ORIGINAL ARTICLE

Bioenergetic constraints on tactical decision making in middle distance running

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Br J Sports Med 2002;**36**:102–104

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Accepted 20 November 2001

Background: The highest velocity that a runner can sustain during middle distance races is defined by the intersection of the runner's individual velocity-time curve and the distance-time curve. The velocity-time curve is presumably fixed at the onset of a race; however, whereas the race distance is ostensibly fixed, the actual distance-time curve is not. That is, it is possible for a runner to run further than the race distance if he or she runs wide on bends in track races. In this instance, the point of intersection of the individual velocity-time curve and the distance-time curve will move downwards and to the right, reducing the best average velocity that can be sustained for the distance.

Methods: To illustrate this point, the race tactics used by the gold and silver medallists at 800 m and 5000 m in the Sydney Olympics were analysed. The paths taken by the runners were carefully tracked and the total distance they covered during the races and the average velocity they sustained over the distances they actually covered were calculated.

Results: In both the Olympic 800 m and 5000 m finals, for example, the winner was not the runner who ran at the highest average velocity in the race. Rather, the winners of these races were able to husband their metabolic resources to better effect by running closer to the actual race distance.

Conclusions: Race results in middle distance running events are dependent not just on the energetic potential of the runners at the start of the race and their strategy for pace allocation, but also on the effect of their tactical approach to positioning on the total distance covered in the race. Middle distance runners should be conscious of minimising the distance covered in races if they wish to optimise their performance.

The major physiological factors associated with successful distance running performance include the runner's maximal oxygen uptake ($\dot{V}O_{2MAX}$) and lactate threshold, the running economy (the oxygen cost of running in ml O_2/kg body mass/km), and the critical velocity.[1] However, very little attention has been paid to the influence of race tactics on the optimal use of a runner's physiological resources and their effects on the outcome of distance races.

The highest constant velocity that a runner can theoretically sustain without fatigue associated with an inexorably developing metabolic acidaemia can be estimated using the "critical velocity" (CV) concept.[2] The time to exhaustion at several different running velocities can be used to construct a runner's velocity-time curve (fig 1). The asymptote of this hyperbolic relation[3] is defined as the CV (m/s), and the curvature constant (D′) represents a constant distance (m) that can be covered above the CV using the currently fixed energy reserves (stored oxygen, high energy phosphates, and energy liberated through anaerobic glycolysis). The relation may therefore be described with the following equations:

$$(V-CV)t = D'$$

or

$$V = D'(1/t) + CV$$

where V is running velocity (m/s) for velocities greater than CV.

Because the total race distance (D) is simply the product of running velocity and time, then the equations above may be rewritten as:

$$D = CVt + D'$$

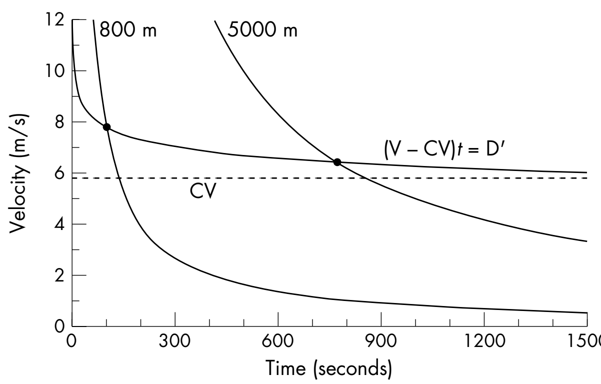

Figure 1 Schematic example of individual velocity-time (V-t) curve. Distance curves to 800 m and 5000 m are also shown. The point of intersection of these curves corresponds to the runner's maximal average velocities (y axis) and/or best possible performance times (x axis) for the distances. CV, Critical velocity; D′, distance curvature. Running velocities above the individual V-t curve are unsustainable because of metabolic limitation, and running at a velocity below the CV for any part of a race will result in a suboptimal performance. See text for further details.

The characteristics of the individual velocity-time curve are therefore important determinants of success in all distance races that have a significant aerobic energy contribution (400 m and above) and that are run at velocities greater than CV (10 000 m and below).[4] Exercise above the CV is associated with both an inexorable accumulation of metabolites such as muscle H^+ and inorganic phosphate ($H_2PO_4^-$) and a continued rise in oxygen uptake to or towards $\dot{V}O_{2MAX}$ and ensuing fatigue.[5,6] The finite amount of chiefly anaerobic energy equivalent to D′ can either be eked out over the full race distance or used rapidly, for example during a sprint finish.[6] There is therefore a need for a runner to consider the allocation of pace carefully in order that his or her energy resources are used effectively.

