Training and performance of women distance runners: a contemporary perspective

David E. Martin

Introduction

World-wide television coverage of the distance events during the 1972 Munich Olympic Games, coupled with the introduction of the 1.500 metres for women, greatly increased public awareness that distance running was exciting and enjoyable. Both the general population and highly talented athletes began to participate more and more in available competitive events. At about this same time, changing rules of sport competition permitted women to run together with men in what became known as mixed road races. Such races, ranging typically from 10 km to the marathon, eventually attracted thousands of participants, creating the well-known ‘running boom’ which continues unabated to this day. Table 1 (on the following page), illustrates this growth for just one event by comparing the number of men and women participants at the New York City marathon during its first 19 years. It can be seen that an enormous surge in participation occurred during the period of 1977 to 1980. However, it is also quite evident that the improvement in quality of competition among the women during this period was much greater than for the men. It was only fitting that this increase in both participation and excellence among women distance runners would be met with the inclusion of women’s competitive opportunities at the highest level. This indeed occurred.

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with successful introduction of the women’s 3,000 meires and marathon at the 1984 Los Angeles Olympic Games, and the women’s 10,000 metres in 1988 at the Seoul Olympic Games.

Presently, world-wide availability of road racing and cross country competitions provides an unprecedented opportunity for women athletes to develop their potential as distance runners. Road races include either mixed events with men and women together or separate races for both, now conducted commonly over distances from 8 km to the marathon. A wide range of distance events for women is also conducted on the track as well, at most of the major national, regional and continental championships. A dedicated interest by the International Amateur Athletic Federation to assist the improvement of athletics opportunities in developing nations has broadened the possibilities and encouraged the interest in participation by both women and men. Being the simplest of events for which to train, and requiring few facilities, distance running for women (as well as for men) has truly become a globally unifying sport endeavour.

This increased participation has raised several interesting questions, two of which form the basis for this presentation. These questions typically arise when one examines, as shown in Table 2, the world’s fastest performances for men and women from 800 metres through the marathon. The men run about 10% faster over the entire spectrum of events. One question is whether this 10% discrepancy is due to physiological gender differences between the men and women. The other question is whether there is a gender difference in response to the stress of physical training, and whether the same principles of training can be used by both sexes.

Until the last decade, it has been difficult to obtain an accurate picture not only of the types of gender differences that exist between men and women distance runners, but also the extent to which these, along with training, influence performance. One of the reasons for this relates to study design. To identify gender differ-

### TABLE 1

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TOTAL # FINISHERS</th>
<th># MEN FINISHERS</th>
<th>WINNING TIME</th>
<th># WOMEN FINISHERS</th>
<th>WINNING TIME</th>
</tr>
</thead>
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<tr>
<td>1970</td>
<td>55</td>
<td>55</td>
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<td>0</td>
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<tr>
<td>1974</td>
<td>278</td>
<td>269</td>
<td>2:26:31</td>
<td>9</td>
<td>3:07:29</td>
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<tr>
<td>1975</td>
<td>339</td>
<td>303</td>
<td>2:19:27</td>
<td>36</td>
<td>2:45:15</td>
</tr>
<tr>
<td>1976</td>
<td>1,549</td>
<td>1,486</td>
<td>2:10:10</td>
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<td>2:39:11</td>
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<td>1977</td>
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<td>1,701</td>
<td>2:11:28</td>
<td>184</td>
<td>2:43:10</td>
</tr>
<tr>
<td>1978</td>
<td>8,588</td>
<td>7,819</td>
<td>2:12:12</td>
<td>769</td>
<td>2:32:10</td>
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<tr>
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<td>10,477</td>
<td>9,274</td>
<td>2:11:42</td>
<td>1,203</td>
<td>2:27:33</td>
</tr>
<tr>
<td>1980</td>
<td>12,512</td>
<td>10,891</td>
<td>2:09:41</td>
<td>1,621</td>
<td>2:25:41</td>
</tr>
<tr>
<td>1981</td>
<td>12,233</td>
<td>11,466</td>
<td>2:08:13</td>
<td>1,757</td>
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<td>13,599</td>
<td>11,700</td>
<td>2:09:29</td>
<td>1,899</td>
<td>2:27:14</td>
</tr>
<tr>
<td>1983</td>
<td>14,546</td>
<td>12,341</td>
<td>2:08:59</td>
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<td>14,492</td>
<td>12,106</td>
<td>2:14:53</td>
<td>2,386</td>
<td>2:29:30</td>
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<tr>
<td>1987</td>
<td>21,244</td>
<td>17,555</td>
<td>2:11:01</td>
<td>3,689</td>
<td>2:30:17</td>
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<tr>
<td>1989</td>
<td>24,659</td>
<td>19,971</td>
<td>2:08:01</td>
<td>4,688</td>
<td>2:25:30</td>
</tr>
</tbody>
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TABLE 3

<table>
<thead>
<tr>
<th>DISTANCE</th>
<th>MEN</th>
<th>WOMEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 m</td>
<td>1:41.73 Coe</td>
<td>1:53.28 Kratochvilova</td>
</tr>
<tr>
<td>1,000 m</td>
<td>2:12.18 Coe</td>
<td>2:30.6 Providokhina</td>
</tr>
<tr>
<td>1,500 m</td>
<td>3:29.46 Aouita</td>
<td>3:52.47 Kazankina</td>
</tr>
<tr>
<td>5,000 m</td>
<td>7:29.45 Aouita</td>
<td>8:22.62 Kazankina</td>
</tr>
<tr>
<td>10,000 m</td>
<td>27:08.23 Barrios</td>
<td>30:13.74 Kristiansen</td>
</tr>
<tr>
<td>marathon</td>
<td>2:06:50 Densimo</td>
<td>2:21:06 Kristiansen</td>
</tr>
</tbody>
</table>

ences, men and women must be similar in fitness, and working at comparable exercise intensities in relation to their maximum capabilities, so that the effects of these performance variables will not contribute to the differences observed. Before 1980 it was difficult for scientists to obtain an equally large study population of equivalent trained men and women distance runners. And so the study populations were small, with a typically wider range of performance quality among the men subjects than among the women. This made it difficult to separate gender-related differences. In 1975 a group of highly skilled male distance runners was studied comprehensively from the viewpoints of biomechanics, anthropometry, cardio-pulmonary performance, hematology, etc. (Pollock, 1977). It was not until 1985 that a comparable study was undertaken for women (Pate et al., 1987).

A second reason for the lack of knowledge about the effects of training is that very few longitudinal studies, i.e., repeated study of individuals (who can serve as their own control) to identify athlete response to various training regimes, have been published for male or female distance runners. The vast majority of performance-comparison studies have been cross-sectional, i.e., a one-time survey of characteristics of a given athlete population.

This review describes some of the gender and training related similarities and differences between men and women distance runners. It summarizes conclusions from studies conducted primarily during the past few years, including data from our own laboratory studies that have involved the long term performance profiling of about 50 Olympic level men and women distance runners. It also describes a general outline of concepts which explains how various components of training can be integrated into a plan that will improve performance in women distance runners. The possible impact on performance by the hormonal changes occurring during menstrual cyclicity will be discussed separately.

