55-meter sprints and a 3-km run followed by a blood sample to determine blood lactate concentration (BL) were performed. The data were analyzed using simple and stepwise multiple regression. VO2, HR, and RER at maximal exercise were 54.7 ± 6.1 ml/kg/min, 205.9 ± 4.0 bpm, and 1.14 ± 0.05, respectively. The average time for the 3-km run was 14.29 ± 1.23 min. Correlations were observed between the following variables and run time: BF (0.42), RE at 6 mph (-0.25), VO2max (-0.36), fractional utilization (FU) during the 3-km run (-0.67; p = 0.10), 55-meter rime (0.21), and BL (-0.39). At p ≤ 0.05, no correlations were statistically significant. The multiple regression analysis did not yield any further results. The failure of sprint time and post-3 km BL to be significantly associated with running performance is in contrast to data on younger and less mature children. In contrast, the moderately high relationship between distance running performance and the FU used is in agreement with what has been reported with adult runners. In conclusion, it would appear that during the pubertal transition, the influence of anaerobic ability on distance running performance abates, and that training designed to enhance the development of aerobic power will optimize running performance at this distance in this age-group. However, due to the limited sample size and mixed gender, these results should be viewed with caution.
PREFACE

As an Honor student in the Exercise Science and Wellness program, I had the opportunity to work as an undergraduate fellow in the Human Performance Lab under the direction of Dr. Tony Mahon, an exercise physiologist. At first I observed exercise testing procedures and eventually assisted in data collection. Naturally, this experience evolved into a thesis project which challenged me in a way that none of my classes have. For this reason, my thesis is the capstone of my undergraduate education at Ball State University.
CHAPTER 1
INTRODUCTION

Background

A number of physiological characteristics are related to endurance performance in adults. These include a high maximal oxygen uptake (VO$_{2\text{max}}$), good running economy, and high fractional utilization. VO$_{2\text{max}}$ is the highest oxygen uptake during a graded exercise test to maximal exertion. In the average college student VO$_{2\text{max}}$ ranges from 35 - 45 ml/kg/min, whereas an elite marathon runner may have a VO$_{2\text{max}}$ of 70 ml/kg/min or higher (Wilmore and Costill, 1994). Although most endurance events are not performed at maximum, a high VO$_{2\text{max}}$ establishes the potential for high intensity performance.

Evidence of the importance of VO$_{2\text{max}}$ in predicting distance running performance is provided by Costill (1967) who performed a study to determine the relationship between several variables and 4.7-mile running time. The subjects were trained cross country runners, divided into two groups. The fastest nine runners were placed in group A and the slowest eight runners were placed in group B. There was a strong relationship between VO$_{2\text{max}}$ and distance running performance. Average VO$_{2\text{max}}$ values for groups A and B were 61.1 ± 4.0, and 53.3 ± 2.0 ml/kg/min, respectively, suggesting the better runners are characterized by a higher VO$_{2\text{max}}$. These results were supported in a later study by Costill et al. (1973). The correlation between VO$_{2\text{max}}$ and 10-mile running performance was $r = -0.91$. Subjects were once again divided into four groups according to 10-mile race time. Mean VO$_{2\text{max}}$ values were as follows: 78.6, 67.5, 63.0, and 57.4 ml/kg/min, respectively.
Although VO$_{2\text{max}}$ is an important determinant of running performance, other factors are also known to be significant. Running economy (RE) is the steady-state VO$_2$ at a constant running speed and is directly related to running performance (Daniels, 1985). Good RE is associated with lower energy expenditure to perform a given task resulting in a reduction in energy expenditure and a delay in glycogen depletion as well as less heat production. Several factors influence RE, including age. Children are less economical than adults while older adults are less economical than younger adults (Daniels, 1985). RE is a useful way to compare individuals, especially with a homogeneous group (with respect to VO$_{2\text{max}}$) of runners, and it has been suggested that RE may possibly be the best characteristic in determining success (Daniels, 1985).

Fractional utilization (FU) is the percentage of VO$_{2\text{max}}$ used during performance. Elite runners tend to perform at a high percentage of VO$_{2\text{max}}$. It appears that FU is influenced by lactate threshold (LT) as most long distance runners set a race pace at approximately the intensity associated with LT (Farrell et al., 1979; Wilmore and Costill, 1994). LT is the exercise intensity in which blood lactate concentration rises above the resting level. This point marks when the body becomes more reliant on glycolytic energy production (Costill and Wilmore, 1994). Activating the glycolytic system accelerates glycogen depletion and results in accumulation of intracellular lactic acid which may result in fatigue due to a shift in the acid-base balance (Farrell et al., 1979). Runners with a LT occurring at a higher percentage of VO$_{2\text{max}}$ typically perform better than runners whose LT occurs at a lower percentage of VO$_{2\text{max}}$.