The objective in distance running races is to cover the race distance in less time than one's competitors or in a time that provides a personal or other record. This will ideally require a runner to become exhausted—that is, to have fully used his or her metabolic resources—at the exact moment that the race ends. The race tactics that a runner uses to maximise his or her chances of winning are therefore influenced by his or her current CV and D′ and also by those of the other competitors. For example, a runner with a relatively high CV but a relatively low D′ would be better suited to a constant high velocity throughout the race. Conversely, a runner with a relatively low CV but a relatively high D′ may choose tactics that result in a slower average velocity for all competitors during the race but that allow the use of his/her superior capacity to generate energy anaerobically in a sprint finish.

The highest average velocity that can be sustained by a runner over a specified distance between about 400 m and about 10 000 m, and thus the fastest time in which they can complete the distance, is given by the crossing point of the individual velocity-time curve and the distance-time curve (fig 1). There are several interesting features of this relation.[6] Firstly, by definition, running velocities above those bounded by the individual velocity-time curve cannot be attained. Secondly, running any part of the race distance at a velocity below the CV will prevent the runner from achieving his or her best possible time for the distance.[6] Finally, running at a velocity below the highest sustainable average velocity for the distance for a portion of the race may still result in the best possible time for the distance provided that the selected running velocity is above the CV. This is because the runner can harness his or her anaerobic energy reserves in the remainder of the race to compensate for the slower section(s).[6]

The individual velocity-time curve is fixed at the onset of a race and presumably cannot be altered during it. Therefore a runner has to use his or her physiological attributes to best advantage by choosing an appropriate velocity (based on the ratio between his or her D′ and CV) that ensures that the energetic resources are exhausted at the end of the race. It is interesting to note, however, that, whereas the race distance is ostensibly fixed, the actual distance-time curve is not. That is, it is possible for a runner to run further than the race distance (but not shorter) if he or she runs wide on bends in track races. Runners often employ such tactics during races—that is, they may run "on the shoulder" of the leaders—to ensure that they are well situated in the event of a fast break by a competitor. However, such tactics will inevitably result in the runner covering a greater distance than the minimum required for the race. Because a 400 m running track comprises two semicircles and two straights, it can be calculated that the distance run in completing one circuit is $2\pi r$ plus the length of the two straights. Therefore, if a runner should run a mere 25 cm wide around the bends in one lap, he will run $6.28(r + 0.25)$ plus the length of the straights—equivalent to running an extra 6.28×0.25 m, which equals 1.57 m. If a runner completes one lap of a 400 m track on the inside of the second lane, then he will have covered an additional 7.04 m. The additional distance naturally has necessary consequences for the best average velocity that can be sustained in a race (fig 2). The point of intersection of the individual velocity-time curve and the distance-time curve moves downwards and to the right, reducing the best average velocity that can be sustained for the distance and increasing the total time taken to cover the distance.

As a practical illustration of this point, we analysed two middle distance races from the Olympic Games in Sydney. We chose to analyse the 800 m and 5000 m races because, in both, the favourite before the race was beaten and we wished to ascertain the effect of the tactics used by the race winners and race favourites on the race results. Using slow motion video playback of the races, we carefully tracked the paths taken by the runners and calculated the total distance they covered during the races. We also used the official race times to calculate the average velocity the runners sustained over the distances they covered in the races. Figure 3 shows the results of this analysis.

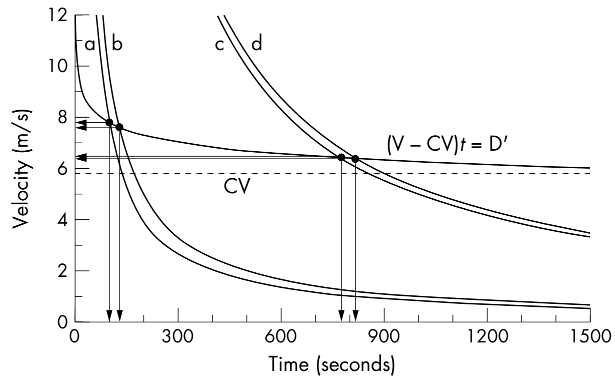

Figure 2 Schematic example of the effect of running further than the actual race distance on the time to complete the race. Curves a and c are the distance curves to 800 m and 5000 m respectively; curves b and d are the distance curves that may pertain if the athlete did not run the shortest possible distance (by running wide on the bends in track races, for example). Note that the points of intersection of the distance curves and the V-t curve shift downwards and to the right, resulting in the athlete maintaining a lower average velocity (y axis) and thus taking more time (x axis) to complete the race. Note also that, because of the shape of the individual V-t curve, a small reduction in average velocity results in a relatively large increase in race time as race distance increases.