Metabolic influences on performance

Both men and women have a similar homoeostatic adaptation to the stress imposed by running, which follows well-known physiological principles. Thus, the structure and performance capability of an organ system (such as skeletal muscle) is determined by a) its genetic constitution and b) the quantity and quality of work it performs. The greater the demand, or stress, placed upon such an organ system (within its physiological limits), the more completely it adapts to that stress. This in turn increases its workload tolerance. Thus, the key to performance improvement is in providing the appropriate training stimulus. An individual’s potential for distance running performance is determined by the combined output of aerobic plus anaerobic energy production mechanisms. Each of these can be described briefly.
**Aerobic power**

Aerobic metabolism uses oxygen for the complete metabolism of fuels (predominantly carbohydrates and fatty acids), producing carbon dioxide as well as large quantities of energy (stored as adenosine triphosphate or ATP). This energy is then available for the production of movement through appropriate interaction among nerves, muscles, connective tissue, and the skeleton. The laboratory measurement of one's maximum volume of oxygen uptake (VO\(_2\) max), usually termed aerobic power, is often considered as an important criterion to identify both aerobic performance potential and change with training among distance runners. Coaches and athletes can sense improving aerobic power as an increased ability to endure long distance training runs with minimal fatigue, and also the ability to run more and more quickly over shorter distances (1,000 to 3,000 metres) with minimal recovery required. Training of both male and female distance runners, therefore, should be directed toward improving aerobic aspects of performance.

If we compare young (20-29 year-old) average fitness males and females with regard to their VO\(_2\) max, a typical range of values for each will be, respectively, 35 - 43 and 44 - 51 ml O\(_2\)/kg body weight/min (Nagle, 1973). If we now compare the VO\(_2\) max values for elite-level highly trained male and female distance runners, the typical range of values is, respectively, 61 - 73 (Pate et al., 1987) and 71 - 84 ml/kg/min (Pollock, 1977). Thus, not only does an inherent gender difference exist, but also both sexes can increase by a similar percentage their aerobic power through endurance-oriented distance running. Whereas the mean difference between mean VO\(_2\) max values for average-fitness men and women is about 17%, this difference decreases to about 13% for the highly fit runners.

Maximum oxygen uptake is determined by the combination of oxygen intake (a pulmonary and circulatory challenge), oxygen delivery (a circulatory challenge), and oxygen utilization (an intracellular challenge involving mitochondrial enzymes). It is calculated as the product of cardiac output (Q) and the difference between arterial and mean venous blood oxygen concentration (a-v O\(_2\) difference). Since cardiac output is in turn the product of heart rate (HR) and stroke volume (SV), we can write:

\[
\text{VO}_2\text{ max} = \text{Qmax} \times \text{max a-VO}_2\text{ diff} = \text{HRmax} \times \text{SVmax} \times \text{max a-VO}_2\text{ diff} \quad (1)
\]

Another laboratory measurement of aerobic fitness is the oxygen utilization at submaximum running speeds, used as an indication of running economy. If 2 runners have identical VO\(_2\) max values, all other factors being equal as well, except that one runner is more economical, this greater efficiency will provide a competitive advantage, since a faster speed will be maintainable before a significant increase in anaerobic metabolism occurs to provide the additional energy requirements. A third assessment of aerobic fitness is to identify the workload (or pace) at which these anaerobic contributions begin to supplement ongoing aerobic energy provisions. This workload is known variously as ventilatory threshold (if identified using changes in expired gas concentrations), lactate threshold (if identified using blood lactic acid assay), or simply as anaerobic threshold.

As aerobic fitness improves, the anaerobic threshold pace approaches (but never reaches) the pace at which 100% aerobic power can be maintained. Typically, well-trained distance runners can run at the intensity of 100% VO\(_2\) max pace for only about 10 - 12 minutes. This is because the cumulative effects of the increasing anaerobic accompaniment make continued performance intolerable at that workload. Thus, events longer than 5,000 metres are raced at considerably less than 100% VO\(_2\) max pace, where the anaerobic contribution is not as large. The 1,500 metres and other shorter distance events can be raced faster than this pace because greater anaerobic stress can be tolerated for a shorter period.
of time. The marathon is raced typically at a pace about 2% - 4% slower than the anaerobic threshold pace.

Anaerobic capabilities

It is well known in scientific circles that a population of distance runners, either men or women, all of whom have a similar VO₂ max and running economy, will not cross the finish line of a competitive race at the same time. Thus, for such a group, other criteria must contribute to competitive performance capability. The runner who has the greatest combination of aerobic plus anaerobic performance ability will most likely be victorious. Such an individual can work for a long period at a high percentage of VO₂ max with relatively less inhibitory effects of increasing anaerobic metabolism on performance, and then be able to unleash and endure the fastest end-of-race kick. Thus, whereas aerobic endurance will get one to the finish line, raw speed from anaerobic tolerance will help get one there first.

Anaerobic metabolism does not require oxygen, and as mentioned earlier, is an important additional mechanism for energy production when the workload becomes so intense that adequate oxygen intake is not possible. However, it requires about 19 times more carbohydrate breakdown than occurs with aerobic metabolism for an equivalent ATP release. Instead of carbon dioxide being the metabolic end product, lactic acid results. Unlike carbon dioxide, this is a non-volatile acid and thus cannot be exhaled. It dissociates into its two components, lactate and hydrogen. While lactate itself can be used as a fuel, the resulting acidosis from accumulating hydrogen ions has an inhibitory effect on the continued high metabolic rate. This is sensed both by the central nervous system, as a progressive intolerance to the high workload, and by the working muscles, whose performance deteriorates due to enzyme inhibition. Proper training of distance runners improves mental tolerance to elevated tissue acidosis, increases the ability of tissues to use lactate as a fuel, and improves buffering abilities of the blood and other body fluids.

Laboratory indicators of maximal anaerobic performance fitness using treadmill runs include such values as maximum blood lactate concentration, maximum carbon dioxide output (VCO₂ max), and anaerobic capacity as measured by accumulated oxygen deficit (Medbo et al., 1988). Coaches and athletes sense improving anaerobic fitness as the ability to run repetitions of short distances (200m through 800m) while maintaining excellent running form despite requiring minimum recovery between each.

Skeletal muscle influences on performance

How does skeletal muscle respond to varying work intensities, and are there differences between men and women in this regard? The skeletal muscles provide force for body movements (such as running), as well as stability for other parts of the body during movement. A larger skeletal muscle mass provides an advantage for strength and power related activities, but is less needed for activities such as distance-running, which are primarily dependent upon submaximal work output over a long time period. Nonetheless, greater strength can improve endurance because, if one athlete is stronger than another, then any chosen submaximal workload will be relatively easier for the stronger athlete to maintain over time.

Skeletal muscle cells (also called fibres) exist in two general groupings based upon their different tension-generating and metabolic characteristics. These features in turn determine the muscle response to various intensities of exercise. Most human skeletal muscles among untrained men and women have about equal numbers of slow-twitch and fast-twitch fibres. Slow-twitch fibres are especially well endowed for submaximal (aerobic), long lasting muscle
tension generation, whereas fast-twitch fibres are specialized for short-term (anaerobic) generation of large amounts of strength or power. Since the activities of life require both fast/strong movements (e.g., quick locomotion) and slow/sustained movements (e.g., posture), it is logical that our muscles be endowed with both capabilities.

Slow-twitch fibres are recruited preferentially with low-level activity, and fast-twitch fibres with higher level activity. The practical significance of this is that training at slow running pace stimulates development of slow-twitch fibres rather than fast-twitch fibres. Faster paced training sessions are essential to stimulate development of the additional fast-twitch fibres that contribute enormously to the maximal performance capability of working muscle.

Athletes tend to perform well at their chosen events in part because of training but also in part because they typically have an appropriate mixture of fast- and slow-twitch fibres that matches their expertise. Thus, excellent marathon runners typically have a larger proportion of slow-twitch fibres in their lower limb muscles than do middle-distance runners. Sprinters tend to have a larger proportion of fast-twitch fibres than either middle or long distance runners.

Untrained males and females have similar quantities of fast- and slow-twitch fibres. This is also true for highly trained male and female distance runners. When either sex undergoes physical training, be it strength or endurance oriented, an appropriate increase in performance capability occurs, depending upon the stimulus. This is manifested by appropriate changes in the quantity of oxidative (aerobic) and glycolytic (anaerobic) enzymes used in fuel metabolism, as well as changes in extent of capillarization around individual muscle fibres. However, one consistently observed difference is that males typically have measurably larger muscle fibre cross-sectional areas than females. Thus, male muscle fibres are larger, especially the fast-twitch fibres (Costill et al., 1987). This is primarily due to the muscle protein-building action of testosterone, which exists in higher concentration among men than women.

