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Model-theoretic Optimization Approach to Triathlon Performance Under Comparative Static Conditions – Results Based on The Olympic Games 2012

Michael Fröhlich (Corresponding author)
Institute of Sport Sciences, Saarland University
Campus B8.1, 66123 Saarbrücken, Germany
Tel: ++49(0)681-302 4911 E-mail: m.froehlich@mx.uni-saarland.de

Janine Balter
Institute of Sport Sciences, Saarland University
Campus B8.1, 66123 Saarbrücken, Germany

Andrea Pieter
Institute for Prevention and Public Health, University of Applied Sciences
66123 Saarbrücken, Germany

Markus Schwarz
Institute of Sport Sciences, Saarland University
Campus B8.1, 66123 Saarbrücken, Germany

Eike Emrich
Institute of Sport Sciences, Saarland University
Campus B8.1, 66123 Saarbrücken, Germany

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Abstract

In Olympic-distance triathlon, time minimization is the goal in all three disciplines and the two transitions. Running is the key to winning, whereas swimming and cycling performance are less significantly associated with overall competition time. A comparative static simulation calculation based on the individual times of each discipline was done. Furthermore, the share of the discipline in the total time proved that increasing the scope of running training results in an additional performance development. Looking at the current development in triathlon and taking the Olympic Games in London 2012 as an initial basis for model-theoretic simulations of performance development, the first fact that attracts attention is that running becomes more and more the crucial variable in terms of winning a triathlon. Run times below 29:00 minutes in Olympic-distance triathlon will be decisive for winning. Currently, cycle training time is definitely overrepresented. The share of swimming is considered optimal.

Keywords: Simulation, Success, Economical considerations, Performance development, Olympic-distance triathlon

1. Introduction and Problem Specification

Overall performance in an Olympic-distance triathlon is based on the additive results of three individual disciplines: 1,500 m swimming, 40 km cycling, 10,000 m running plus the two transition times required between swimming and cycling as well as cycling and running, respectively. The goal of the athletic competitions is to minimize the times in all three disciplines and in the overall result compared to the competitors' times, which leads to a ranking position based on time consumption. Due to the small impact of the time used for the transitions, this aspect can be neglected in the overall analysis. The proportionate share of transitions represents only ≤ 1% of the total time consumed. Therefore, 99% of total competition time is allocated to the three disciplines (Millet & Vleck, 2000). For examples on the structural influence of the transitions on specific pacing strategies, refer to Hausswirth, Meur, Bieuzen, Brisswalter & Bernard (2010) and Vleck, Bentley, Millet & Bürgi (2008).

Due to various geographical, climatic, and regional conditions, such as natural terrain, waves, or selective round courses, the split times in the men's elite group are 17:00-19:00 minutes for a 1,500 m swim, 50:00-55:00 minutes for cycling, and 30:00-32:00 minutes for the final run. Within certain limits, the individual distances can deviate due to regional conditions from the distances officially defined in the rules. Swimming and cycling distances are usually more affected by this aspect than the running distance.

For example, the split times during the Olympic Games in London in 2012 were 16:56-18:59 minutes for the swim, 58:32-1:00:35 minutes for the cycle, which was considered to have been rather slow overall, and 29:07-35:36 for the 10,000 m run, which was considered extremely fast. The time range of the first 10 ranks was between 29:07-30:25 minutes. Based on regression analysis, Moeller (2012) forecast performance requirements of 17:30-18:00 minutes for the swim and 29:00-29:15 for the 10,000 m run in triathlon.

From the small time differences between the first and last athlete in the Olympic cycling race it is already obvious that cycling was performed considering tactical aspects and the perspective of energetic resource saving in a sheltered position in the back of the field, a strategy that is also known as drafting (Hausswirth, Lehénaff, Dréano & Savonen, 1999). Bentley, Millet, Vleck & McNaugthon (2002) state in this concept that low energy expenditure due to tactical drafting in the cycle part of triathlon is associated with increased performance in the subsequent run. Clever drafting reduces the required performance effort by about 30%, which becomes evident in reduced oxygen consumption, lower lactate levels, and reduced heart rate (Hausswirth et al., 2001).

