An Analytical Study of World and Olympic Racing Records

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SINCE earliest times men have competed with one another in athletic contests. These contests reached their culmination with the Olympic Games in ancient Greece and with the revived Olympic Games in the modern world. However, it was not until very recent times, with the development of modern horological equipment, that accurate measurements of the various running, walking, and swimming events could be made. During the past seventy-five years a large number of records have been established for athletes running, walking, and swimming a wide variety of distances. Moreover, records have also been tabulated for horseracing and for long distance automobile racing. Because many of these records represent the best efforts of trained athletes and animals, it seemed of interest to analyze the records to determine which could be improved in relation to the others and to attempt to point out any physiological relationships that might be involved.

Several previous attempts have been made to correlate the various types of racing records. In 1916 Meade (*1*) showed that a smooth curve was obtained when the rates (expressed in sec/mi) for various running events were plotted against the distance. The rates for distances greater than 10 mi were somewhat erratic at that time and did not fit the curve very well. Meade correctly assumed that these rates did not represent the best achievements of trained athletes; however, he made no attempt to derive a mathematical relationship for the records.

An attempt in this direction, that is, establishing such a mathematical relationship, was made by A. E. Kennelly (*2*) of Harvard. After a study of race horses and human athletes Kennelly stated that the relationship between the distance d and the time t for the various types of racing is

$$\log t \cong 9/8 \log d - \text{constant}. \qquad (1)$$

In 1934 Meade (*3*), commenting on his plot of rate versus distance for running events stated: "The smoothness of the curve is striking, but it is not a logarithmic curve, . . . it does not closely follow the formula given by Professor Kennelly."

Alfred W. Francis (*4*) plotted the rates for various running races against the logarithm of the distance and then tried to fit the resulting curve to the equation for a hyperbola. Unfortunately the hyperbolic equation did not give a good fit for either the short distances (below 400 m) or for the longer distances (above 19,000 m). Actually the fit was not too good even in the range from 400 to 19,000 m. The horizontal asymptote of the hyperbola indicated a "dog trot" velocity of 3.2 m/sec for a "perfect runner." This was supposed to be the speed the runner could maintain indefinitely if sleep and nourishment were not necessary.

In a series of papers, A. V. Hill (*5–7*) of the University of London presented a scientific study of athletes. He pointed out that the capacity of the body for exercise depended upon two factors: (1) the maximum rate of oxygen intake during exertion, which is determined by the efficiency of the heart and lungs (this amounts to about 4 lit/min); and (2) the maximum oxygen debt the body can tolerate (this is about 15 lit). Hill made no attempt to derive any mathematical relationships correlating the various racing records.

None of the authors cited nor any others (*8*) who have discussed athletic records seem to have succeeded in deriving a general mathematical relationship correlating the various types of racing. The equations of Kennelly and Francis do not give a completely satisfactory picture of even one type. It will be shown here that a simple mathematical relationship does exist which describes a wide variety of types of racing and that certain quantitative comparisons can be made among them. The following types will be discussed explicitly: running, walking, swimming, bicycle racing, horseracing, and automobile racing. In the case of the running, walking, and swimming events, both world and Olympic records will be discussed. As all the records are printed in the World Almanac (*9*) they will not be tabulated here.

The Log-Log Relationship. Figures 1 to 5 show the semilinear plots that are obtained when the logarithm of the distance is plotted against the logarithm of the time for the various types of racing. It should be noted that the plots for both the running and the swimming events show two distinct slopes. The significance of the points of inflection will be discussed later. Hence the simple relationship between distance and time for the various types of racing is

$$\log d = k \log t + \log a, \qquad (2)$$

where $\log a$ is the y-intercept of the log-log plot, a being a units conversion factor. The slopes k are characteristic of the particular type of racing and portion of the line and have values between about 0.8 and 1.0.

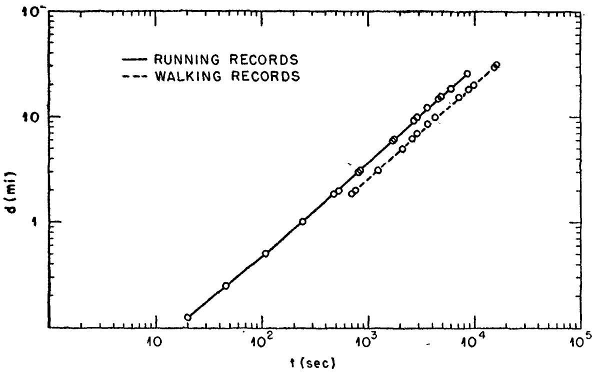

FIG. 1. World running and walking records.

