Appendix A

Running is primarily a conditioning sport. It is not a skill sport as is basketball or handball or, to a certain extent, swimming where technique is of primary importance. Most of us are able to run without special training, and for all practical purposes, all of us who do run, do so with nearly equal efficiency regardless of how “inefficient we may appear or feel. Granted, small differences in style, technique or “efficiency might spell the difference between two otherwise equal competitors, but the fact remains that we all expend about the same relative energy to run at any given velocity which is within our aerobic capacity (a term which will be described later). Quite different is the case of swimming or cross-country skiing, where technique greatly affects the effort we put into any particular speed of movement. For example, a world-class swimmer could easily cruise through an 8:00 400-meter swim with relative ease. A poor swimmer on the other hand, might work at maximum effort just to complete the 400, maybe not even beating the 8:00 barrier. Not only would the poorer swimmer’s total energy expenditure be greater, but so also would the energy cost per distance covered be greater.

In running this is not the case. A great runner can run an 8:00 mile very easily whereas a beginner or less-talented person might be working much harder to run that fast. However, the total energy expenditure for the mile run would be about the same for each runner; even the per-second oxygen consumption (a measure of energy expended) could be identical for both. The difference between the better runner and the not-so-good runner would be in the maximum rate of oxygen consumption which could be reached by each; the better athlete would be able to go faster because of a better maximum rate of energy expenditure being available. What this boils down to is that there is quite a predictable relationship between running velocity and the energy demands of running (which can be measured and expressed in a volume of oxygen consumed per minute). A 4:00 miler and a 6:00 miler might run side by side at an 8:00 mile pace and both be consuming the same amount of oxygen per minute (relative to their individual body weights of course). The difference would be that the 6:00 miler would be working at a greater percentage of maximum than would be the 4:00 miler; this difference in maximum oxygen consumption or aerobic capacity (VO₂ max) is what makes the difference in their race ability. Figure 1 shows the relationship which exists between running velocity (expressed in meters per minute) and oxygen consumption (expressed in ml per kg body weight per minute).

In many sports, mainly skill or strength sports, body structure or anatomical design are very important, and it is easy to see that an Olympic gymnast would probably never become a world-class shot putter because of limited size. Similarly, few people would expect a 7-foot basketball player to ever become an Olympic gymnast or a winning jockey. Rules even provide for structural differences by designating weight classes in some combat sports such as boxing and wrestling. In this case we are admitting that genetic differences give some people an advantage over others, even if all are equally motivated and trained.

Not so easy to accept is the fact that all humans inherit a potential for performance in sports of a non-skill nature also. We all have a set of physiological features or attributes which determine our potential for performing such things as the 1-mile run or the marathon. Outwardly two people may look exactly alike, but may be as different in endurance potential as are a 4-foot 10-inch person and 6-foot 8-inch person different in their ability to perform gymnastics or throw the discus.

If we accept the fact that each person has a maximum potential for endurance running and if we accept the fact that the energy demands of running are quite similar for all people (as shown in Figure 1), then the main physiological feature which separates one athlete from another in distance-running ability is the transportation and utilization of oxygen by the running muscles. This is, in fact, the case. As mentioned above, this attribute is referred to as aerobic capacity or maximum oxygen consumption (VO₂ max).
Of course, some people are more motivated than others and some reach more of their potential than others, but the fact remains that a potential closes exist and for each individual there also exists a describable and quite predictable relationship between running velocity and oxygen consumption. Over the years we have had the opportunity to measure both the oxygen demands of many runners during various velocities of running and the aerobic capacity of these runners. Using these two sets of values and knowing the best performances for the runners at different competitive distances has allowed us to accomplish two things. First, we have developed a regression equation relating VO2 with running velocity (see Figure 1), and second, we have defined a curve, and accompanying regression equation, which describes what percent of an individual’s aerobic capacity the individual
is capable of working at for how long (Figure 2). For example, a person runs at a velocity which demands about 100% aerobic capacity for about 8 - 10 minutes. This means that someone who races 1 mile in 9:00 is working at about 100% VO2 max for 1 mile. A better runner who is capable of a 9:00 2 mile is working at 100% VO2 max for 2 miles (but also for a period of 9 minutes). The relationship is time related, not distance related. Another way of looking at it is that two runners of different ability both can run as hard as they can for about 9 minutes; one might make 2 miles while the other can cover only 1 mile in the same time. Both are operating at 100% VO2 max.

