

An Objective and Individualised Method of Predicting Performances in Running Events

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ABSTRACT

Often we are interested in attempting to get an estimate of the performance that an athlete should achieve in an athletics event. This may be for training purposes (i.e. since training is often over distances that are not commonly raced, we would like to know what our athlete is capable of in that distance at 100% in order to set realistic objectives for intervals), or perhaps to be able to compare an achieved performance against what the athlete should have been theoretically capable of, in order to judge the value of the performance. In this paper the author provides a method for doing this, based entirely on objective data of the athlete him/herself, i.e. without recourse to information on other athletes, or to guess-work, at all. Two performances over distances that are within the athlete's range of competence are needed in order to obtain an estimate of the athlete's capability over any other distance also within the range of competence. The methodology is shown to be accurate to within only a few percentage points by means of considering the actual and predicted times of some top international athletes.

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Introduction

It is often the case that coaches need to know what an athlete is capable of for a distance over which he/she has never actually competed. This might be the case of an athlete considering moving up in distance for competitive races, or it may be the case for working out appropriate times for interval training over a distance that is not a common competitive event. It may also happen that an athlete would like to know if his/her performances at one distance are of comparable quality to what he/she achieves at other, related, distances. For example, should an athlete with personal bests of 13:40 over 5000m and 28:00 over 10,000m be happy or disappointed with a performance of 8:10 over 3000m?¹

Consider a coach who would like to have the athlete do a set of four intervals of 700m at, say, 80% effort. What time should the athlete be aiming to run in each interval? In this paper I provide a methodology that will allow us to calculate, with considerable accuracy, the athlete's maximum capability over that distance, using only information from other performances. For example, say our hypothetical athlete has known best times over 800m and 1500m (or it could be over 400m and 800m), then we will be able to accurately estimate what he/she would run over 700m at 100% effort, from whence it can be calculated what should be achieved at 80% effort. Similarly, if the coach knows what time the athlete can run at 80% effort over two reasonably similar distances (say 600m and 800m), then directly we can calculate the time at 80% effort over 700m.

It must be clearly pointed out that the methodology will only work accurately for distances *within an athlete's range of competency*. For example, it is not reasonable to use the 100m and 400m times of a 1500m runner to try to predict the capability of that athlete over 1000m. Likewise, the methodology will break down when trying to predict times beyond 200m based only on times at distances below 200m. This is simply because below 200m most athletes will run at the same pace always (full speed), and extrapolating into longer distance, say 400m, based on that data will lead to an absurd prediction of the 400m also being run at the full speed all the way. The methodology explicitly takes into account the fatigue that athletes will experience as they move into longer distances, but only when the two reference data points are also differentiated by some degree of alteration in basic pace. The methodology can be used to predict times at a distance either between the two reference distances, or shorter than both or longer than both. However it is most accurate for predicting times at distances between the two references, and it will tend to lose accuracy the larger is range between the two reference points, and the larger is the gap (either above or below) the reference point range when attempting to predict outside

of the reference range. Nevertheless, the methodology works generally very well for middle and longer distance events.

Predicting Within a Range of Known Performances

Expected value time predictions

To start with, let's look at some logical options for our prediction. Take a base distance of d meters. Consider performance, measured in sec, over distances d and $2d$. Call these times t_1 and t_2 , respectively. The average time achieved is $\frac{(t_1+t_2)}{2}$.

This is one possible reference point for the expected time for the distance $\frac{d+2d}{2} = \frac{3d}{2}$.

Let's look at some hypothetical examples. Start with the distance 400m and 800m. Say an athlete has run 50 sec for 400m, 112 sec for 800m (1:52), and consider what this athlete should run over the distance 600m (exactly half-way between 400m and 800m). The average of the two reference times is $\frac{50+112}{2}$.

That is, 1 minute 21 sec. This is our first approximation to the 600m time.

Another example. An athlete has run 22.5 sec for 200m, and 48.3 sec for 400m. How fast should he run for 300m? The expected time is

$$\hat{t} = \frac{22.5 + 48.3}{2} = \frac{70.8}{2} = 35.4$$

This method of locating intermediate distance objective times can also be done for intermediate distances that are not exactly half-way between the two extreme distances. Say the two distances with known times are d_1 and d_2 , where $d_1 < d_2$. Any intermediate distance, say d_3 can be expressed as $d_3 = \gamma d_1 + (1 - \gamma)d_2$, where γ is a concrete number between 0 and 1. For example, in what we did above, we simply had $\gamma = \frac{1}{2}$. However, using this general expression, we can easily calculate that, for any given d_1, d_2 and d_3 , the relevant weighting is $\gamma = \frac{d_2 - d_3}{d_2 - d_1}$.