For this reason men engaged in maximum-effort strength training can gain more muscle mass than women, and develop a strength advantage over women in those events requiring a strength emphasis. Or, to put it another way, in the longer (endurance) events, competitive performance times for women should approach more closely those of men, since the strength component of performance is less important. Table 3 compares the height and weight of the 10 best men and women track performers during 1988 in events from the 100 metres through the marathon. The physiological tendency for men to be both taller and heavier is clear, particularly for the sprints. With the events from 1,500 metres and longer, although sizeable weight variations occur between men and women, Table 2 indicates that a similar 10% performance difference remains, suggesting that weight may not be as important as other factors. As will be described shortly, this performance discrepancy for the middle and long distance events is due, to a large extent, to gender differences in oxygen transport ability.

Influence of stored fat on distance running performance

The difference in percent body fat between highly trained male and female distance runners is less than that between average-fitness males and females. This is one important contributing factor that explains the greater VO₂ max similarity among the trained rather than untrained male and female athletes described earlier. The ranges of percent body fat values for the elite-level male and female distance runners evaluated in our laboratory are,
TABLE I
COMPARISON OF HEIGHT AND WEIGHT OF BEST 10 MEN AND WOMEN PERFORMERS OF 1988 IN RUNNING EVENTS*

<table>
<thead>
<tr>
<th>EVENT</th>
<th>MEN</th>
<th>WOMEN</th>
<th>DIFFERENCE</th>
<th>MEN</th>
<th>WOMEN</th>
<th>DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m</td>
<td>182</td>
<td>169 + 7.2</td>
<td>7.2%</td>
<td>58 + 4.7</td>
<td>20.6%</td>
<td></td>
</tr>
<tr>
<td>200 m</td>
<td>184</td>
<td>173 + 5.8</td>
<td>6.0%</td>
<td>60 + 4.4</td>
<td>22.1%</td>
<td></td>
</tr>
<tr>
<td>400 m</td>
<td>181</td>
<td>170 + 5.0</td>
<td>6.1%</td>
<td>58 + 4.7</td>
<td>19.5%</td>
<td></td>
</tr>
<tr>
<td>800 m</td>
<td>183</td>
<td>169 + 5.2</td>
<td>7.7%</td>
<td>55 + 3.5</td>
<td>19.2%</td>
<td></td>
</tr>
<tr>
<td>1,500 m</td>
<td>178</td>
<td>167 + 6.0</td>
<td>6.2%</td>
<td>56 + 4.1</td>
<td>12.5%</td>
<td></td>
</tr>
<tr>
<td>5,000 m</td>
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<td>48 + 4.9</td>
<td>23.9%</td>
<td></td>
</tr>
<tr>
<td>10,000 m</td>
<td>172</td>
<td>164 + 6.4</td>
<td>4.7%</td>
<td>49 + 4.1</td>
<td>19.7%</td>
<td></td>
</tr>
<tr>
<td>marathon</td>
<td>172</td>
<td>166 + 4.4</td>
<td>3.5%</td>
<td>52 + 5.0</td>
<td>13.4%</td>
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</table>

*Data obtained from Annual Rankings, Track & Field News, Jan/Feb 1989, based upon a combination of honors won, fastest performances, and head-to-head competition. All values except percent differences are means of the top 10 performers + 1 standard deviation.

respectively, 5 - 8% and 10 - 14%. These values are of course lower than those found among average fitness males and females: 12 - 16% and 22 - 26%, respectively (Wells, 1986). Body fat does not contribute to movement, and is an extra load that must be transported in weight bearing and locomotor activities. Muscle mass, by contrast, is present in larger quantity in males. It influences muscular strength, power, endurance, and speed, all of which can increase running performance.

Hormonal differences explain the greater quantity of stored fat in women, and the greater muscle mass in men. Estrogenic hormones, present in higher concentration among women, promote fat removal from the blood (a so-called hypolipemic effect), resulting in fat storage subcutaneously and in other areas. Testosterone and related hormones, present in higher concentration among men, promote muscle tissue growth (a so-called anabolic effect). Fat tissue is only 10% water, whereas muscle is 75% water. Fat floats and is less dense than muscle. Thus, a 50 kg woman looks larger than a 50 kg man, and she is, because of her lesser body density. She has greater body surface area in relation to her body mass.

Influence of cardiopulmonary and haematologic variables on performance

Oxygen transport aspects

When the VO₂ max values described above are expressed in terms of lean body mass rather than total body weight, thereby eliminating the influence of differing percent body fat among the two sexes, the values are more similar, but still not identical (Sparling, 1980). Thus, it is not percent body fat by itself that contributes to the VO₂ max differences between highly fit athletes of the two sexes. Differences between men and women in several aspects of oxygen transport and cardiopulmonary function also contribute to the typically larger VO₂ max observed in males than in females.

The most important factor explaining the difference in oxygen transport capabilities is the blood haemoglobin concentration. Since haemoglobin production is influenced by testosterone, men typically have more haemoglobin than women. Haemoglobin transports 98.5% of the blood oxygen supply. Thus, men, with their higher haemoglobin level, can transport more oxygen than women. When combined
with greater skeletal muscle mass among men, these 2 factors contribute measurably to their higher maximum aerobic power than that seen in women of comparable fitness and weight.

The extent of the difference between men and women in haemoglobin oxygen content can be readily calculated (Martin, 1984). We will assume that the oxygen binding capacity of haemoglobin is the same in both sexes (1.31 ml/gm), and that 97% of the oxygen binding sites on haemoglobin are occupied with oxygen. Among the elite distance runners who have been studied in our laboratory, the mean haemoglobin value for men is 15.5 mg/dl, whereas for women it is 14 mg/dl. We can calculate the haemoglobin-bound oxygen in men as

$$1.31 \times 15.5 \times 0.97 = 19.70 \text{ ml/dl}.$$ 

For women this value is 17.79. The difference is 10%.

It is also true, however, that women have less blood per kilogram of body weight, so they are not simply scaled-down versions of men. Typical values for men are 77 ml blood/kg body weight, as compared to women at 66 ml/kg. Since fat tissue is not as well-vascularized as skeletal muscle tissue, this difference is reduced but not eliminated when the two sexes are compared in terms of lean body mass.

Cardiac aspects

The maximum achievable heart rate for both sexes is similar. However, the female heart is smaller in dimensions, even when correction is made for the size difference between the sexes. This is again due to the smaller testosterone-mediated protein anabolic stimulus in women. The female heart is not necessarily weaker, however, because when \( VO_2 \) max is expressed in terms of ml \( O_2 \)/kg lean body mass/min/gm of heart tissue, values for the two sexes are similar. A smaller heart size in women means a smaller maximum stroke volume, which, as seen in Equation (1), is an important determinant of \( VO_2 \) max. As exercise intensity increases, both heart rate and stroke volume increase in a self-optimizing manner to maximize cardiac output and performance efficiency. This means that, at any given submaximal running pace, the female heart rate will likely be higher. This decreases cardiac efficiency by shortening the rest time between beats, during which the majority of blood perfusion to the cardiac muscle itself occurs.

Endurance training can effectively increase cardiac dimensions, particularly on the left side, in both men (Maron, 1986) and women (Pollak et al., 1987). The result is an increase in stroke volume, but because of the larger heart in men before training, and similar training effect on both sexes, the larger stroke volume in men remains after training.