Costill et al. (1973) were interested in blood lactate concentrations (BL) and FU and their relationship to running performance. While no relationship between maximal BL and endurance
performance was found, a difference in BL during submaximal exercise was apparent when comparing a group of runners with a fast versus a group of runners with a slower 10-mile run time when running at 268 meters/minute (1.2 versus 8.8 mmol/L, respectively). In highly trained distance runners lactate may not begin to accumulate appreciably until exercise intensity exceeds 70% VO$_{2\text{max}}$. This is significantly higher than what is usually observed in normally active adults. Costill et al. concluded that training appears to allow a greater percentage of VO$_{2\text{max}}$ to be utilized without blood lactate accumulation. Similarly, Farrell et al. (1979) found that a high VO$_{2\text{max}}$ and the ability to utilize a large percent VO$_2$ may allow a runner to run at a faster pace before lactate begins to accumulate in the blood.

Physiological parameters related to running performance in children have also been studied. Several studies have shown that high VO$_{2\text{max}}$ and good RE are indicators of success in distance running. For example, Palgi et al. (1984) conducted a study to determine the extent to which VO$_{2\text{max}}$ can be attributed to a difference in endurance performance in 10- to 14-year-old male children. The adolescents performed a treadmill exercise test to determine VO$_{2\text{max}}$ and a 2-km run for endurance performance. The correlation between VO$_{2\text{max}}$ and 2-km running performance was fairly high ($r = -0.73$) suggesting that variations in VO$_{2\text{max}}$ contribute significantly to variations in endurance performance of children in this age range.

Krahenbuhl and Pangrazi (1983) conducted a study using two groups of fifth-graders, those placing above the 55th percentile of a 1.6-mile run (A runners) and those placing below the 45th percentile (B runners). Although the correlation between VO$_{2\text{max}}$ and 9-minute run time was not significant ($r = 0.19$), A runners tended to have a higher VO$_{2\text{max}}$ than B runners (55.1 ± 3.6 and 48.6 ± 4.5 ml/kg/min, respectively). There was no significant difference in RE between A
and B runners. Krahenbuhl and Pangrazi also compared RE of the A and B runners with RE of elite 8- to 11-year-old-cross-country runners, data collected from a study by Mayers and Gutin (1979). The elite cross-country runners were more economical, suggesting that RE may be an important variable in elite runners, but not in normally active children.

Unnithan et al. (1995) examined the correlation between aerobic capacity and 3-km race time in trained, pre-pubertal boys. They reported that peak VO$_2$ was highly correlated to running performance ($r= -0.83$). Mahon et al. (1996) also studied the relationship between aerobic variables and 3-km running performance in pre-pubertal boys. VO$_{2\text{max}}$ ($r= -0.61$) and $\%$VO$_{2\text{max}}$ at 8.04 and 9.65 km/hr ($r= 0.79$ and 0.70, respectively) were significantly correlated to 3-km run time while RE was not. Mahon’s group concluded that $\%$VO$_{2\text{max}}$ accounted for the influences of VO$_{2\text{max}}$ and RE, collectively.

The fact that indices of aerobic ability are related to running performance in children is similar to what has been observed in adults. However, unlike adults, indices of anaerobic ability have also been reported to be related to running performance. Mahon et al. (1996) also examined the relationship between anaerobic variables and 3-km run time. Both sprint time and vertical jump (VJ) height were significantly related to 3-km running performance ($r= -0.59$ and -0.67). In fact, VJ was more strongly related to running performance than VO$_{2\text{max}}$. For Krahenbuhl and Pangrazi’s study (1983), A runners ran at a faster sprint speed (359.7 m/min) than B runners (314.1 m/min). They also ran the 1.6-mile run at a faster percentage of their maximum sprint speed, and exhibited higher post-9-minute run BL.

From this information it is clear that aerobic and anaerobic parameters are equally related to endurance performance ability in pre-pubertal children suggesting that children are not
metabolic specialists. At what point during growth and development the transition to either an aerobic or an anaerobic specialty occurs has not been determined, but it would seem reasonable to believe that it occurs with pubertal development.