The time difference between the first place in cycling and the last athlete in the field was only 2:03 minutes. Therefore, cycling is more and more assigned a purely supporting function for the decisive running part of the competition considering tactical and technical rationalities (Brisswalter & Hausswirth, 2008; Millet & Bentley, 2004). Accordingly, the correlation between discipline and overall performance relating to the ranking by discipline and time realized is the highest in running (correlation coefficients of 0.71-0.99). However, for swimming and cycling, there are significantly less or no correlations between overall time and overall ranking (Fröhlich, Klein, Pieter & Emrich, 2008; Moeller, 2012; Vleck et al., 2008; Vleck, Brügi & Bentley, 2006).

For instance, Fröhlich, Klein, Pieter, Emrich & Gießing (2008) used multiple regressions to show that both swimming and cycling times do not represent sufficient predictors for forecasting overall time and ranking. In this context, however, further assumed performance physiological, anthropometric, and biomechanical parameters, such as VO_{2max}, lactate level, running economics, step frequency, etc. as performance-differentiating determinants will not be discussed in detail here (Bentley et al., 2002; Dengel, Flynn, Costill & Kirwan, 1989; Knechtle & Kohler, 2009; Schabort, Killian, St Clair Gibson, Hawley & Noakes, 2000).

Looking at the overall time for an Olympic-distance triathlon, the shares of the individual disciplines are 15-18% for swimming, 52-55% for cycling, and 28-30% for running (Landers, Blanksby, Ackland & Monson, 2008; Millet & Vleck, 2000). Similar time share distribution is assumed for training in the respective disciplines (Millet et al., 2002). Currently, the average training scope for swimming is approximately 1,000-1,300 km, for cycling approximately 10,000-14,000 km, and for running approximately 2,800-4,500 km a year. However, due to the anecdotal evidence and descriptive narratives in sports, it is safe to assume that the training investment in cycling is disproportionately high, but without effect in the context of the development structure in Olympic-distance triathlon. In line with the higher degree of significance of running, a stronger orientation of training concepts toward running is discussed (Moeller, 2012). Since no empirical evidence on the decreasing results of increased training investment in terms of time (Fröhlich, Emrich, Büch & Gießing, 2008) or on the resulting performance in the individual disciplines of Olympic-distance triathlon exists, the following central questions with a focus on economics and training science arise: how are triathletes supposed to distribute their training time under optimal conditions, and which effects are to be expected (i.e., the relative contribution of training time invested in the three disciplines for the overall competition performance is to be analyzed)? Also, from a cross-period, dynamical point of view, the investment strategies in terms of dynamic inter-discipline competition is to be identified, as well as the performance development trends to be expected. Considering identical optimization strategies, but different potential of the athletes, various unintended effects may become evident (Fröhlich, Emrich & Büch, 2007).

2. Methods

2.1 Model-theoretic Analysis of Olympic-distance Triathlon

As already mentioned time minimization in the individual disciplines and overall time applies, meaning that from a formal-logical perspective the fastest swimmer with the fastest cycle time and the fastest run time has the fastest overall time and is thus the overall winner of the collective. For the analysis of this model we will neglect the facts that this person probably will never exist and that the competition structure will result in different constellations, because the optimization function pertaining to the individual disciplines and overall time is the center of our observations.