Pulmonary aspects

Pulmonary differences also contribute to differences in \( VO_2 \) max between the sexes. As a result of their average smaller stature, women have a smaller thorax, and therefore less lung tissue. When pulmonary function evaluation is performed, these differences can be quantified. Women have a lower vital capacity and a smaller residual volume, and thus a smaller total lung capacity (Morris et al., 1971). Women also have smaller maximum expired ventilation rates, due in part to decreased lung volumes but also to a smaller mass of skeletal muscle tissue associated with exercise breathing (diaphragm plus abdominal and other accessory muscles).

When population means are compared, it does not appear that the serious training of an endurance runner increases lung volumes or flow rates beyond those seen in untrained people (Martin & May, 1987). However, the sizable range of individual values tends to obscure differences that may actually exist in flow rates when age, sex, and height matched trained and untrained runners are compared. This is particularly true for maximum breathing capacity and peak expiratory flow rate for both male and female runners.
Blood chemistry changes suggestive of hard training and overtraining

The blood composition of an athlete who is successfully managing a high-volume or high-intensity distance training programme is often different in several respects from that found among sedentary people. Blood composition reflects the metabolic state of the tissues perfused by it, particularly the working skeletal muscles, since they comprise such a large tissue mass. Changes indicating increased red blood cell destruction and its management can also be seen. It is essential to realize that the training process includes both a breakdown phase (characterized by fatigue) and a recovery phase (where fatigue is replaced with freshness). The breakdown of tissues from hard work results in beneficial (adaptive) recovery and actual improvement in performance output capability. If this balance is maintained, the observed alterations in blood composition simply reflect this breakdown and rebuilding process. Inadequate recovery in relation to the applied breakdown load, if permitted to continue too long, may trigger a complex combination of psychophysiological signs and symptoms of a more far-reaching nature than simply fatigue. The profound inability to continue forward progress suggests a trend toward actual cellular injury, or profound fuel exhaustion in working muscles, or a breakdown of the body’s defence mechanisms, and other aspects as well. This phenomenon is now called overtraining or staleness. Considerable interest has been directed towards the identification of specific blood chemistry values or other easily measured physiological variables that would be highly suggestive of the onset of overtraining. Because the staleness phenomenon is multifaceted, the likelihood of such a simple solution is unlikely. Ideally, it would be preferable to identify the risk of onset of overtraining before it indeed occurs. This too is a challenge, because if specific changes unique to overtraining are identifiable, these would not occur until after overtraining has begun.

One approach has been to realize that arduous training by itself causes measurable changes in cellular physiology that can be seen by profiling various blood chemistry and physiological values. By frequent (for example, quarterly) evaluation of such variables for each athlete, a normal pattern will be established which represents that athlete’s ongoing manageable response to hard training. As the athlete unknowingly begins to pass from manageable training to overtraining, further deviations from normal among the already changed values can suggest that the body may no longer be maintaining homeostatic equilibrium.

Our experience with more than a decade of such periodic (quarterly) measurement of performance fitness and blood chemistry status among top-level American distance runners has permitted identification of several variables, different from those seen among untrained people, which provide an indication of management of hard training. Blood and urine are collected early in the morning, after an overnight fast and at least 16 hours after the previous day’s training. Results of such monitoring give an indication of the body’s ongoing management of hard training, and thus can be considered as ‘training norms.’ Women respond quite similarly to men regarding such changes. Monitoring the extent of deviations from this individual athlete’s norm, as seen, for example, following a profound metabolic challenge such as a marathon race, or during a period of increased training load can then provide useful information for determining 1) when normal post-race training can resume, 2) the response to a planned increase in workload, or 3) the possible onset of overtraining. Some of the more informative blood chemistry values for evaluation of the above mentioned responses can be described briefly.

One group of blood chemistry values relates to adequate iron stores and oxygen
transport capability. Iron is part of the haemoglobin molecule. Since mature red blood cells are about one-third haemoglobin, adequate iron stores must be available in the bone marrow for red blood cell production. All cells store iron, primarily bound to a protein, the complex being called ferritin. Blood levels of ferritin are an accurate reflection of tissue ferritin levels. Thus, a low blood ferritin level despite normal haemoglobin may be suggestive of iron depletion. If this depletion persists long enough to cause reduction of haemoglobin (and thus decreased red blood cell production), the resulting iron deficiency can produce anaemia, with its accompanying symptoms of fatigue and decreased exercise tolerance (Newhouse & Clement, 1988).

Iron, however, is required for more than just haemoglobin production. Skeletal muscles have an oxygen-binding pigment called myoglobin, which is iron-containing. Also, in the mitochondria of cells are located the majority of enzymes required for aerobic fuel metabolism (the Krebs cycle enzymes) as well as the cytochrome proteins which permit the final capture of energy from aerobic metabolism in the form of ATP. More than half of the Krebs cycle enzymes, as well as the cytochrome proteins, are iron containing. Thus, if iron stores are sufficiently low for a sustained period, there is the distinct possibility that, before iron-deficiency anaemia occurs (with its accompanying fatigue), an iron depletion state can also decrease working capacity (Martin, 1986). This state is also characterized by fatigue during training, as well as increased recovery time required between training sessions. Our laboratory values suggest that blood ferritin levels below 20 ng/ml represent zero bone marrow iron stores. Values from 20 to 50 ng/ml represent sizably decreased iron stores, and those between 50 and 150 ng/ml indicate adequate iron stores representative of the healthy trained (and untrained) population (Martin et al., 1986).

Along with ferritin measurement, several other markers are available which can indicate iron loss or potential iron non-availability. Two of these relate to increased red blood cell destruction, or haemolysis, from the stress of training (Figure 1). This can occur from 1) foot-strike impact stress, 2) increased red blood cell membrane fragility in blood made more acidic from fast running, 3) trauma due to increased velocity of red blood cell movement through the bloodstream, and 4) distortion by skeletal muscle compression of blood vessels during higher-intensity exercise.

Loss of this iron through the urine is greatly reduced by 2 processes, which can serve as markers for hard training. One involves the action of a normally-circulating blood protein called haptoglobin, which can bind to free haemoglobin, permit its recycling back to the liver, and thereby prevent loss of iron. Thus, decreased blood levels of haptoglobin can signal increased haemolysis (Dufaux, 1981). A morning fasting blood level of less than 20 mg/dl signifies considerable training-related haemolysis, with the risk that, for variable periods during hard training, haptoglobin may be depleted entirely, causing haemoglobin entry into the urine. A blood level from 20 to 50 mg/dl represents a lesser amount of haemolysis typical of reasonably serious training. Levels greater than 50 mg/dl are representative of untrained people and athletes who have very minimal ongoing haemolysis due either to excellent training adaptation or a period of moderate training.

The other marker is in the urine, and relates to the reabsorption and chemical sequestering of iron in kidney tubule cells. If sufficient haemolysis has occurred to deplete available haptoglobin supplies, the remaining haemoglobin will be filtered into the kidney tubules. These cells have a maximum iron absorption rate, after which any excess filtered haemoglobin is excreted (this is called haematuria). The iron absorbed by the tubule cells is bound to an insoluble
protein called haemosiderin. As kidney tubule cells are lost through normal replacement, the presence of haemosiderin in urine sediment also indicates ongoing iron loss.

In addition to these markers of increased red blood cell breakdown, indicators are also available to suggest the adequacy of bone marrow production of red blood cells for meeting increased needs. Increased numbers of reticulocytes and shift cells may be present in the blood. These are immature forms of red blood cells. Normally, cells leaving the bone marrow are essentially all fully mature, with their full complement of haemoglobin. The presence of these immature cells in the bloodstream is a clinical indicator of an elevated bone marrow response to the need for more oxygen-carrying capacity. Decreased iron availability in the bone marrow in turn limits its ability to synthesize haemoglobin. This can decrease the presence of shift cells or reticulocytes in the blood, which may signal an impending lowering of red blood cell concentration.