Purpose

Information related to circumpubertal children and endurance performance is limited. It is still unclear when the body begins the transition process towards metabolic specialization. The purpose of this study was to examine how indices of aerobic and anaerobic ability relate to endurance performance in circumpubertal children. Understanding the physiological determinants of running performance will help coaches when training distance runners during this phase of growth and development.

Assumptions

This study was conducted with the following assumptions:

1. The effects of growth and maturation were minimal.
2. The testing procedures and equipment were accurate, reliable, and valid.
3. Sprint speed and post-run blood lactate concentrations accurately represent anaerobic ability.

Definition of Key Terms

1. **Running economy** is the VO$_2$ at a given running velocity (Daniels, 1985).
2. \( VO_2_{\text{max}} \) is the abbreviation for maximal oxygen uptake and is defined as the highest oxygen consumption utilized during an incremental exercise test performed to maximal effort (Wilmore and Costill, 1994).

3. Fractional utilization is the \%\( VO_2_{\text{max}} \) utilized during an endurance performance.

Limitations

The subject population was a small group of male and female children at different maturation levels. Neither gender nor maturity comparisons could be made.

Delimitations

Seven male and female children, ages 12 - 14, participated in this study. The children were members of their school's track team.
CHAPTER 2

METHODS

Subjects

Seven children (3 male, 4 female), ages 12 - 14 years, volunteered as participants in this study. All children were distance runners on a local school track team and were trained at the time of testing. Written informed consent was obtained from each child's parent prior to any testing in accordance with the requirements of the Institutional Review Board. Exercise testing was conducted on three separate days, with each session at least 48 hours apart. All testing was completed in a 3 - 4 week time period to minimize effects due to growth and maturation.

Testing

On the first day, the subjects' age, height, weight, body fatness, and maturation were recorded. Body fatness was determined by measuring skinfold thickness (Harpenden Calipers) in duplicate at six anatomical locations: subscapula, tricep, abdomen, ilium, thigh, and calf. Each site was measured to the nearest 0.1 mm and averaged. These averages were then summed to express total skinfold thickness. Subjects determined their own level of maturation by choosing the appropriate diagram of pubic hair development when shown the five Tanner stages of sexual development (Tanner, 1962). Each child then practiced walking and running on a motor driven treadmill for approximately 17 minutes to become acquainted with the equipment and testing procedures.

On the second day, each child performed a graded exercise test on the treadmill to
On the second day, each child performed a graded exercise test on the treadmill to determine running economy and VO$_2$max. The protocol was as follows: 2 minutes at 3.0 mph and 0% grade; 4 minutes at 5.0 mph and 0% grade; 4 minutes at 6.0 mph and 0% grade; and 4 minutes at 7.0 mph and 0% grade. Thereafter, the speed remained constant, but the grade increased 2.5% each minute until volitional exhaustion. Verbal encouragement was provided throughout the duration of the test to encourage each subject to run as long as possible. Two subjects were unable to run comfortably at 7 mph, thus the elevation increase commenced after four minutes at 6 mph.

Heart rate was recorded every 15 seconds using a Polar Heart Rate monitor. Subjects breathed through a Hans-Rudolph two-way, non-rebreathing valve while wearing a nose clip. A Parkinson-Cowan dry-gas meter measured pulmonary ventilation during inspiration. Expired oxygen and carbon dioxide were passed to a mixing chamber. Oxygen concentrations were measured by an Applied Electrochemistry S-3A analyzer and carbon dioxide concentrations were measured by a Sensormedics LB-2 analyzer. Ventilation and expired gas measurements were recorded every 30 seconds on an integrated IBM compatible computer system using a rolling 60-second average.

On the final day, subjects reported to a 200-meter indoor track. Each subject ran two self-paced laps followed by flexibility exercises for a warm-up. Next, the children performed two 55-meter sprints, which were used as a measure of anaerobic ability. Sprints were timed in duplicate to the nearest 0.01 second, using hand held stopwatches, and averaged. The fastest average was used for analysis. After a short rest period, the subjects ran 3 km to determine distance running performance. A hand held stopwatch was used to record the running time for
each subject and times were recorded to the nearest 0.1 second. During the run, intermediate times were given on each lap. Heart rate was recorded every 15 seconds using a Polar Heart Rate monitor. Immediately following the 3-km run, a finger stick blood sample was taken from each child to determine BL.