Then, assuming as above that the time for distance is and the time for distance d_1 is t_1 and the time for distance d_2 is t_2 , the weighted average time is $t = \gamma t_1 + (1 - \gamma)t_2$.

$$\text{Substituting } \gamma = \frac{d_2 - d_3}{d_2 - d_1} \text{ and } 1 - \gamma = \frac{d_3 - d_1}{d_2 - d_1},$$

$$\text{this can be written as } t = \frac{(d_2 - d_3)t_1 + (d_3 - d_1)t_2}{d_2 - d_1}$$

Take, for example, an athlete who has run 1500m in 3:40 (i.e. 220 sec), and 5000m in 13:42 (i.e. 822 sec). What can we expect this athlete to run at 3000m? For this example, we have $d_1 = 1500$, $d_2 = 5000$, $d_3 = 3000$, $t_1 = 220$ and $t_2 = 822$. Our reference time is then

$$t = \frac{(5000 - 3000) \times 220 + (3000 - 1500) \times 822}{5000 - 1500} = 478$$

that is, 7:58.

Let's take some concrete case studies to see how well t expected value methodology predicts intermediate times.

Case 1: Sebastian Coe. Coe ran 1:41.73 (101.7 sec) for 800m and 3:29.77 (209.8 sec) for 1500m. Substituting $d_1 = 800$, $d_2 = 1500$, $d_3 = 1000$, $t_1 = 101.7$ and $t_2 = 209.8$ into the equation for t , we find that the expected time for 1000m is 132.59 sec, or 2:12.6. Of course, he actually ran a shade under 2:12.2. Not a bad approximation!

Case 2: Hicham El Gerrouj. Over 1500m, El Gerrouj still holds the world record at 3:26.00 (206 sec), and he also ran 12:50.24 for 5000m (770.4 sec). Therefore, using $d_1 = 1500$, $d_2 = 5000$, $d_3 = 3000$, $t_1 = 206$ and $t_2 = 770.4$, our estimation for his time over 3000m is 447.89 sec, that is 7:27.9. Again, a little slower than what he actually achieved, which was 7:23.09.

Case 3: Haile Gebreselassie 1. For 3000m, Gebreselassie ran 7:25.09 (445.1 secs.), and over 10,000m he achieved 26:22.75 (1582.8 secs.). Using this data, for 5000m, where his true best was 12:39.36 (759.4 secs.), we should have expected a time of 770.16 sec, i.e. 12:50.2 more or less.

Case 4: Haile Gebreselassie 2. Even though moving off the track is likely to introduce many imprecisions, let's see how the formula works for Gebre's performances over 5000m and half-marathon as a predictor of his 10,000m time. Over 5000m he achieved 759.4 sec, and over the half-marathon (21,195 meters) he achieved 58:55 (i.e. 3535 sec). For this data we get an estimated 10,000m time of 1616.3 sec. That is, 26:56.3.

One thing is notable: for all four cases, the actual intermediate time achieved is faster than the predicted time. Given that, let's look at a second option for predicting.

Predictions based on pacing

Another option for prediction is to use the average per meter pace. The average pace for a given distance d_i run in a time t_i is $p_i = \frac{t_i}{d_i}$.

Now take the intermediate distance, $d_3 = \gamma d_1 + (1 - \gamma)d_2$. The weighted average of the two average paces is $p = \gamma p_1 + (1 - \gamma)p_2$. Using this, a second estimate of expected time at the intermediate distance d_3 is given by $p \times d_3$. Since we know that $\gamma = \frac{d_2 - d_3}{d_2 - d_1}$ and $1 - \gamma = \frac{d_3 - d_1}{d_2 - d_1}$

we can write the predicted time based on average pacing as

$$p \times d_3 = \left[\left(\frac{d_2 - d_3}{d_2 - d_1} \right) \times \frac{t_1}{d_1} + \left(\frac{d_3 - d_1}{d_2 - d_1} \right) \times \frac{t_2}{d_2} \right] \times d_3$$

Let's go back to our three legendary case studies.