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Figure 1: High intensity and/or high volume training can both increase the red blood cell destruction rate, with an accompanying risk for increased urinary iron loss unless haemoglobin can be recovered. (Reprinted with permission from Martin, D.E. & Coe, P., "Training Distance Runners", Human Kinetics Publishers: Champaign, Illinois, USA, 1990)
Problems with adequate iron stores for ensuring optimum aerobic metabolic capabilities stem from:
1) its poor absorption through the gastrointestinal tract, especially during periods of intense training,
2) its unavailability in the diets of many distance runners, and
3) its continual loss, due in part to training.

Optimum iron balance can be expected for sedentary women, if their iron intake is at least 18 mg/day, and, for men 10 mg/day (Haymes, 1986). Only about 10% of dietary iron intake is absorbed even under optimum conditions. This occurs when the two primary sources of iron are consumed together - the so-called haeme iron in lean red meat and non-haeme iron present in a variety of other foods (the presence of the former enhances absorption of the latter). Dietary iron intake among distance runners is often inadequate to meet their increased metabolic requirements, for several reasons. First, in many nations of the world red meat is scarce or unavailable. Second, in many nations where it is available, runners often prefer not to eat it. Third, during more intense training periods, a commonly observed lowered food intake due to decreased appetite reduces iron intake even further. Increased sweating can also increase iron loss, since it is a component of sweat. Fourth, excessive use of anti-inflammatory agents such as aspirin can promote gastrointestinal bleeding, thereby producing an iron loss. Fifth, for female runners, menstruation among those still maintaining normal menstrual cyclicity also contributes to iron loss.

Several coaching suggestions can be offered to distance runners that might help to optimize iron store availability for synthesis of haemoglobin and other iron-containing proteins involved in aerobic metabolism:
- Minimize impact stress by selecting training shoes that provide adequate impact absorption, or if running barefoot, emphasize the use of dirt trails which are not too firmly packed.
- Eliminate needless training which does not improve aerobic performance (such as very slow training done simply to increase the distance covered per week).
- Include periodic rest days which will permit better dietary iron replacement, physical recovery, and mental refreshment.
- Select training periods during cooler parts of the day to minimize iron losses via perspiration.
- Where possible attempt the inclusion of a modest amount of lean red meat into the diet.
- Restrict the intake of substances which inhibit iron absorption (such foods include bran, coffee, tea, and eggs) during those meals where iron-rich foods are ingested.
- Consider the possible benefit of a small quantity of oral elemental iron supplementation, with periodic monitoring of iron stores to assess its continued need.
- Where possible, use iron cooking utensils.

Recent articles (Eichner, 1988; Peota, 1989) have suggested that the notion of performance impairment in athletes as a result of iron store depletion without measurable anaemia may be more fallacy than fact. Unfortunately, this conclusion is being made on the basis of studies ranging from laboratory experiments using 'active women' with moderate training schedules (Lamanca & Haymes, 1989) to observations made on Indonesian women with repeated pregnancy-induced and poor diet-induced iron deficiency (Celsing et al., 1988). Such a conclusion is not at all applicable to the situation of elite level endurance runners, attempting to cope with the metabolic demands resulting from red blood cell destruction, as well as increasing incorporation of iron into mitochondrial enzymes, both of which form a part of the adaptation to increased tolerance of stress loads of 80 miles/wk (130 km/wk), and often much more, for weeks on end.
In addition to blood chemistry variables related to aerobic metabolism, fatigued skeletal muscles have an increased cell membrane permeability, permitting leakage of some of their enzymes into the blood plasma. One of the most well-known is creatine kinase. Such increases can be seen following sudden elevations in training volume or intensity, or after races. In both instances, if overtraining is not occurring, enzyme levels will return promptly toward the normally accepted range for the athlete being studied. Continued elevation beyond an appropriate recovery period is an indicator for reduction in training load until recovery occurs. Our upper range of normal creatine kinase levels is 275 units/L, with some distance runners maintaining levels as high as 325 units/L without progressive fatigue. Following a marathon race, we have observed creatine kinase levels to rise as high as 5,000 units/L during the first week post-race, returning to normal within three weeks.

Gender differences in heat tolerance

Earlier studies suggested that women may be at a greater disadvantage than men when competing in thermally stressful conditions (i.e., warm temperatures with or without humidity). More recent analysis has tended to refute this view, and in fact the response of women to work in the heat may give them an advantage over men during longer events such as the marathon and beyond.

It was initially reported (Wyndham et al, 1965) that women had higher heart rates, raised their core (inner) body temperature more than men, and terminated their exercise bout earlier than men, when instructed to work until voluntary exhaustion. Such studies suffered from the flaw in logic that was mentioned earlier, namely that both sexes were assigned an identical absolute workload in terms of running pace, temperature, and humidity. Because the VO2 max values for the men exceeded those of the women, each submaximal workload was relatively more difficult for the women. More importantly, this elevated metabolic demand for the women resulted in greater heat production (Drinkwater, 1988). Thus, the increased response among females was appropriate to their relatively increased workload but not appropriate in comparison to results of men working at a comparatively easier load.

Both sexes can acclimatize, or adapt, to the increased stress of warm-dry or warm-humid environments. With specific submaximal workloads, sweating begins at a lower core temperature and more sweat is produced. This lowers skin temperature by a small amount and slows the rise of core temperature. Also, the working heart rate is less and blood volume is increased but these are the result of adaptation to endurance training and not heat-stress-specific responses (Convertino et al., 1980). No good evidence indicates that this sweat response changes throughout the menstrual cycle as a result of cyclic hormone changes.

It appears that women may sweat less than men, which paradoxically may make them more effective regulators of heat stress than men under certain circumstances (Frye & Kamon, 1983). Men tend to sweat excessively in relation to their heat dissipation requirements. Sweat dripping off the body does not assist in body cooling. Among women, this tendency is less prevalent, so that they obtain an equivalent heat dissipation with less sweat loss. Thus, men and women respond more similarly to the stress of warm dry environments, where the rapid rate of evaporation minimizes the loss of nonfunctional sweat. But women appear at an advantage in warm humid weather. The advantage of reduced sweat loss during a longer race is seen in the developing dehydration resulting because absorption of ingested fluids cannot match net sweat losses. In accordance with Equation (1), during the final stages of a marathon, heart rate must increase to maintain cardiac output, since stroke volume is decreasing from progressive haemo-
concentration. This increasing heart rate has its limits, determined in part by the effectiveness of cardiac muscle perfusion during the rest period between beats. As cardiac output begins to decrease, an accompanying slowing of pace is inevitable. Women, with a smaller heart, thus seem to be protected more than men from the added cardiac stress of dehydration. Neither sex, of course, is immune from the very serious consequences of exceeding their abilities to cope with heat stress.

The combined knowledge that 1) increased heat and humidity form an added stress to sport performance, and 2) this can be magnified by the enormous fluid loss during very long races, seems to have been considered wisely by the IAAF in their support of a 15 km race as a women’s world road-racing championship rather than a longer distance event such as the half marathon (21.1 km) or full marathon. Athletes living in cool-weather conditions flown to such a race held in warm conditions will have inadequate time to acclimatize. Such acclimatization would require about 6 to 7 days of 1 to 1.5 hours exercise each day in the warm environment. But athletes during such a period prior to a major competition are tapering their training, and thus can adapt only minimally. The 15 km distance, however, is not extremely long, so that the competitive advantages of a heat trained runner will be minimal. Also, the risk of medical heat stress emergencies typical of longer races is reduced. Additionally, of course, it is well known that the 15 km distance is well within the racing expertise of both the marathoners at the longer end of the distance running spectrum and the 3,000 metres specialists at the shorter end. Thus, it is an almost ideal distance to test safely the competitive expertise of a large population of distance runners.

Biomechanical influences on distance running performance

The idea that running mechanics may influence maximum competitive perfor-
the women appeared to take significantly longer strides (108%) than men (104%).