**Blood Analysis**

A 30 ul finger stick blood sample was taken in duplicate from each subject and mixed with 100 ul of perchloric acid. The samples were then frozen at -20°C until analysis. Finally, all samples were thawed, centrifuged, and analyzed using a standard enzymatic technique (Lowry and Passoneau, 1972).

**Statistical Analysis**

All data are reported as mean ± standard deviations. Pearson product moment correlations were used to determine the relation of body fatness, running economy at 6.0 mph, VO$_2$max, 55-m sprint time, and BL to 3-km running performance. Stepwise multiple regression analysis was performed to determine the combined influences of the dependent variables on running performance. Statistical significance was set at $P \leq 0.05$. 
CHAPTER 3

RESULTS AND DISCUSSION

Results

The purpose of this study was to examine how aerobic (RE, VO_{2max}, and FU) and anaerobic indices (sprint time and blood lactate) relate to endurance performance in circumpubertal children. This information is significant for coaches when training distance runners in this stage of growth and development.

Three boys and four girls participated in this study. The physical characteristics for the seven subjects are presented in Table 1. The mean height and weight values are within the normal range for this age group (Espenschade, 1963). Body fatness was expressed as the sum of six skinfolds, and based on the results presented in Table 1 it appears that all the subjects were relatively lean.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>13.7 ± 0.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.2 ± 10.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>47.4 ± 8.1</td>
</tr>
<tr>
<td>Sum of Skinfold Thickness</td>
<td>50.5 ± 8.7</td>
</tr>
</tbody>
</table>

Submaximal exercise responses are documented in Table 2. The average VO_2 at 5, 6, and 7 mph are similar to what would be expected based on prediction equations (ACSM, 1995). As
would be expected the VO$_2$ and heart rate increased as a function of increased speed. Expressed as a percentage of VO$_{2\text{max}}$, the three speeds elicited approximately 57 to 77% of VO$_{2\text{max}}$.

Table 2
Submaximal Exercise Data (Mean ± S.D.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>5 mph</th>
<th>6 mph</th>
<th>7 mph (n=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_2$ l/min</td>
<td>1.5 ± 0.3</td>
<td>1.8 ± 0.3</td>
<td>2.1 ± 0.4</td>
</tr>
<tr>
<td>VO$_2$ ml/kg/min</td>
<td>31.3 ± 4.0</td>
<td>36.9 ± 3.8</td>
<td>43.9 ± 5.7</td>
</tr>
<tr>
<td>%VO$_{2\text{max}}$</td>
<td>57.5 ± 5.6</td>
<td>67.7 ± 5.6</td>
<td>77.2 ± 6.5</td>
</tr>
</tbody>
</table>

Mean values for maximal exercise responses are outlined in Table 3. The mean VO$_{2\text{max}}$ is higher than normally active children of this age group (Bar-Or, 1983). This is most likely attributed to the fact that the subjects in the present study were trained runners. Based on maximal heart rate and RER data it appears that the subjects performed at a maximal effort.

Table 3
Maximal Exercise Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_2$ l/min</td>
<td>2.6 ± 0.5</td>
</tr>
<tr>
<td>VO$_2$ ml/kg/min</td>
<td>54.7 ± 6.1</td>
</tr>
<tr>
<td>Heart Rate (bpm)</td>
<td>205.9 ± 4.0</td>
</tr>
<tr>
<td>RER</td>
<td>1.14 ± 0.05</td>
</tr>
</tbody>
</table>

The average time to run 3 km was 14.3 ± 1.2 minutes. This represents an approximate pace of 7:56 per mile. FU, calculated from the VO$_2$-running speed relationship was 88.7 ± 9.4%
of VO$_{2\text{max}}$, BL following the 3 km run was $6.5 \pm 3.0$ mmol/l. Lastly, sprint time for 55 meters was $8.5 \pm 0.3$ sec.

Correlations between 3-km run time and sum of skinfold thickness, VO$_{2\text{max}}$, FU, RE at 6 mph, 55-meter sprint time, and BL are given in Table 4. At $p \leq 0.05$, the correlations were not statistically significant. However, the relationship between FU and run time did approach significance ($p=0.10$). Moreover, stepwise multiple regression analysis did not yield any further results.