Case 1 (Coe): Using the pacing formula, and based on his times at 800m (d_1) and 1500m (d_2), using the average pacing formula we would have expected a 1000m time for Coe of 130.77 sec. That is, 2:10.8 more or less.

Case 2 (El Gerrouj): Based on his times at 1500m and 5000m, the pacing formula gives a 3000m time of 433.53 sec. The predicted time is an impressive 7:13.5!

Case 3 (Gebreselassie 1): Based on the performances at 3000m and 10,000m, the expected 5000m time is 756.0 sec, or 12:36.0.

Case 4 (Gebreselassie 2): Based on the performances at 5000m and half marathon, the expected 10,000m time is 1564.8 sec, or 26:04.8.

Of course, any number of cases can be studied. However, it is certainly notable that for each of the cases in question, the two predictions give us a range of times (i.e. a maximum and a minimum), such that the actual time achieved always falls within these two boundaries².

Given that observation, we should use as our final estimation for the intermediate time that should be achieved for a performance that is somewhere between the two boundary limits. For ease of calculation, and for want of any better number, let's just take the mid-point of each range as our best predictor of the intermediate time. Thus, we set our best approximation at t^* , where

$$t^* = \frac{t + p \times d_3}{2} = \frac{t}{2} + \frac{p \times d_3}{2}$$

For Coe, this delivers a predicted 1000m time of $\frac{132.59+130.77}{2} = 131.68$ (that is, 2:11.7).

For El Gerrouj we get a 3000m time of

$$\frac{447.89+422.53}{2} = 440.71 \text{ (that is, 7:20.7), for}$$

Gebreselassie 1 we get a 5000m time of

$$\frac{770.16+756.0}{2} = 763.08 \text{ (i.e. 12:43.1), and for}$$

Gebreselassie 2 we get a 10,000m time of

$$\frac{1616.3+1564.8}{2} = 1590.6 \text{ (i.e. 26:30.6).}$$

We can see that these are now realistic predictions for all four cases, given what they each actually achieved.

Predicting Outside of the Range of Known Performances

Imagine now that we have an athlete with known times at two distances who wants to know what to expect in a third distance that is longer than each of the first two? Or, an athlete

who would like to know his/her value at a distance that is shorter than the two for which he/she has times recorded. The formula for t^* will still work. For example, go back to the athlete who has run 400m in 50 sec. He is planning to compete in his first 800m race, and is unsure about what time to run for the first lap. What can we advise? We get the athlete to run a 600m time trial at full effort in training, which, say, turns out to be 1:20.5, that is, 80.5 sec. We can then use our formulas to find out the expected time for 800m as follows.

We have the time for distance d_1 (400m), and now the time for the intermediate distance d_3 (600m). We need to find the time for the longer distance, d_2 (800m). We also know for this example that $\gamma = \frac{1}{2}$, since 600 is exactly half-way between 400 and 800. Now, we are using as our time at the intermediate distance the best predictor, t^* , and so we take $t^* = 80.5$, and write out the equation for the best predictor at the distance of 600m:

$$t^* = 80.5 = \frac{1}{2} \times \left(\frac{50 + t_2}{2} \right) + \frac{1}{2} \times \left(\left(\frac{1}{2} \times \frac{50}{400} + \frac{1}{2} \times \frac{t_2}{800} \right) \times 600 \right)$$

Notice that the only unknown variable left in the equation is t_2 , which is precisely the corresponding time for 800m. We need only solve the equation for t_2 . Doing so gives us the result that $t_2 = 112.57$, that is, 1:52.6. This is then our best estimate of the time that this athlete would run for 800m. Therefore we might suggest that he tries to cover the first lap in about 55.5 sec.