Considering model-theoretic aspects and the varying influence of the individual disciplines on overall time F(x), the function to be minimized applies to Olympic-distance triathlon:

$$\mathrm{F}(x) = c_1x_1 + c_2x_2 + c_3x_3$$

with $(x_1, x_2, x_3)'$ representing vectors for the individual run times (x_1), cycling times (x_2), and swimming times (x_3), and with the vector components of $(c_1, c_2, c_3)'$ being the coefficients describing the influence of the individual discipline on the overall result. The vector $(x_1, x_2, x_3)'$ therefore represents the central influencing values and the vector $(c_1, c_2, c_3)'$ the volume of these values. Theoretically, they map the different potentials of the athletes. Moreover, it can be assumed that the times for the disciplines x_1, x_2, x_3 improve or deteriorate depending on the share of training time invested for the individual discipline with p_1, p_2, p_3 ($0 \leq p_1, p_2, p_3 \leq 1$). The individual physiological and structural strain limits restrict the maximum time input because the body reacts with overload or over-train symptoms. The individual point of load culmination should not be exceeded (Fröhlich, 2012), which means that we assume a decreasing, but positive marginal benefit under optimal conditions. Furthermore, ideally, a direct relationship – which is not further specified empirically – between training times invested and performance within the discipline should be assumed. The following applies:

- p_1 = share of training time for running in overall training time
- p_2 = share of training time for cycling in overall training time
- p_3 = share of training time for swimming in overall training time

We also assume that the shares of training time for the individual discipline add up to one (overall training time) and are greater than zero. For example, if p_1 and p_3 increase, p_2 must decrease in the same amount (but will not become negative; value range between 0 and 1). So if someone invested 100% of training time in swimming, the record time or world record should be attainable in this discipline under formal-logical conditions.

2.1 Limiting Plausibility Assumptions

To continue with the simulation of performance development based on the comparative static model, a few limiting assumptions must be stated:

- Peak performances on a global scale (world record or similar) of specialists must be transformed and defined as the basis.
- The weighting shares of the individual disciplines in the overall result (final time) must be identified empirically, weighted, and included in the calculation.

The normative transformation basis for estimating the currently possible performance potential for swimming is the world record over 1,500 m on the 50 m lane set by Sun Yang in London (OS August 4, 2012) at a time of 14:31,02 minutes. Here, it is already obvious that the transformation rule must not be taken into account without limitations. For example, the triathlon swimming competition takes place in open water and with a mass start, and the distance to be swum is not always exactly 1,500 m due to the respective regional conditions. Furthermore, turn time gains (0.6 seconds per turn) in lane competitions, climatic and weather conditions during open water swims, neoprene suits providing additional buoyancy, etc. must be taken into account, as well (Moeller, 2012). For the model observations here, however, these limitations will not be considered.

The best possible specialist time for cycling was determined by the single pursuit race over 44 km – broken down to 40 km – at the Olympic Games in London on August 1, 2012. Bradly Wiggins would have achieved a time of 46:04 minutes for 40 km (44 km in 50:39:54 minutes). This normative basis is also to be considered within limitations because a single pursuit race is not really comparable to a drafting mass race. Moreover, in triathlon, a certain tiredness and energetic strain can be expected due to the swimming competition before.

The reference time for the run was the world record of 26:44 minutes set by Leonard Patrick Komon in Utrecht on September 26, 2010 in a 10,000 m street race. Limitations apply here, as well: the strain from the swimming and cycling disciplines must be taken into account. Furthermore, the triathletes usually do not start their 10,000 m run simultaneously, which adds a slightly different character to this race than to a mass start.

3. Simulation Results

If these assumptions and contextual limitations are applied, and if the specialist times of the individual disciplines are the basis for a benchmark, the following potential for improvement exists: (based on the time of Olympic champion 2012 Alistair Brownlee [he is the benchmark]: swimming 17:04, cycling 59:08, running 29:07, overall time including transitions 1:46:25) approx. 17.6% in swimming, approx. 28.4% in cycling, and 8.9% in running. Based on the respective specialist times, an overall time of 1:27:19 would hypothetically be possible. In an optimized analysis taking into account the influence of the individual disciplines in the overall time scope (estimated based on the beta weights of the incremental, multiple linear regression with an adjusted coefficient of determination of $R^2 = 1$ with $\beta = 0.77$ for running, $\beta = 0.23$ for cycling, and $\beta = 0.32$ for swimming (see Fröhlich et al., 2008), the formula

$$\text{(II) } c_1 = 0.77 / (0.77 + 0.23 + 0.32) = 0.58, c_2 = 0.17, c_3 = 0.24$$

and the side condition of an upper limit is the basis for simulating the competition time. The upper plausibility limit for the simulation consists of the maximum times for the individual disciplines at the Olympic Games 2012.