The more recent comprehensive study of elite women distance runners (Williams et al., 1987) has confirmed the conclusion of Nelson et al. regarding longer relative stride lengths in elite women runners as compared to elite men. The women also had more hip flexion, and thus greater angular velocities in both hip extension and flexion. It seems unlikely, however, that women are indeed over-striding. Instead, this is simply a difference due to women running at a greater percentage of maximum performance ability than men. The running speeds were the same for both sexes rather than being adjusted to represent equivalent percentage values of maximum speed capabilities. No reason exists why women should not optimize their stride dynamics (frequency and length) in a manner similar to men. Future research should evaluate a group of comparably trained male and female runners who are all of similar stature. This would remove the effects of body stature and training as performance variables between the two sexes, and allow the gender component to become more clearly identified.

Pulmonary and biomechanical variables relating to performance couple similarly in both men and women. Both sexes synchronize stride frequency with breathing frequency. As an example, at most submaximal speeds an inhalation and exhalation each occur during the time span of two steps. Because women typically have smaller lungs than men, it is more efficient for them to increase breathing frequency rather than breathing depth as running speed increases. Their shorter absolute leg lengths, coupled with less skeletal muscle tissue, also make an increased stride-frequency preferable to a longer stride length. As an example, at any given absolute running speed, such as 87 sec/400m (5:50/mi; 3:38/km), a female runner might take 45 breaths/minute and 180 steps/min. A male runner, in contrast, might require only 40 breaths/minute, and take 160 steps/minute. Thus, the quicker running cadence of women runners conveniently matches their increased breathing rate.

**Injury risks and their reduction**

Frequent mention in the clinical literature of a possible greater risk among females for musculoskeletal running injuries has brought concern among both coaches and athletes. The results of earlier studies again were biased against females because, in comparison to men, women were typically lower in fitness and level of conditioning. More recent studies suggest that, instead of one sex being more prone to injury than the other, various injuries may be more common in one sex than the other (Nilson, 1986). Thus, tendonitis (Achilles and patellar) may occur more often in men, perhaps because they tend to have less posterior leg flexibility than women (Marshall et al., 1980). Stress fractures, however, may be more prevalent among women, due perhaps to the decreased bone mineral content more prevalent in amenorrheic athletes, caused in turn by depressed oestrogen levels (Cann et al., 1984).

One of the more frequently cited factors that might increase injury risk in female distance runners is their wider pelvis. Actually, it is not so much the pelvis being wider in females than in males as other dimensions in women being comparatively smaller. The picture is made more complex because measurements at various levels of the pelvis give comparatively different results. For example, pelvic width at the level of the greater trochanters or the iliac crests is greater among females but, it is similar to that of men between the anterior superior iliac spines (Williams et al., 1987). Most important clinically is how these dimensional relationships may contribute to increased injury risk.

Women seem to have an increased incidence of patellofemoral problems, particularly with a wider pelvis at the level 59
of the anterior superior iliac spines. Then there is a greater angulation of the femur relative to the knee joint (the so-called Q angle), seen visually as an appearance of being knock-kneed (genu valgum). This is more evident in women than men because women also tend to have shorter femurs, which results in a narrower angle between the neck of the femur (where it attaches to the pelvis) and its shaft. As this angle gets smaller the shaft is directed more toward the midline, bringing the knees closer together. This arrangement makes it difficult to achieve an even balance of pull between the vastus medialis and vastus lateralis. In turn, this predisposes the patella to track with more pressure on one side of its articular surface than the other.

There is little doubt that running is a sport having associated with it a fairly high incidence of injury. For both men and women, a large proportion of injuries are the result of overuse due to a combination of training errors and the reality that such athletes are extremely high-achievers, willing to train as much as necessary to achieve excellence. Thus, a good coach has the responsibility for keeping training loads within acceptable limits as well as providing a favourable training plan for improvement. A common training error is to use needlessly excessive training volumes for improvement of aerobic power. Every foot-strike has an impact force ranging from 3 to 8 times body weight, depending upon speed and uphill or downhill running. A woman running 5 miles (8 km) at 6:10 per mile pace (3:30/km), taking steps that average 55 inches (140 cm) in length, will experience about 2,875 landings per foot (Figure 1). Even with excellent biomechanical symmetry and no anatomic imbalances, a training regimen of 80 miles/wk (129 km/wk), or about 46,000 landings per foot, carried out on concrete or asphalt roadways which have cambered surfaces, with excessively worn shoes - is an enormous chronic stress. Many top-level athletes cover far more distance than this each week. As aerobic fitness steadily improves, such continued high weekly training distances at moderate paces may not be justified, if further VO₂ max gains are outweighed by an exponentially rising injury risk due to fatigue from the effects of chronic impact stress. Reduction in training volume and substitution of higher quality training may be preferable.

Bone has a remarkable ability to engage in ongoing repair as well as deposit additional calcification where stress is greatest, but fatiguing muscles become less able to help the bones and tendons to absorb impact stresses. Tendons have an extremely limited blood and lymphatic circulation and thus are poorly equipped to increase their metabolic response to greatly increased stress loads as can result from rapid increases in training volume or intensity. Thus, it is not surprising that most of the problems causing runners to stop training represent either tendonitis or bone calcification. The idea has often been suggested that self-selection for sport preference may result in a particular body type being better suited for adapting well to the training challenge of distance running. Thus, for distance runners, the body type which is least prone to injury, or best able to adapt to high volume training, ought to be most likely found in those achieving competitive excellence.

The odds are that front-of-the-pack runners - men as well as women - when compared to those farther behind, have several genetic predispositions on their side:
1) longer legs in relation to body length,
2) shorter (and often narrower) torso, and
3) more inherent hamstring looseness.

With a smaller torso, more of the total body weight will be contributed by the lower limbs, and thus a greater percent of the total body weight contributes directly to locomotion. Greater hamstring looseness ensures a longer push-off and greater forward swing. When coupled to a tendency toward longer legs among elite level runners,
both features make a longer stride easier to achieve.

A narrow pelvis should be an advantage to distance runners. By minimizing out-of-plane rotation, less lateral movement is required. This conserves energy and permits the legs to track a straighter line during running. Our studies involving anatomic measurements of various structural reference points suggest that elite male and female distance runners both tend to have a narrower pelvis than age and height matched sedentary controls. This is also suggested by structural measurements made in similar groups of elite distance runners (Pollock et al., 1977; Williams et al., 1987).

Training concepts using physiological principles

A distance runner with the best combination of 1) a high VO₂ max (i.e., enormous aerobic power), 2) excellent running economy, 3) low blood lactate level at any given submaximal pace, and 4) a high blood lactate level at the maximum tolerable workload stands the greatest chance of being competitively successful in a wide range of distance running events. How does an athlete manage to develop such talents optimally? Very simply, an athlete must develop a good base of both aerobic and anaerobic fitness, and then attempt to improve these systems using the well-known principle of overloading by progressively increasing the intensity of training.

Effective training consists of a periodic cycling of workloads so as to provide both breakdown and recovery. With time, increasing tolerance to greater volume and intensity will become manageable without undue fatigue or injury. In turn, this increases the ability to sustain the fastest possible pace for the longest possible time period, with the added ability to insert tactical manoeuvres during a race as appropriate to gain a competitive edge.

The terminology used for describing training sessions that involve running is incredibly simple. All such training sessions consist of a given distance run (the interval), done a specified number of times (called repetitions), and at a specific pace (or tempo). If there is more than one repetition, then an optimum time period for recovery must be provided between each. Such sessions can range from very simple to quite complex. A simple session might be a morning run of 5 mi (8 km) done at an easy tempo (60% of VO₂ max pace), followed by stretching exercises. A more complex session might include 2 sets of 200m intervals, with 4 repetitions in each set, where the tempo is 30 sec/200m, the recovery time between intervals is 2.5 minutes, and the recovery time between sets is 3.5 min. Unfortunately, an enormous variety of jargonized phrases have proliferated throughout the world to describe training sessions. Terms such as pyramids, cruise intervals, breakdowns, ladders, and far too many more are understood only by those who coin them, leaving those attending coaching clinics with little knowledge of what may be described. The principles of training an athlete are universal; so should be the language.