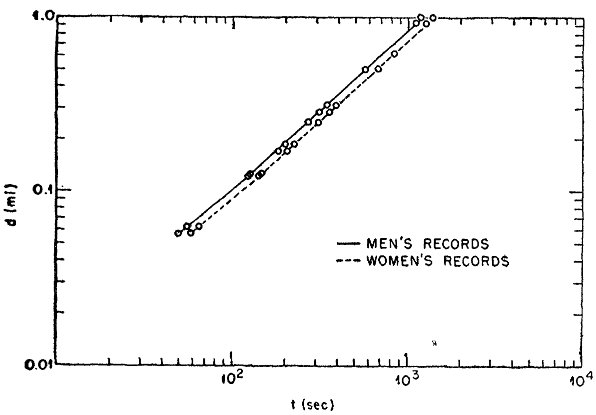

FIG. 2. World swimming records.

Actually a slope of 1.0 is never realized because it would mean that the initial rate in the racing event was being maintained. Since the rates decrease with distance because of physical exhaustion, the slope of the distance-versus-time plot must be less than unity.

***Analysis of Racing Records* (*10*). The log-log plot, while it shows the relationship between distance and time for the various types of racing, is not a sensitive enough plot to permit a careful analysis of the records. For this purpose rate curves must be plotted. Figures 6 to 9 show the curves that are obtained when the average rate $\bar{r}$ for each distance is plotted against the distance for the running, walking, and swimming records. Included in Figs. 6 to 9 are both world and Olympic records. A smooth curve has been drawn through the highest rates, as these rates presumably measure the maximum efforts of the most highly trained athletes under the most nearly ideal conditions. If several records are recorded for a given distance on tracks of different lengths, only the smallest time is used in the plot. This is justified because shorter courses with more turns represent a physical obstacle to an athlete's maximum effort. All points that fall below the curve represent records that can be broken substantially, as the rates involved are lower than those recorded for the best efforts. To calculate the time in which any event that falls below the curve** should be done in order to bring it onto the curve, it is merely necessary to divide the distance by the rate on the curve. The difference in the two times is the amount by which the record can be broken to make it consistent with the "best efforts" to date.

Let us consider in more detail the running records. When the average rate for a given distance is plotted against the time on a logarithmic scale the curve shown in Fig. 10 is obtained. The logarithmic scale is used merely to shorten the time axis. From this curve several interesting conclusions can be drawn. The maximum in the curve occurs at 15.0 sec with a rate of

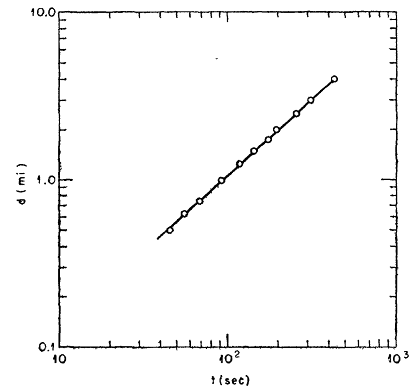

FIG. 3. Horseracing records (running).

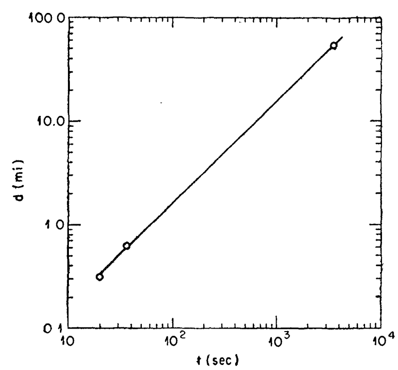

FIG. 4. Bicycle racing (flying start, motor paced).

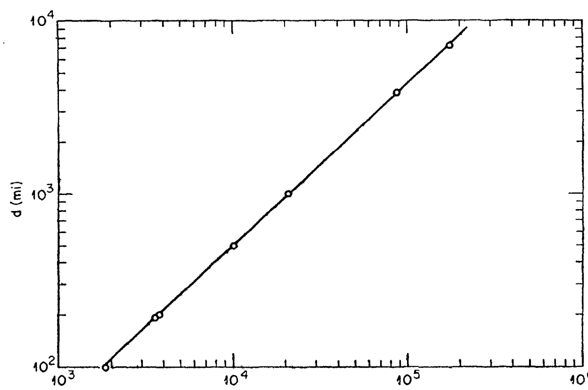

FIG. 5. World auto racing records (starting start).

0.00620 mi/sec. This corresponds to a distance of about 150 m, which is the optimum distance to run from a stationary start in order to achieve the maximum possible average rate. This agrees with the distance of about 0.1 mi which is indicated on Fig. 7. Because it represents the distance over which a runner could achieve his maximum possible rate, 150 m would seem a more logical distance to run in track meets than either 100 or 200 m.

