Optimal pacing strategy in competitive athletic performance

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2008

document version
Publisher's PDF, also known as Version of record

citation for published version (APA)
Hettinga, F. J. (2008). *Optimal pacing strategy in competitive athletic performance*. [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam]. PrintPartners Ipskamp.

SUMMARY

The present thesis investigates several assumptions that are of critical importance in modeling performance and simulating various pacing strategies **(chapters 2 to 6)** in order to model the effect of different pacing strategies on performance **(chapters 7 and 8)**. Modeling the effect of different pacing strategies can help athletes in their search for their optimal race strategy.

In **chapter 2**, different pacing strategies and their effect on patterns of anaerobic and aerobic energy distribution in cycling were studied. Distribution of anaerobic energy turned out to be the determining factor in pacing strategy. Pattern of aerobic energy distribution did not seem to vary with pacing strategy and different pacing strategies can be modeled by varying the distribution of anaerobic energy over the race, as done with the energy flow model in **chapters 7 and 8**. Also, electromyographic activity was measured and analyzed in combination with power output. This was done to study the central fatigue hypothesis that suggested that a drop in power output at the end of time trial exercise was caused by a central down-regulation. This was not the case and central fatigue in the form of a central down-regulation at the end of exercise did not seem to occur in a 4000-m supra-maximal time trial.

The total amount of anaerobic work that can be produced during a time trial is assumed to be a fixed amount. **Chapters 3 and 4** studied this assumption by imposing different pacing strategies and different time trial lengths. **Chapter 3** showed that indeed, even when extreme patterns of distributing (anaerobic) power output were imposed, anaerobic and aerobic work did not differ per pacing strategy. Total work differed in favor of an even-paced strategy. Though relevant for sports performance, differences were relatively small (~2%). The assumption that anaerobic work is a constant value independent of pacing strategy seems to be a valid assumption in the range of different strategies that are currently simulated in the energy flow models. Looking at time trials of different distances (750 m, 1500 m, 2500 m and 4000 m) on the other hand, total anaerobic work over the race increased with time trial distance, as shown in **chapter 4**. The closed loop nature of time trial exercise provides the possibility of varying power output over short periods of time. This may contribute to the larger total anaerobic work than may be accomplished when power output is forced to remain high in open loop exercise. This possibility might be particularly favorable for time trials > 2-3 minutes, the maximal duration assumed to be necessary to exhaust anaerobic resources.

One of the important ingredients in modeling sports performance is gross efficiency (GE). **Chapter 5** investigated the effect of ambient temperature on GE, and showed that GE was about 0.9% lower in heat compared with thermo-neutral circumstances. A high muscle temperature and increases in rectal temperature were not large enough to account for the complete difference and it is suggested that the extra $\dot{V}O_2$ in the heat is at least partially attributable to the extra myocardial $\dot{V}O_2$. A higher cardiac output has to exist to continue supplying the muscles with the same blood flow, while extra blood has to be sent to the skin for cooling. The lower gross efficiency in heat could explain about half of the decrements in time trial performance that have been shown to occur in heat.

Limited research has been done on the $\dot{V}O_2$ response of time trial exercise in the supra-maximal domain or during free range exercise typical of competition. In **chapter 6**, $\dot{V}O_2$ response during supra-maximal time trial was measured and modeled for time trials of four different distances (750 m, 1500 m, 2500 m and 4000 m). The burst in power output over the first 15 s of exercise, that is characteristic for a start in time trial exercise, was largest in the 750-m time trial. The higher initial burst in power output in 750 m was accompanied by a faster $\dot{V}O_2$ response, possibly linked to the [PCr] response to exercise. To make optimal use of the aerobic system, the initial burst of power output that is characteristic for time trial exercise of maximal effort seems to be of high importance.

The obtained information from **chapters 2 to 6** contributed to making the energy flow model more accurate. In **chapters 7 and 8**, the energy flow model was used to predict optimal performance and favorable pacing strategies. In **chapter 7**, the relative importance of changes in pacing strategy and changes in mean power output to variations in self-paced performance were investigated. Four self-paced time trials were performed. Comparing the fastest intra-individual time trial with the slowest, a difference of about 4 s was found, that was caused mainly by variations in mean power output. Pacing strategy was in both fastest and slowest performance close to optimal, and athletes seemed to be able to effectively adjust their pacing profile based on their ‘status of the day’. In **chapter 8**, it was tried to ‘override’ the athlete’s self-paced performance, by imposing a theoretically optimal pacing profile based on the energy flow model. This study was performed in speed skating, a sport where maintaining body position and technique is of large importance. Athletes were instructed to start with a faster initial pace than their self-paced exercise. Distribution of power output over the race indeed slightly changed towards a faster initial pace, but in contrast to predictions, this did not lead to better performance. Technical aspects also changed with the changing of pacing strategy, resulting in a higher aerodynamical drag coefficient. Technical aspects seem to be integrated in the well-developed performance template of the athlete and deviating from that seems to have relatively large consequences for speed skating. Proper practicing before applying such a pacing strategy is necessary.

Optimal pacing strategy

The question particularly relevant for the athlete is of course: what is the optimal race strategy? Based on the present thesis, it can be concluded that it seems favorable to start the first 5-15 s as fast as possible. This speeds up the aerobic pathways **(chapter 6)**, and a high initial power output also has beneficial effects on the efficient distribution of the available energy, as was shown by the predictions of optimal strategy in **chapter 7 and 8**. To be able to perform well with a faster start strategy, training is required. Especially in a sport such as speed skating, where maintaining body position is of high relevance and fatigue has a relatively large effect on effectiveness of movement, this important.

Further, it was shown that athletes seem to have an accurate ‘sense’ of optimal pacing strategy, since they are relatively close to their optimum depending on mean power output they can generate over the race and also technical aspects seem to be incorporated, as discussed in **chapters 7 and 8** respectively. Based on previous experience, athletes learn to judge the signals that their body gives them relative to the task they know they have to perform. To be able to accurately judge possibilities, it is advisable for athletes to experiment and keep experimenting with different pacing strategies together with their coaches and in this way obtain a well-documented up to date exercise template, based on prior experience. Accurate models predicting optimal performance could help directing the athlete towards favorable pacing patterns. The present thesis contributed to making the energy flow model, used to predict optimal performance and favorable pacing strategies, more accurate.