More generally, we can take our best predictor for the time at the intermediate distance, t^* , and use that for t_3 . Then, substituting our equation for the average time, t , and the prediction based on average pacing, $p \times d_3$, into the equation for the best predictor, t^* , we can see that our best prediction for the performance at the intermediate distance d_3 is

$$t_3 = \frac{t + p \times d_3}{2} = \frac{1}{2} \left\{ \frac{(d_2 - d_3)t_1 + (d_3 - d_1)t_2}{d_2 - d_1} + \left(\frac{d_2 - d_3}{d_2 - d_1} \right) \times \frac{t_1}{d_1} + \left(\frac{d_3 - d_1}{d_2 - d_1} \right) \times \frac{t_2}{d_2} \right\} \times d_3$$

Notice that this equation can be expressed in terms of any of the three times, t_3 , t_1 or t_2 . All that is needed is the three distances, and recorded times at two of them. Concretely, a little algebra on the above equation for t_3 re-

veals that the best predictor for the time run at distance d_1 based upon observations at the two longer distances d_2 and d_3 is

$$t_1 = \frac{2t_3(d_2 - d_1)d_1d_2 - t_2(d_3 - d_1)(d_2 + d_3)d_1}{(d_2 - d_3)(d_1 + d_3)d_2}$$

Likewise, the best predictor for the time run at distance d_2 based upon observations at the two shorter distances d_1 and d_3 turns out to be

$$t_2 = \frac{2t_3(d_2 - d_1)d_1d_2 - t_1(d_2 - d_3)(d_1 + d_3)d_2}{(d_3 - d_1)(d_2 + d_3)d_1}$$

We can see how all this works in a simple graph (Figure 1).

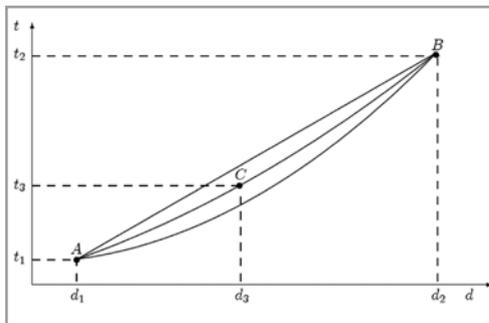


Figure 1: The graphs of average time, average pacing time, and the best predictor

Figure 1 describes points in the space of distances (on the horizontal axis) and time (on the vertical axis). Thus, a point in the graph is a performance measured in terms of time for a given distance. In particular, point A is a performance at a short distance (d_1), and point B is a performance at a longer distance (d_2). The straight (uppermost) line joining A and B is the graph of the average time, t , and the lowermost curve joining the same two points is the graph of the predictor based on average pacing, $p \times d_3$. The intermediate curve (containing point C) is located exactly halfway between t and $p \times d_3$, and so it is the graph of t_3 for any distance between those indicated at the two extreme points. Thus, point C is a point that indicates the predicted performance at an intermediate

distance, d_3 . The three curves in the graph can be located with knowledge of only two of the points A, B or C, although we do need all three distance measures (d_1 , d_2 and d_3).

If, for example, we have knowledge of performances at two extreme distances and we are interested in a prediction at an intermediate distance, then we would be able to locate the coordinates of point A, which corresponds to the known performance at distance d_1 , and point B, which corresponds to the known performance at distance d_2 . Given that we have the two extreme points, we are then able to draw the intermediate curve. We then only need to look at the height of this curve at any intermediate distance d_3 to get the best approximation for the performance at that distance, point C. Second, say we want to find point B given two known performances at two shorter distances. In this case, we locate points A and C at the two shorter distance performances, and again we are able to trace out the intermediate curve, and thus locate the height of point B. The case of finding point A given two points C and B is analogous.

To see how this process works with some real data, let's find the best estimate of each of the longer distances for our three legends, based on their performances at the two shorter distances. In each case, we need only to use the equation above for t_2 .

Case 1 (Coe): Using the times of 1:41.7 for 800m and 2:12.2 for 1000m, what time should we have expected for 1500m? The answer is 2:12.0 sec, or 3:32.0. Just over 2 sec slower than what he actually achieved.

Case 2 (El Gerrouj): Using the times of 3:26.0 for 1500m and 7:23.1 for 3000m, what time should we have expected from him over 5000m? Our equation tells us that he should have run 777.38 sec, or 12:57.38. Of course he actually ran some 7 sec faster than this.