The maximum time for running was 35:36, for cycling 60:35, and for swimming 18:59. The side conditions for the discipline times with minimum (a) and maximum (b) based on (a_1 = 26:44, a_2 = 46:04, a_3 = 14:31, b_1 = 35:36, b_2 = 60:35, b_3 = 18:59) are:

$$26{:}44 \leq x_1 \leq 35{:}36$$

$$46{:}04 \leq x_2 \leq 60{:}35$$

$$14{:}31 \leq x_3 \leq 18{:}59$$

If one simulates based on the plausibility assumptions, the side conditions, and the empirically identified weighting factors using the equation function:

$$x_1 = a_1 p_1 + b_1 (1 - p_1)$$

$$x_2 = a_2 p_2 + b_2 (1 - p_2)$$

$$x_3 = a_3 p_3 + b_3 (1 - p_3)$$

these split times are the result: 18:05 for swimming, 57:41 for cycling, and 30:17 for running with an overall time of 1:46,03, which means a smaller overall time than the current Olympic champion achieved. The training shares in this simulation are p_1 = 60% running, p_2 = 20% cycling, and p_3 = 20% swimming.

Due to the fact that the time simulated here is only 22 seconds less than the time of the current Olympic champion, the empirical analysis shows based on the beta weights that the training time available should be significantly increased for running. Since Alistair Brownlee's result is so close to the optimum of the simulation, it is safe to assume that he invested his training time based on the shares identified (Moeller, 2012). If the simulation is applied under the side conditions described to the three medal winners of the Olympic Games, it is evident that the training shares for running predominate for all three candidates. Image 1 is a graphical representation of the dimension of the individual disciplines x_1, x_2, and x_3, with all points on the dark gray level within the cube illustrating possible solutions.

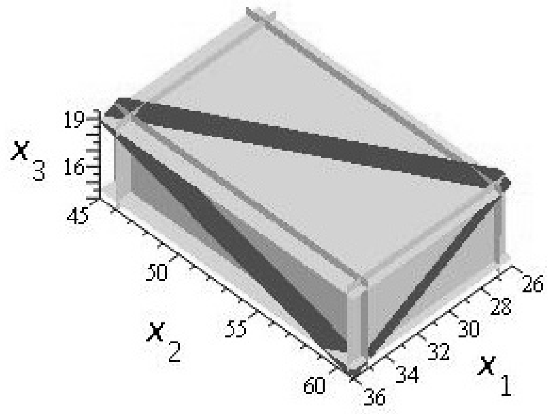

Figure 1. Optimization of the dimension of the individual disciplines running (x_1), cycling (x_2), and swimming (x_3) in Olympic-distance triathlon

In an extended optimization simulation with the training times p_1 = 50% (running), p_2 = 30% (cycling), and p_3 = 20% (swimming), the overall time of 1:45:29 could even be achieved. At the discipline level, this would be:

$$x_1 = 31{:}10,\ x_2 = 56{:}14,\ x_3 = 18{:}05$$

Thus, at an individual level and under comparative static conditions, the training times for athletes who did not win a medal should be slightly increased for swimming, significantly reduced for cycling, and significantly increased for running – if that has not been implemented yet.