Table 4

<table>
<thead>
<tr>
<th>Variable</th>
<th>r-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of Skinfold Thickness</td>
<td>0.42</td>
<td>0.34</td>
</tr>
<tr>
<td>VO$_{2\text{max}}$</td>
<td>-0.36</td>
<td>0.42</td>
</tr>
<tr>
<td>FU</td>
<td>-0.67</td>
<td>0.10</td>
</tr>
<tr>
<td>RE at 6 mph</td>
<td>-0.25</td>
<td>0.58</td>
</tr>
<tr>
<td>55-meter time</td>
<td>0.21</td>
<td>0.39</td>
</tr>
<tr>
<td>[Bla]</td>
<td>-0.39</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Discussion

Of all of the variables measured, sum of skinfold thickness, VO$_{2\text{max}}$, FU, RE at 6 mph, 55-meter time, and BL, none were significantly related to running performance, although, FU did show a trend for significance. A number of factors including a small sample size may have contributed to the lack of association between the various dependent variables and running time for 3 km.
The correlation between VO\textsubscript{2max} and run time is unusually low compared to what has been reported by others. Palgi et al. (1984) found VO\textsubscript{2max} to be highly correlated to 2-km run time ($r = -0.73$) in untrained 10- to 14-year-old boys and girls. Mahon et al. (1996) and Unnithan et al. (1995) found significant relationships between VO\textsubscript{2max} and 3-km run time in untrained 9- to 12-year-old boys ($r = -0.61$) and trained 10- to 12-year-old boys ($r = -0.83$), respectively. In adults, Costill et al. (1973) reported a significant correlation between VO\textsubscript{2max} and 10-mile run time ($r = -0.91$). Because the relationship between two variables is established by a range of scores, a possible explanation for the lack of correlation in this study may be due to a small range of VO\textsubscript{2max} scores. Consistent with this notion is the fact that VO\textsubscript{2max} is not a good predictor of running performance in a homogeneous group.

The moderately high correlation between FU and 3-km run time is in agreement with that of adult runners. Percent VO\textsubscript{2max} at 268 m/min was directly related to 10-mile running time ($r = 0.94$) according to Costill et al. (1973). Farrell et al. (1979) reported that all runners in the study performed at a high FU during the investigated races (94% for a 3.2-km race and 75% for a marathon). The ability to sustain a high relative effort will likely increase the speed of which the distance run can be performed.

The relationship between RE at 6 mph and 3-km run time was minimal which is consistent with other studies (Mahon et al., 1996; Palgi et al., 1984). However, the general consensus in this area is that superior RE is associated with fast performance times (Unnithan et al, 1995). Farrell's group (1979) showed RE at 268 m/min was significantly correlated to 19.3-km running performance in adult runners ($r = -0.56, p < 0.05$). While RE had no relationship to running performance for Costill et al. (1973), they compared RE at several running speeds to that of a
group of nationally ranked marathon runners. The marathon runners clearly consumed less oxygen at each speed. The more economical a runner is, the less energy is required to run a race. Thus, glycogen depletion and heat production, two factors that may limit prolonged endurance performance are delayed.

In younger children indices of anaerobic ability (anaerobic capacity, BL, sprint time, and VJ) have been reported to be related to running performance. Palgi et al. (1984) used a Wingate test to determine anaerobic capacity (AC) in children. The correlation between AC and 2-km run time was $r = -0.77$, and explained 59.5% of the variance in performance. In fact, AC and $VO_{2\text{max}}$ together accounted for 66% of variance in running performance. Mahon’s group (1996) reported VJ and 55-meter sprint time to be related to 3-km run time ($r = -0.67$ and $r = 0.59$, respectively). VJ and %$VO_{2\text{max}}$ at 5 mph collectively explained 83% of the variance in running performance. Krahenbul and Pangrazi (1983) reported that sprint time and BL are related to running performance in children. In the present study involving young adolescent runners 55-meter time and BL failed to be significantly related to running performance and is in agreement with adult studies. In 1967 Costill reported that VJ is not related to distance running performance ($r = 0.18$). Costill et al. (1973) showed that while no relationship between BL and running performance existed, the better runners were able to perform at faster speeds with less lactic acid accumulation. Lactate accumulation is related to muscle fatigue, acidosis, and inhibition of fat utilization (Farrell et al., 1979). Thus, limiting BL is advantageous for adult runners.

The failure of indices of anaerobic ability to be significantly associated with running performance is in contrast to data on younger, less mature children. In contrast, the moderately high relationship between distance running performance and FU is in agreement with what has
ben reported for adults. In conclusion, it appears that during the pubertal transition, the influence of anaerobic ability on distance running performance abates. This suggests that training designed to enhance the development of aerobic power will optimize running performance at 3-km in this age group. However, the results of this study should be viewed with caution due to a limited sample size and mixed gender.
REFERENCES