Case 3 (Gebreselassie 1): Using the times of 7:25.1 for 3000m and 12:39.4 for 5000m, what time should we have expected from him

Table 1: Predicted times for each distance based on results achieved at the other two distances (actual best times in parentheses)

	d_1	d_2	d_3
Coe	1:42.4 (1:41.8)	2:11.7 (2:12.2)	3:32.0 (3:29.8)
El Gerrouj	3:28.8 (3:26.0)	7:20.7 (7:23.1)	12:57.4 (12:50.2)
Gebreselassie 1	7:21.2 (7:25.1)	12:43.1 (12:39.4)	26:05.6 (26:22.8)
Gebreselassie 2	12:36.3 (12:39.4)	26:30.6 (26:22.8)	58:21 (58:35)

Note: for Coe $d_1 = 800$, $d_2 = 1000$ and $d_3 = 1500$. For El Gerrouj, $d_1 = 1500$, $d_2 = 3000$ and $d_3 = 5000$. For Gebreselassie 1 $d_1 = 3000$, $d_2 = 5000$ and $d_3 = 10,000$. For Gebreselassie 2 $d_1 = 5000$, $d_2 = 10,000$ and $d_3 = 21195$.

over 10,000m? Our equation gives the answer as 1565.6 sec, or 26:05.6, about 17 sec faster than what he actually achieved.

Case 4 (Gebreselassie 2): Using the times of 12:39.4 over 5000m and 26:22.8 over 10,000m, what should we have expected over the half marathon? We find that he was worth 3500.8 sec, or about 58:21, something that although he did not quite manage, he was certainly capable of.

Similarly, we can use our equation for t_i to calculate the prediction for Coe over 800m based on his times at 1000m and 1500m, for El Gerrouj over 1500m based on his times at 3000m and 5000m, etc. All of the results of these calculations are given in Table 1.

Table 2 reports the prediction error (in terms of the difference between the actual time achieved and each of the predicted times in Table 1, expressed as a percentage of the actual time achieved).

Table 2: Prediction error in Table 1

	d_1	d_2	d_3
Coe	-0.69%	0.38%	-1.05%
El Gerrouj	-1.36%	0.54%	-0.93%
Gebreselassie 1	0.88%	-0.49%	1.09%
Gebreselassie 2	0.41%	-0.49%	0.40%

Note: the distance columns are as for Table 1.

A negative value in Table 2 indicates that the athlete actually ran faster than the prediction at that distance based on performances at the other two. Note, for example, that the largest number (in absolute value) corresponds to El Gerrouj for 1500m. This says that his 1500m best was significantly better than what he achieved at the two longer distances. The same can be said of Coe over 1500m relative to what he achieved over 800m and 1000m. However, in both of those cases, it is the intermediate distance (3000m for El Gerrouj and 1000m for Coe) that is the real culprit. That is, both El Gerrouj and Coe underperformed at their intermediate distance compared to the two extremes (which we should expect, given that they ran these intermediate distances very infrequently, and they ran the two other distances very often).

Gebreselassie 1 has the opposite result. He has a positive percentage difference at the two extremes (3000m and 10,000m), and a negative difference at 5000m. This says that Gebreselassie over performed over 5000m relative to what he managed at 3000m and 10,000m. Again, we may ascribe this to a lack of opportunities at the two extreme distances; he ran the 3000m infrequently, and the majority of the 10,000m races he ran were championship events rather than events in which record chasing can be done.

Finally, the case of Gebreselassie 2 is also noteworthy. In this case, the numbers are really low (less than half of a percent, either positive

or negative), especially considering that we are talking about long distances here. This happens because these three distances (5000m, 10,000m and half marathon) are extremely similar in nature, leading to the athlete performing largely as expected in each relative to the others. It is a testament to the fact that the methodology of prediction works best when applied to distances that are by-and-large of a similar nature.

All in all, Table 2 points to the predictions in Table 1 being reasonably accurate; the predictions are generally within one percent of what is actually achieved. And of course a good deal of the prediction error might be able to be explained by exogenous factors such as different track surfaces, weather conditions, and the degree of competition on the day.

A Thought Experiment

Here is an interesting question for you.³ Which athlete out of Sebastian Coe, Steve Ovett, Hicham El Gerrouj, Steve Cram, Nouredinne Morcelli, Noah Ngeny and Said Aouita would have run the fastest time in a race over 1200m, and what would that time have been? For this experiment, it is important that we only use objective information on times that each athlete actually did achieve at different distances, and not performances that we consider an athlete, hypothetically, should have been able to achieve. Table 3 has information (according to Wikipedia) on these athletes:⁴

Table 3: Best performances of 7 legendary athletes

	800m	1000m	1500m
Coe	1:41.73	2:12.18	3:29.77
Ovett	1:44.09		3:30.77
Morcelli	1:44.79	2:13.73	3:27.37
Aouita	1:43.86		3:29.46
Cram	1:42.88		3:29.67
Ngeny	1:44.49	2:11.96	3:28.12
El Gerrouj	1:47.18	2:16.85	3:26.00