With the two regression equations presented in Figures 1 and 2 and with the aid of the mathematical techniques described in Appendix B, the tables in this book have been produced. What these tables accomplish is to relate performances over various distances with a reference value, which is also a rough estimate of the VO2 max which would allow the related performances to be accomplished. It is not necessary to worry about comparing these VO2 values with those which might be measured in a laboratory test because differences in efficiency of oxygen utilization will cause discrepancies between the two values. The point is that if an individual’s VO2 max is under or over-estimated it doesn’t matter because that individual’s performance capabilities will still be related to each other accurately. In fact, the reference VO2 max can be used just as a number for reference purposes only, to compare values from one table to another.

There are several very useful purposes for these tables. One is to compare world records for relative merit. It should be kept in mind that these tables were generated without reference to records and the fact that world records, even by different people, relate to very similar reference values supports the physiological importance of VO2 max and the oxygen demands of running in endurance events. As an illustration, examine the various times which are related to a VO2 max reference of 80.5. We find the following: 3:49.9--mile, 8:11.5--2 mile, 45:26.7--10 mile, 3:33.0--1500, 7:35.0--3000, 13:33.5--5000, 27:32.5--10,000 and 2:06 :57.5--marathon. It is easy to see how very similar these performances are and how close to world records they all are. The 10 mile record should be better, as should the marathon, according to these comparisons, but it is easy to understand why they are not -- the 10 mile is a seldom run event and the

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\% = 0.8 + 0.1894393 \times \exp(-0.012778 \times T) + 0.2969556 \times \exp(-0.01932605 \times T)
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\% = \% VO2 max/100, T=estimated\ time-minutes
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marathon is not run on a smooth, flat course. Examination of the current world records shows the 3000, 5000 and 10,000 to be the best; the record times of 7:32.1, 13:08.4 and 27:22.5 all relate to a reference of 81.1 which is slightly better than the 80.9 \( VO_2 \) max which is related to the mile and 1500 world records of 3:49.0 and 3:32.1, respectively. The weakest distance record is the 1:31:31 30Km, but again, the reasons for this have been stated above. A glance at various women’s times shows some interesting findings. The women’s record 1500 is 3:56.0; the 3000 is 8:27.1. These relate to reference \( VO_2 \) values of 71.4 and 71.1, respectively, and are obviously nearly identical performances. However, the Women’s current marathon best is 2:27:33, a performance which is somewhat inferior to what might be expected based on the 1500 and 3000 records and their related \( VO_2 \) maxes. This implies several things: (1) The best women have not yet become very involved in marathoning because they are world-class in more attractive, somewhat less demanding, and more widely available distance events. Therefore, marathon running is left more open for women whose main interest is marathon running, which may not yet include very many of the best physiological specimens. (2) Women are not better distance runners as we sometimes hear. The women’s records for 1500 and 3000 are both about 11.5% slower than the corresponding men’s records for these events. In the marathon on the other hand the women’s record is over 14% slower than the men; the longer the distance, the greater the difference. However, (3) based on our earlier findings that at any submaximal running velocity, women demand the same oxygen consumption as do men, it can be predicted that women’s times in the marathon will come down to the low 2 hour-20s before a noticeable improvement takes place in men’s marathon times. A 2-hour 23 minute time would put the women at the same 11+% slower than the men. In the shorter distance events. (4) Of interest is that the \( VO_2 \) max reference differences between men’s and women’s world record 1500 and 3000 meters are about 10 ml/kg, a value which has been found to be just about the difference between the best men and best women endurance athletes when tested in the laboratory. (5) Women with high \( VO_2 \) reference values can expect to outperform other people who have lesser values, whether they are men or women, at any of the distances for which they choose to train. In other words, these tables do not discriminate in any way; they apply equally to all ages and either sex. It is important to understand that during growth the relationship between \( VO_2 \) and running velocity is constantly changing. This means that a youngster 12 years old who runs a 5:00 mile is also probably capable of a 10:43 2 mile if training is adequate for the longer race. However, the reference \( VO_2 \) is quite probably an underestimation of the individual’s true \( VO_2 \) max. This is because until growth ends the energy demands of running are gradually getting less and less; an 8-year old requires relatively more energy to run an 8:00 mile pace than does a 12-year old. The 12-year old would probably use more oxygen per kilogram body weight to run at that pace than would an adult, however. In fact, this improvement in “efficiency” with growth accounts for a great deal of the improvement in race times as youngsters age. Upon examination of your own best times for various distances listed in these tables you may find all your performances to be quite similar. If, on the other hand, you find that the longer distances relate to lower reference \( VO_2 \) values you are either better suited, genetically, for shorter distances or your training has been geared for better performances at the shorter distances (or you may just have a better attitude toward running the shorter races). Chances are, however, that by concentrating your training more for the longer events your longer distance times will come in line with what the tables indicate they should be. Of course, the opposite can also be true—your longer distance times may be relatively better than you can race for shorter runs. This, again, reflects either a better genetic endowment for longer races, more interest in longer races or training geared for longer races. Naturally, we are not all suited for equal performances at all distances; the world record holder at 800 meters may never be capable of equalling the marathon world record, regardless of the type of training engaged in, and visa versa, but the average runner will run quite predictably at whatever distance he or she decides to concentrate on.