Up to 150 m the curve has a positive slope, indicating the strong influence of the start on the rate. After 150 m the curve has a negative slope which indicates that the start exerts a smaller and smaller influence on the average rate and also that the point where maximum exertion can be made has been passed.

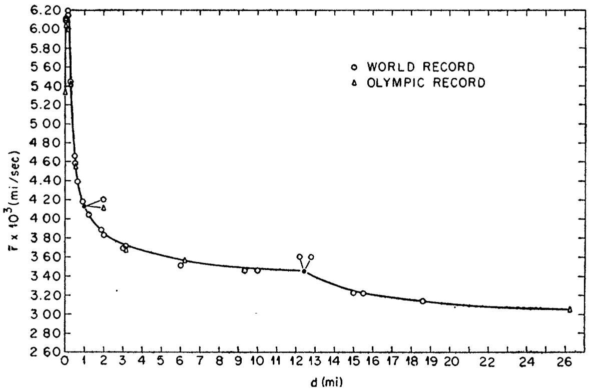

FIG. 6. Rate curve of world and Olympic running records.

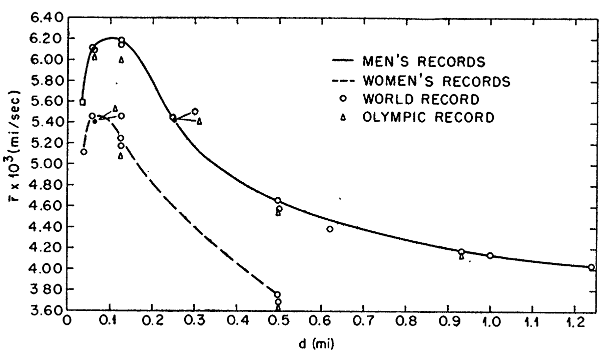

FIG. 7. Rate curves of world and Olympic running records.

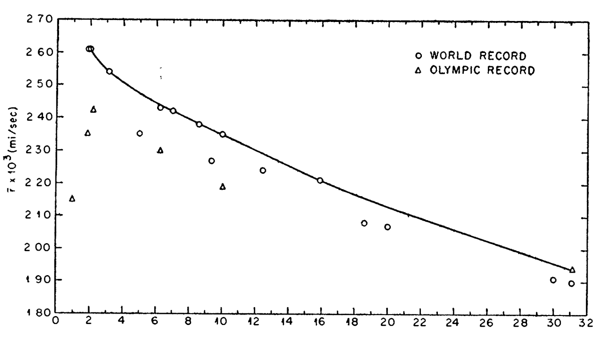

FIG. 8. Rate curve of world and Olympic walking record.

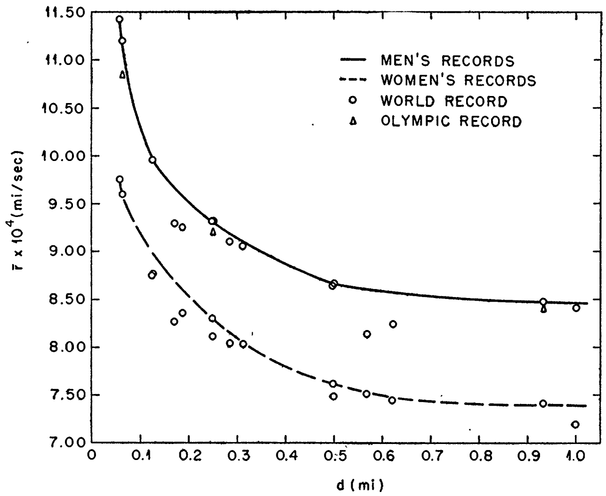

FIG. 9. Rate curve of world and Olympic swimming records.

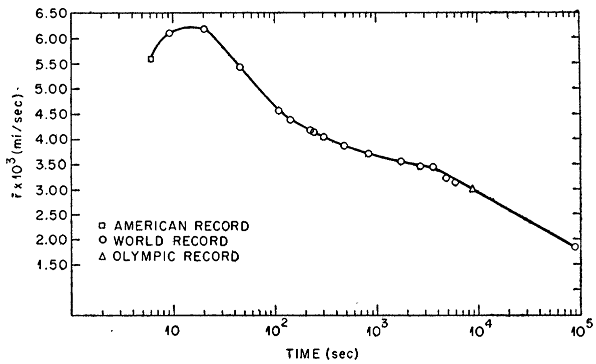

FIG. 10. Rate versus time curve for running records.

At a rate of about 0.00450 mi/sec and time of 140 sec (corresponding to a distance of nearly 1000 m) the average rates begin to decrease less sharply with time, while at the rate of 0.00345 mi/sec and time of 3600 sec (corresponding to a distance of about 12.5 mi) the rates begin to fall more sharply.