Let's first find out their expected 1200m time using only the 800m and 1500m times as a reference. On this basis, they end up with the following numbers: Coe 2:42.38, Ovett 2:44.18, Morcelli 2:42.81, Aouta 2:43.40, Cram 2:42.97, Ngeny 2:43.10, and El Gerrouj 2:43.32. However, if instead of using Ngeny's 800m time, we use his 1000m time, he ends up with 2:42.04.⁵

Thus, the ranking when we limit ourselves to keeping the 1200m as an intermediate distance between the reference points is⁶

1. Noah Ngeny, 2:42.04
2. Sebastian Coe, 2:42.38
3. Nouredinne Morcelli, 2:42.81
4. Steve Cram, 2:42.97
5. Hicham El Gerrouj, 2:43.32
6. Said Aouita, 2:43.40
7. Steve Ovett, 2:44.18

Naturally, El Gerrouj would almost certainly have headed the list if he had only run a few 800m races when in the peak of his career. Indeed, in order to have gone to the number 1 slot, he would only have had to run 800m in 1:45.12, a time that most observers would feel he was easily capable of. But since I only want to use objective, and not subjective estimates, I cannot use this kind of argument to move El Gerrouj up on the list. But wait, there is still a surprise in store for us. El Gerrouj did run a fantastic 4:44.79 over 2000m, and Morcelli achieved 4:47.88 over that distance. We can then ask, what time at 1200m is consistent with each of their 1500m times and their 2000m times? That is, we can extrapolate downwards to find their 1200m predictions. The answer is that the formula predicts a fantastic time of 2:40.07 for El Gerrouj over 1200m, and an only marginally slower 2:40.58 for Morcelli! However, since we also know that extrapolating outside of the range given by our input data is likely to be a little less precise than predicting within the range, I enter both El Gerrouj and Morcelli into my final ranking with a *, but at least I get them into the places they rightly deserve on the list.

1. Hicham El Gerrouj, 2:40.07*
2. Nouredinne Morcelli, 2:40.58*
3. Noah Ngeny, 2:42.04
4. Sebastian Coe, 2:42.38
5. Steve Cram, 2:42.97
6. Said Aouita, 2:43.40
7. Steve Ovett, 2:44.18

Conclusion

In this paper I have explored the option of predicting an athlete's best potential time at one distance, given only objective data on performances that have actually been achieved by the same athlete at two other distances. The methodology is quite robust to the distances chosen, although it should be used with care in some circumstances (e.g. extrapolating over very large ranges, extrapolating outside of an athlete's natural range of competence, or extrapolating based only on times in pure sprint events). By way of example, I have shown that the methodology is accurate (to approximately 1% or less).

The methodology has been explained in terms of 100% efforts at all distances, that is, we can find out the maximum potential capability of the athlete at one distance given their maximum capabilities at two other distances. However, we may also use the technique to find out what time an athlete should run when only at, say, 80% (or indeed any other effort level less than 100%) of maximum speed, by simply using the performances at two other distances at the same (80%) effort level. In that way, we can easily adapt the methodology to suit coaches who need to know what times to set their athletes for interval training at given effort levels.

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REFERENCES

1. The answer is disappointed. This athlete should have been capable of 8:03 over 3000m.
2. In fact, a little algebra suffices to show that the average time, t , is always less than (i.e. faster than) the average pace predictor, $p \times d$, whenever it holds that the pace at the longer distance is higher (i.e. slower) than the pace at the shorter distance, something that we should always expect. That actual realised performances seem to always fall between the two boundaries cannot of course be proved mathematically, but our examples are persuasive for it tending to hold true generally.
3. I am not the only one to wonder about this. See the blog thread on http://www.letsrun.com/forum/flat_read.php?thread=2509407&page=0
4. A blank cell indicates that no personal best for the distance is available.
5. Coe, Morcelli and El Gerrouj all end up with slower 1200m estimates when we use their 1000m time instead of their 800m time.
6. The fastest 1200m on record is 2:44.75, run by El Gerrouj en route to a 2:26.96 1500m in Rieti 2002. See http://trackandfieldnews.com/archive/at_1200_enroute_m.html