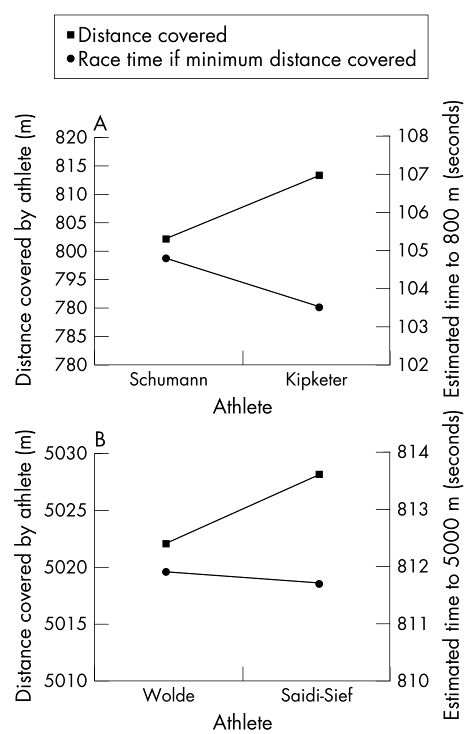

Figure 3 Example of the effect of race tactics on race outcome in the 2000 Olympics mens' 800 m (A) and 5000 m (B) finals. Estimated distance covered by the gold and silver medallists and the estimated race time for the competitors if only the minimum race distance had been covered are shown. See text for further details.

The Olympic 800 m final for men was won by N Schumann of Germany in 1:45.08, and the silver medal was won by the race favourite, W Kipketer of Denmark in 1:45.14. Schumann ran close to the kerb throughout the race and covered a total distance of 802 m. Kipketer, in contrast, ran in lanes 2 and 3 throughout the race and covered a total distance of 813 m. Schumann's average velocity (over 802 m) was 7.63 m/s and Kipketer's average velocity (over 813 m) was 7.73 m/s. Using these average velocities, the race times to cover 800 m can be calculated to be 1:43.46 for Kipketer and 1:44.82 for Schumann (fig 3A). The margin of Kipketer's "victory" to cover 800 m will be slightly underestimated in this analysis because his highest average velocity over 800 m would be slightly higher than his highest average velocity over 813 m.

The Olympic 5000 m final for men provides a more subtle example of this effect. This race was won by M Wolde of Ethiopia in 13:35.49, with second place being taken by the favourite A Saidi-Sief of Algeria in 13:36.20. Wolde ran close to the kerb whenever possible during the race, whereas Saidi-Sief ran a portion of the race towards the outside of lane one (on the shoulder of the leader). Wolde covered a total distance of 5022 m while Saidi-Sief covered a total distance of 5028 m. Wolde's average velocity (over 5022 m) was 6.158 m/s and Saidi-Sief's average velocity (over 5028 m) was 6.160 m/s. Using these average velocities, the race times to 5000 m can be calculated to be 13:31.65 for Saidi-Sief and 13:31.91 for Wolde (fig 3B). Again, the margin of Saidi-Sief's "victory" will be slightly underestimated in this analysis for the reason given above.

DISCUSSION

This analysis highlights the profound effect that the race tactics can have on the eventual race outcome. In both the Olympic 800 m and 5000 m finals, the winner was not the runner who ran at the highest average velocity in the race. Rather, the winners of these races were able to husband their metabolic resources to better effect by running closer to the actual race distance. Although other and more striking examples could have been chosen from other competitions, the present analysis serves to underscore the importance of the inexorable bioenergetic consequences of lane selection strategies. These can be costly, demanding a suboptimising shift along the subject's velocity-time curve, the physiological determinants of which are set at the onset of the race, the best possible performance being defined by the crossing point of the velocity-time and distance-time curves. It is clear that runners should be conscious of minimising the distance covered in races if they wish to optimise their performance. Occasionally, it will be necessary for a runner to run wide on a bend to overtake a fatiguing or slower competitor, or in the final stage of the race to avoid being "boxed in", but this should be considered in the light of the bioenergetic consequences. In conclusion, we have shown that race results in middle distance running events are dependent not just on the energetic potential of the runners at the start of the race and their strategy for pace allocation, but also on the effect of their tactical approach to positioning on the total distance covered in the race. The magnitude of this effect is sufficient to make the difference between finishing first and second, even in the Olympic Games.

Take home message

The highest velocity that an athlete can sustain for the appropriate time in a middle distance race is determined by the crossing point of the athlete's velocity-time curve and the distance-time curve for the event. The latter can be altered during a track race if the athlete runs further than the minimum distance, for example by running wide on bends. Middle distance runners should be conscious of minimising the distance covered in races if they wish to optimise their performance.

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