The principles underlying design of year-long training plans specific for all running events (periodization) were outlined clearly in a previous issue of NSA (Bompa, 1988). Each training assignment that includes running will fit within 4 zones of workload intensity ranges, illustrated in Figure 2 (on the following page). These training zones are named for the predominant physiological benefit resulting with a manageable session in each. The discussion below describes the kinds of training appropriate to each zone, and the kinds of adaptations that result. There are 2 goals. One is to improve oxygen transport and utilization, thereby minimizing the contribution of anaerobic metabolism to meet energy requirements (seen as low blood lactate levels) until workloads become quite intense. The other is to improve the body’s buffering capacity to compensate
for lactate accumulation when it does occur during intense training and competition.

Using the data depicted in Figure 2 as an example, we have evaluated the performance abilities of a very talented female distance runner and have identified her VO₂ max as 70 ml/kg/min. By measuring her oxygen consumption at several submaximal speeds, we can estimate that her pace at a work intensity of 100% VO₂ max is 69 sec/400m (4:35/mile; 2:51/km). If laboratory evaluation is not available for such precise measurements, coaches can use another method to estimate 100% VO₂ max pace. Recalling that a work intensity of 100% VO₂ max can be maintained for about 10 to 12 minutes, this athlete could run an appropriate time-trial on the track. Using real data from this athlete, under ideal conditions, she ran a 4,000m time trial in 11:45, which represents a slightly slower pace of 71 sec/400m (4:44/mile; 2:56/km).

We also determined in the laboratory that her anaerobic threshold occurred at a higher-than-average 89% of her VO₂ max pace. This equals 5:05/mile, or 3:10/km using treadmill calculations (5:33/mile or 3:27/km using extrapolation from time trial data). The anaerobic threshold is more difficult to quantify using track-oriented time trials. A common preference among coaches of talented female distance runners is to assume a threshold of 80% VO₂ max, calculate the pace equivalent, and then have the athlete do an anaerobic conditioning session at this pace (see below). If the session is too easy, the pace can be quickened appropriately.

At this point, knowing nothing else about this athlete, we would not know whether she is a long or middle distance specialist. Table 4 illustrates comparable race performance times that might equate to her 4,000m time trial, and assuming that she would race a marathon at about 2% to

Figure 2 - Four training zones identifiable during treadmill stress testing of an athlete. Energy provisions (aerobic and anaerobic) are graphed against increasing exercise intensity (here, steadily increasing pace on a level surface). Starting at 7:30/mile pace (4:40/km) (P), the sudden departure from rest provides a temporary oxygen demand that exceeds uptake, with anaerobic metabolism coupling with aerobic to satisfy requirements until Q, when increased cardiovascular perfusion of working muscles permitted an aerobic steady state. This state continued until R, where aerobic demands again could no longer be managed aerobically. The steadily increasing anaerobic contribution, starting from this threshold work level, becomes a primary limiting factor for increased work, along with peaking of aerobic capabilities (S). Voluntary exhaustion at T stopped the test, with peak blood lactic acid levels occurring about 5 minutes later. (Adapted from Martin, D.E. & Coe, P., "Training Distance Runners", Human Kinetics Publishers: Champaign, Ill., USA, 1990, with permission.)
4% slower than anaerobic threshold pace. There is, of course, a danger in constructing such tables because of the erroneous (but often suggested) conclusion that any athlete with a VO\textsubscript{2} max of 70 ml/kg/min is capable of achieving all of the indicated performances regardless of training emphasis. Marathon training is, of course, very different from middle distance training, and as well, the racing skills are also not the same.

**Aerobic conditioning**

This represents the bulk of a distance runner’s training. The mainstay of such a programme is large volumes of over-distance running, at between 55% and 75% of VO\textsubscript{2} max pace. The purpose of longer distance, slower paced running is to improve oxidative metabolic capabilities in both cardiac and skeletal muscle, as well as joint and tendon strength. Increases occur in the quantity of stored fuels (carbohydrates and fatty acids) in working skeletal muscle (particularly the slow-twitch fibres). An increasing plasma volume and capillary density in working muscles will improve tissue perfusion.

Shorter distance runs can range from 8 to 15 km, depending upon event speciality, and longer runs might range from 10 to 35 km. Running at less than 55% VO\textsubscript{2} max brings little measurable aerobic improvement, and merely adds to impact stress. Running too fast, e.g., more than 75% of VO\textsubscript{2} max pace, brings excessive glycolytic activity, with the possibility of lactate accumulation, which should be reserved for training sessions in the other 3 zones. Using the pace suggestions here and application from treadmill data, 55% of VO\textsubscript{2} max pace for our athlete represents 6:39/mile (4:08/km), whereas 75% represents 5:44/mile (3:34/km). Using such a pace range, particularly within the slower half, a conversation should be maintainable rather easily. For this reason, such runs are often done together with training partners, providing camaraderie and adding enjoyment to sessions that may last 2 hours or more. Determination of paces from extrapolation to this athlete’s 4,000m time trial would produce slightly slower training paces. By assigning a training session within both pace ranges, it then becomes possible to determine how this athlete compares to the two types of test running conditions.

**Anaerobic conditioning**

The best method for introducing an anaerobic conditioning stimulus is to include training sessions at a comfortably hard
pace (marginally too fast for maintaining conversation), for a moderate time period (no more than about 15 to 20 minutes). Training pace should range from just below marathon race pace to the vicinity of anaerobic threshold pace, or from about 85% to 89% of VO₂ max pace in our example. For her, this would be a pace between 5:05/mile (3:10/km) and 5:16/mile (3:16/km). An example of a training session might include a few kilometres of warm-up, then a 5,000m run in 16:03, and a few kilometres of cool-down. Such sessions are often referred to as ‘tempo runs’, but since all sessions of running are done at a given tempo, restriction of usage of the phrase ‘tempo runs’ to solely anaerobic conditioning runs is clearly inappropriate.

Although slow-twitch fibre stimulation is emphasized with such training, many fast-twitch fibres are also activated. The increased metabolic rate in all of these fibres stimulates glycolysis, but there is minimum lactate accumulation. Thus the training load is rather easily tolerated. The slow-twitch fibres have a form of lactic dehydrogenase which minimizes lactate formation, and the small amount of lactate produced by the fast-twitch fibres can be used as fuel by nearby inactive muscle fibres or by other tissues. The additional oxidative stimulus also contributes to a VO₂ max improvement. The relatively high submaximal load, constant for a somewhat prolonged time period, improves cardiac function by stimulating an increase in ventricular chamber size, thereby increasing stroke volume.

**Aerobic capacity training**

Once a sizable foundation of aerobic development has occurred, the best method for promoting a further increase in VO₂ max is to include a weekly session of quicker tempo intervals of running - at between 90% and 100% of VO₂ max pace, determined periodically by laboratory testing or track time-trial. Because this is fast running, each interval cannot be too long, otherwise the increasing acid accumulation makes the session too unpleasant. The first few minutes of each run will be largely anaerobic before aerobic metabolism begins to predominate and aerobic working capacity is reached. Beyond about 5 or 6 minutes of running time, the steadily accumulating metabolic acid adds measurably to the stress of continued pace maintenance for a training session.

Depending upon the event orientation of the athlete (middle distance versus long distance), the acceptable running interval time will vary from about 6 to 9 minutes. Recovery will be quite rapid, because blood lactate levels will not become excessive, and it is appropriate to make each recovery period similar to that of the run. The typical distance covered during aerobic capacity training can range from 1,000 through 3,000m, depending upon athlete’s event specialty. The entire session should be limited to about 6,000m. Thus, a longer distance specialist might complete two 3,000m runs, while a middle distance athlete might find six 1,000m runs more appropriate.