The potential of these performance tables to predict race times brings up another use for the tables, handicapping. You don’t have to have a time for every runner entered in a race you plan, to handicap. If you have one or more times at any distance you can do a respectable job of predicting that individual’s performance for the race about to be run. If you plan to have a handicap 10,000, use times for 3000 or 15km or 6 miles, or whatever is available. The closer to the distance to be run, the better, but a good effort at 15km would be a better predictor than a poor one at 3000m. The best predicted reference \( VO_2 \) should
be the one used in each case, unless of course the course is known to be inaccurately measured. It is always fun to try to beat the time your best reference $V_02$ predicts for you. Using best-predicted reference $V_02$ values for grouping runners in large fields is also a possibility. For example, let’s say you are planning a 15km race and the course won’t allow a real good start for everyone, so you decide to put the better runners on the front line and slower ones behind. The trouble is you probably don’t have 15km times on more than a handful of the entrants. The solution is simple, just place the people with the best reference $V_02$s (based on any distance race run) up front and work back. You could even group athletes by $V_02$, all over 70 in one group, the 60s in the next group, etc. The problem with this is that the pack stays pretty tight, but at least it gives the runners of equal ability a chance to be together, as it should be.

A final use of the tables that we will deal with here relates to the matter of improving performance. Most research indicates that $V_02$ max (expressed in absolute values—either liters per minute or milliliters per minute) can be improved by about 20% with proper training. Moderate-to-easy training (as little as 3 to 4 miles per day, 5 days per week) will elicit about a 10% improvement, so a person who has been training 15 to 20 miles per week can still look forward to an additional 10% improvement in absolute $V_02$ max.

**Absolute $V_02$ max** is a person’s relative $V_02$ max (expressed in ml per Kg body weight per minute) multiplied by the person’s weight (expressed in kilograms). The reference $V_02$s in the tables express aerobic capacity in relative terms—ml/Kg per minute. To find your absolute $V_02$ max look up your best performance (the one which relates to the highest reference $V_02$) and multiply that by your body weight in kilograms (weight in pounds multiplied by .454). For example, let’s say you weigh 125 pounds (125 x .454 = 56.75 Kg) and your best performance is a 38:46 10,000m. This time corresponds to a reference $V_02$ (relative) of 53.9 ml/Kg per min. Your absolute $V_02$ max would then be 53.9 ml/Kg per min X 56.75 Kg = 3059 ml per minute. If you have been a moderate trainer then we assume you can improve your $V_02$ max (absolute) another 10%, to 3365 ml/min (1.10 X 3059). If you do in fact realize that much improvement and your weight stays the same (56.75 Kg), then your improved relative $V_02$ max would be 3365/56.75 = 59.3 al/Kg per min. If you have been a moderate trainer then we assume you can improve your $V_02$ max (absolute) another 10%, to 3365 ml/min (1.10 X 3059). If you do in fact realize that much improvement and your weight stays the same (56.75 Kg), then your improved relative $V_02$ max would be 3365/56.75 = 59.3 al/Kg per min. If you have been a moderate trainer then we assume you can improve your $V_02$ max (absolute) another 10%, to 3365 ml/min (1.10 X 3059). This improved reference $V_02$ (59.3) relates to a 10,000 of 35:43, a 3 minute improvement. Now let’s say you are also a little over weight and in addition to improving your absolute $V_02$ max by 10% with training, you also lose 8 pounds of fat. Your weight is now 125 - 8 = 117 pounds, or 53.12kg. Your relative $V_02$ max is flow 3365 al/min divided by 53.12 Kg or 63.4 ml/Kg per min. This is an 18% improvement over your original 53.9. A reference $V_02$ of 63.4 relates to a 33:43.8 10,000, another 2 minutes faster and a full 5 minutes better than your original time of 38:46. All this is due to a 10% improvement in absolute $V_02$ max. The importance of eliminating excess body fat becomes obvious, but a person should be careful not to lose so much weight that a loss in muscle also occurs. This would lead to a decrease in absolute $V_02$ max also, which in effect is detraining aerobic capacity.