4. Implications

Looking at the current development in triathlon and taking the Olympic Games in London 2012 as an initial basis for model-theoretic simulations of performance development, the first fact that attracts attention is that running becomes more and more the crucial variable in terms of winning a triathlon. Due to this significant character of running performance, it is only conditionally subject to tactical influences (Ebeling, Moeller & Knoll, 2009).

Swimming and cycling, however, should be performed using drafting to save resources (Brisswalter & Hausswirth, 2008; Chatard & Wilson, 2003; Peeling, Bishop & Landers, 2005). Therefore, swimming and, more explicitly cycling are increasingly performed considering individual-tactical aspects. The influence of team-tactical considerations in major competitions, such as world championships or Olympic Games can only be assumed, but has not been empirically proven yet.

The simulation showed that proportionate changes in training scopes in swimming, cycling, and running can result in further performance development. The following implications can therefore be drawn: Runners who are not able to run the distance in approximately 29:00 minutes – and in the future, probably below 29:00 minutes – due to individual genetic disposition or limited strain tolerance, will not have any chance to reach a top ranking in any international championship.

In swimming, the current weighting of training scope and the resulting achievement seems to be well balanced. This means that the currently implemented training scopes largely correspond to the results achieved and do not need to be changed substantially ceteri paribus.

The high amount of training time invested in the individual discipline of cycling is not associated with the relevance for a good ranking and is therefore recommended to be reduced in favor of training time for running.

The comparative static simulation shows that relevant performance improvement is still to be expected in Olympic-distance triathlon. However, it is to be considered that the intended interaction effects resulting from a redistribution of training shares cannot be estimated.

5. Limitations

The simulation calculation is not only subject to the limiting plausibility assumptions, but also the limitation that only purely quantitative performance and training indicators, such as time used and time invested were considered. Statements on training quality, e.g., which content is to be used for achieving the performance, cannot be made and were not included in the analysis. Within the scope of qualitative individual analyses, the extent of qualitative and quantitative changes to the training process in favor of running that have already been implemented could be elicited post-hoc. Moreover, the results only apply to Olympic-distance triathlon in the elite group and the application of the drafting rule considering the specifics of energetic resource saving and tactical action options (Chatard & Wilson, 2003; Landers et al., 2008). Therefore, statements on woman races or other competition forms, such as the Ironman race, without the drafting rule applied, cannot be made. Athletes who are less efficient in running could consider the IRONMAN 70.3 with half the Ironman distance (1.9 km swim, 90 km cycle, and 21.1 km run, overall distance 113 km or 70.3 miles) or the classic IRONMAN as an alternative because the swimming, cycling, and running shares and the influence on the overall time are distributed differently (Abbiss et al., 2006). Knechtle and Kohler (2009) were able to prove, however, that in Triple Ironman triathlon races, the influence of running on the overall competition result (overall competition time and running time (r^2 = 0.87) is larger than that of cycling (r^2 = 0.62)).

Finally, normative evaluation comparisons must be taken into account because in contrast to direct performance comparisons like decathletes vs. specialist athletes, based on rule-bound measurement guidelines the performance comparisons of triathletes vs. specialist athletes are subject to tolerable measurement accuracies (e.g., distance, exogenous influences, strain accumulation in the three disciplines, etc.).

It is to be noted that only the simplified relationship between training and time achieved was included in the simulation, with only the increasing function in terms of marginal benefit having been considered, and decreasing marginal achievements not having been factored.

6. Conclusion

The current competition structure in Olympic-distance triathlon favors excellent runners because the impact of running on the overall result is higher than the other two disciplines. By redistributing priorities and additional extension of training time in running, further performance increases in the sense of reducing the overall time are to be expected. Run times of below 29:00 minutes in Olympic-distance triathlon will become decisive for winning. Modified training concepts, e.g. "high intensity interval training (HIIT)" methods could compensate for the high amount of time invested in cycling and thus, alternative ways to success could be found (Paton & Hopkins, 2004).

Conflict of interest

No conflicts of interest exist.

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