The distance 1000 m to 12.5 mi may perhaps define the range in which a trained runner experiences the physiological lift commonly referred to as a "second wind." After 12.5 mi this effect becomes less pronounced and the rates decrease more rapidly again. The distance 1000 m also corresponds to the point of inflection on the plot of log distance versus log time. The two slopes of the log-log plot may also indicate that the style of running is changed above 1000 m, the shorter races representing the "sprint events" and the longer races representing the "distance events."

So far nothing has been said about the records that fall on the rate curve—those that represent the best efforts of the best competing athletes in the world. It is unlikely that any record on the curve will be exceeded by any significant amount in the near future. This is especially true of the records for the shorter distances where one- or two-tenths of a second represent just about the maximum to be expected. As a smooth curve can be drawn through the rates for the best records, any significant change in one would indicate that the adjacent records could also be changed. The records falling on the rate curve seem to be so consistent with each other than it is unlikely that any is significantly out of line.

Although it is entirely obvious, it must be pointed out that although a number of the world records have been broken, the athlete breaking the record has not been given credit for so doing, simply because he was not timed over that particular distance. For example, the world record for 220 yd is 20.2 sec, the same as the record for 200 m. A simple calculation shows that Patton in setting the 220-yd record ran the 200 m in 20.1 sec. Many other records, particularly in the walking and swimming events, have been broken in the same way. If the very best athletes were timed over both the English and adjacent metric distance it might be possible for them to break two or more records in one race and get credit for both.

Many records are low simply because the distances they represent are not popular. Examples are the American running records for 300, 600, and 1000 yd, and 3/4, 3, 7, 8, 9 mi, and so on. The times for all these events are longer than they should be according to the rate curve. Hence if a top-notch runner put a maximum effort into each of these distances individually he ought to be able to establish new American records for the distances.

The "Exhaustion Constant." An "exhaustion constant" can be calculated for each type of racing. As has been shown above, Eq. (2) is the equation relating distance and time for all types of racing. Removing logarithms,

$$d = at^k, \text{ or } t = (d/a)^{1/k}.$$

The average rate $\bar{r}$ is given by

$$\bar{r} = d/t = at^{k-1} = a^{1/k}d^{(k-1)k}.$$

Therefore

$$\log \bar{r} = (k-1)/k \log d + 1/k \log a,$$

or

$$\log \bar{r} = k' \log d + 1/k \log a,$$

where

$$k' = (k-1)/k.$$

The constant k', which is the slope of the line obtained when $\log \bar{r}$ is plotted as a function of $\log d$, is a measure of how the average rates decrease with distance. Hence k' can be called the "exhaustion constant." The values of k' can be calculated for each type of racing directly from k, the slope of the plot of log distance versus log time. The values for the types of racing considered in this paper are given in Table 1.

The "exhaustion constants" give a quantitative measure of the rate of fatigue in each type of event. A high absolute value of the constant means that the rates are decreasing rapidly with distance, hence the fatigue rate is high. As can be seen in the table, women fatigue much more rapidly relative to men in running than in swimming. In fact, quantitative ratios can be calculated from the values in the table. Over the distance for which records have been recorded the rates decrease very little for bicycle racing (motor paced, flying start). The fact that auto racing follows the same pattern as the other types of racing suggests that it may be the fatigue of the driver that determines the pattern of the auto racing records. An alternative explanation may be "car fatigue," a decrease in the efficiency of the car caused by such factors as wearing of parts and accumulation of carbon in the motor.

TABLE 1. Values of exhaustion constant k.

Type of event	k
Running (women)	−0.239
Horseracing	− .1136
Running (men)	− .0941
Swimming (women)	− .0858
Swimming (men)	− .0720
Walking (men)	− .0661
Auto racing (standing start)	− .0627
Bicycle racing	− .0142

It has been shown that a simple log-log relationship between distance and time gives a linear plot for the various types of racing. The slopes of the log-log plots vary for most racing events between 0.8 and 1.0. Kennelly was on the right track with his equation, but he failed to generalize it sufficiently. Apparently he did not realize that the slopes varied for the various racing events and were characteristic of the particular type of racing. A consequence of the log-log relationship between distance and time is a log-log relationship between the average rates for a given distance and the distance. The slopes k of the latter plots give a quantitative measure of how the average rates decrease with distance and hence may be called "exhaustion constants."

On the basis of rate curves plotted for the various types of racing it is possible to predict what records are out of line when compared to the best efforts in these events. In fact it is possible to calculate by how much they can be improved to bring them in line with the best efforts to date. Whereas improvement is possible in the records that fall below the curve, the records on the curve will prove difficult to better by any great amount.

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