It is hoped that this description of how performance relates to $V_02$ and how performance is improved, as well as a presentation of the tables themselves will prove useful to you in analyzing your limitations and potentials.

Appendix B
Procedure used in arriving at performance times based on oxygen demands of running and maximum aerobic capacity ($V_02$ max).

The idea behind the prediction process is as follows. An individual has, at a given time, an aerobic capacity which peaks at some maximum ($V_02$ max). Because the individual doesn’t perform at exactly 100% of that maximum value except in a few specialized cases, knowledge of the effects of anaerobic capacity, as well as fatigue on the percent of aerobic work capacity used (%$V_02$ max), can be applied to the situation in order that a reasonable estimate of the individual’s maximum can be determined for any situation.

It’s well known that the anaerobic contribution to work is fairly limited, but it does allow an individual to run at a speed in excess of the speed at which he or she could run using only aerobic mechanisms.
The equation for %V0\textsubscript{2} max, which is used to determine the percentage of maximum aerobic work capacity used, is reflective of the short term anaerobic effects as well as the longer term fatigue on the aerobic component. This %V0\textsubscript{2} max equation is completely dependent upon time, not distance run, and it reflects that the longer you run, the lower the %V0\textsubscript{2} max you can maintain. Obviously, the % V0\textsubscript{2} max/time relationship is an integral part of the equations describing the performance tables developed herein.

The second component in the development of the performance tables regards the oxygen demands of running at any given velocity or speed. The relationship (equation) of speed and rate of oxygen consumption is used to determine the speed at which a distance can be run for the oxygen demanded. Then using the computed rate of speed the time required to run the distance is determined. Recall that the % V0\textsubscript{2} max is also dependent upon time (the longer the time, the lower the % of V0\textsubscript{2} max you can use) so time needs to be inserted into the %V0\textsubscript{2} max equation to compute an adjusted oxygen consumption rate, which is in turn used to compute a new performance level (speed). This new speed again modifies the time required to run the distance. The new time further affects the %V0\textsubscript{2} max/time relationship and so on. This is an example of what is referred to as a non-linear relationship and the solution techniques for such problems are well known. The simplest way to solve non-linear equations is to “guess” an answer, and insert the “guess” in the equations to compute a new answer. Based on the nature of the resulting new answer, a modified “guess” can be formulated and inserted in the equations. The process of formulating a new “guess” from the previous answer is continued until the “guess” used equals the answer obtained from the equations. Computers make such tedious tasks inconsequential so are frequently used for this purpose. However, it may be required that several iterations through the equations are necessary for the answer and “guess” to converge on a single value. Potentially, this uses a lot of computer time. Another scheme, called the Newton-Raphson process, is much more rapidly convergent than the above method, and involves the time rate of changes (calculus derivatives) of the equations. With a reasonable guess (within ± 5 percent), Newton-Raphson will converge with one pass through the equations so the computing process is more efficient.

In generating the performance tables contained herein, each time for distance entry was computed by using as a “guess” input, the answer (time) for that distance from the previous VDOT (V0\textsubscript{2} max) table value. For example, in computing the estimate for the mile for a VDOT of 60.5, the “guess” used was the mile time for VDOT = 60.4, or 4:55.4. This time, 4:55.4, is input to the Newton—Raphson scheme with an answer computed corresponding to a VDOT of 60.5 and the result is 4:55.0. Were this output time of 4:55.0 reinserted in the equations keeping the VDOT value of 60.5 the same, the same answer, 4:55.0, would result meaning the solution has converged. But if a VDOT value of 60.6 were used, an output time reflective of that oxygen consumption would result. Incidentally, the “guess” used for the mile entry is not used for the two mile or other distance “guesses”. All distances are kept separate, thus rapid solution convergence is assured.

By making allowances for the short term effects of anaerobic power and fatigue on the aerobic capacity, representative predictions of performances at various distances can be made. This is because V0\textsubscript{2} max is used as a reference and calculus techniques utilized to accommodate the off maximal situations. Hence, a relatively good idea of an individual’s VDOT and his or her potential to run six miles (or whatever distance) can be determined from a three mile time (or any other distance time for that matter), assuming the conditions don’t drastically change from one situation to the next, and assuming training is adequate for both distances.