Continuing the example of our woman distance runner whose VO₂ max is at 70 ml/kg/min (69 sec/400m pace), a workload of 90% VO₂ max pace is 5:03/mi (3:08/km; 76 sec/400m). In our coaching of distance runners, we find it quite effective to cycle aerobic capacity training around a 5 week block, with one session per week. As one example of such a cycle, we might use a sequence of 2 x 3,000m, 3 x 2,000m, 4 x 1,600m, 6 x 1,000m, and repeating the 2 x 3,000m session the fifth week. The longer runs will be performed at a slower pace than the shorter runs. As development continues during the training season, the running speed for each distance should quicken, but not faster than 100% VO₂ max pace. If physiological adaptation to such training has occurred, the fifth week session will be more easily tolerable than that same session done the first week. As improvement occurs, either the recovery between runs can be reduced, or the distance over which the pace...
is maintained can be increased. It is not appropriate to quicken the pace beyond 100% VO$_2$ max intensity, since this merely increases the anaerobic component, and that is not the purpose of aerobic capacity training.

The physiological adaptations resulting from this kind of stimulation include 1) an increase in glycolytic enzymes in working muscles, 2) activation of fast-twitch muscle fibres in addition to those stimulated at lower work loads, and 3) a small increase in blood buffering capacity. Both slow-twitch and fast-twitch muscle fibres are active during such training. Near-maximum-rate aerobic metabolism is emphasized in both, with anaerobic metabolism providing the additional energy requirements for pace maintenance (fast-twitch fibres will contribute especially in this aspect). The combination of work intensity and duration keeps blood lactate at a tolerable level.

**Anaerobic capacity training**

Particularly for athletes specializing in events where it is essential to change pace quickly and effectively, or sustain long, fast end-of-race maximum-intensity running, anaerobic tolerance must be well developed. The middle distance events (800m, 1,500m, and 3,000m - both flat and steeplechase) are all contested at paces faster than 100% VO$_2$ max pace, and thus tolerance to steadily accumulating blood and working muscle tissue lactate levels is mandatory. The longer distance events, particularly 5,000m and 10,000m, will also be raced best by those who can maintain the fastest possible pace with the least lactate accumulation. An inherited sizable fast-twitch muscle cell endowment, with its specialization for anaerobic metabolism and tolerance, would thus be of great value to a middle distance athlete. If that athlete also attempts to improve aerobic capabilities, the best possible preparation results. Similarly, an inherited greater slow-twitch muscle cell endowment, if well developed by training designed to raise VO$_2$ max, would be of great value to a long distance runner, supplemented with development of as much anaerobic potential as possible. For these reasons, we tend to find high VO$_2$ max values among both middle and long distance runners, but the highest maximum blood lactate values among the middle distance runners. This is true both for males and females.

Training sessions that increase anaerobic capacity are done at a very fast tempo i.e. quicker than 100% VO$_2$ max pace. The intervals run are fairly short, and the recovery period between each run must be adequate, which may require up to 5 times the running interval. Special emphasis should be given to maintaining excellent form throughout each run, despite having to cope with the effects of increasing fatigue. The longer the running interval, the less is the maintainable intensity of effort, and here maximal or near-maximal intensity effort is important. Blood lactate levels continue to rise during the recovery period, and remain high as the next interval begins despite the relatively long recovery period. This prolonged high blood lactate level is helpful for improving the body’s buffering capacity. As can be imagined, slow- and fast-twitch muscle fibres are both active, with increased neuromuscular recruitment to bring still more muscle fibres into action. For this reason, a strength building stimulus occurs in these muscle fibres. Runners perceive this strengthening especially at submaximal paces, which now seem much easier. There has been the suggestion that anaerobic overload training improves running economy (Daniels, 1989), but the same author states elsewhere that ‘training seems to play a minimal, if any, role in narrowing the between-individual variations that exist’ in running economy (Daniels et al., 1986). Thus, the specific kinds of training that may improve running economy have yet to be clearly identified.

The typical range for running intervals which best increases anaerobic capacity is
200m through 800m. Our experience suggests that a training session within this zone should not exceed about 2,400m. Again using our example of training sessions for a female distance runner whose VO₂ max pace is at 69 sec/400m, 105% of this pace is at 65.5 sec/400m or 33 sec/200m, while 110% of this pace is at 62 sec/400m, or 31 sec/200m. The longest distance at which the assigned pace can be maintained is selected as the ideal distance for development. Training adaptation results in tolerance to progressively longer distance at this same pace. A session of 10 x 200m @ 33 seconds with 2.5 minutes recovery between each run might be one example of a beginning session with this athlete. It may be convenient to divide the session into sets of interval runs, with more rest between sets of repetitions than between individual repetitions. Using the above example, one recommendation might be a set of 4, then 3, and again 3 x 200m, with 3.5 minutes rest between sets, 2.5 minutes between intervals within each set. As fitness improves, the quality of these sessions can be improved in any of three ways: 1) eliminating the additional recovery time between sets of intervals, 2) reducing the recovery time between intervals, and 3) lengthening the distance at the assigned pace.

Summary

Both male and female distance runners adapt to the challenge of serious aerobic and anaerobic training directed toward improving competitive performance capabilities. There are far more similarities than differences among the two sexes in their response to such training. The difference is more one of magnitude of adaptation than uniqueness. Although the best women typically race a little slower than the best men, this is not to be viewed as an inferiority of one sex (or superiority of the other) regarding their ability to respond to such training. Both sexes respond similarly, but differences in physical constitution account for the performance discrepancy. Highly trained female distance runners have more body fat than their highly trained male counterparts, which must be transported and is non-contributory to performance. Such women also have less skeletal muscle mass, in part due to shorter stature but also due to less circulating testosterone. This makes them less strong than men, and gives men an edge in shorter-distance running events which have a greater strength orientation. Women also have less total haemoglobin and total blood volume, and a smaller heart. These combine to make the highest VO₂ max achievable by females smaller than that of men. In the longer distance events, where aerobic performance assumes a greater role in determining maximum sustainable pace, elite level, highly trained men can race at a faster pace than highly fit elite level women.

Women can use the same training concepts as men, and can expect similar kinds of performance improvement. The majority of training should be directed toward raising aerobic power as much as possible, thereby minimizing lactate accumulation as a result of anaerobic metabolism adding significantly to provide required energy. Once a high aerobic power is achieved, then this ought to be maintained using the least amount of the most specific additional aerobic training. This is best achieved using less frequent, but longer distance aerobic runs. The decreased total impact stress then permits the inclusion of specific training directed at improvement of anaerobic capacity. Depending upon competitive event specialty, more or less anaerobic conditioning and anaerobic capacity training will be appropriate. Again, the essence is to provide a training stimulus sufficient to yield optimum improvement with minimum risk of injury or overtraining. If any question exists as to whether a particular training stimulus is appropriate, it is preferable to err on the side of under-preparation, since that minimizes the onset of excessive loading. Throughout a training
year, it is entirely appropriate to include training sessions within each of the 4 physiological zones described, realizing that the tempo of each will be appropriately slower earlier in the season. This ensures a continual gradual developmental stimulus to all skeletal muscle fibres, minimizing the risk of over-stressing particular fibre types, if they are allowed to detrain from long periods of relatively little use.

Increasing opportunities for both sexes to improve their knowledge of how to train and compete in high-level sport competitions, bode well for continuing improvements in world-best or world record performances. While the depth of top level performances among the women is not as great as for the men, this should change markedly in the coming decade as more nations include developmental sport programmes for women and as women in larger numbers improve their knowledge of how to develop fitness and competitive expertise.

REFERENCES


