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Competitive Performance of Elite Olympic-Distance Triathletes: Reliability and Smallest Worthwhile Enhancement

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PURPOSE. The reliability of competitive performance of athletes in a given sport provides an estimate of the smallest worthwhile change in performance, which is crucial when testing athletes and when assessing factors that affect performance in that sport. We have therefore analyzed the reliability of athletes competing in international Olympic-distance triathlons. METHODS. We obtained official results from websites for triathlons performed before drafting in the cycling stage was permitted. We analyzed times for 103 athletes who entered two or more of nine such races over 19 months. Our measure of reliability was the typical race-to-race variation of an athlete's time, derived as a coefficient of variation by analysis of log-transformed times. RESULTS. (a) Typical race-to-race variations were: swim 1.6%, cycle 2.3%, and run 3.6%. When combined independently or dependently with the durations of each phase (20, 60 and 35 min), these variations yielded predicted variations in total time of 1.6% or 2.6% respectively, whereas the observed variation was 1.8%. (b) Transition times, which were available for three races, averaged 89 s for the swim-cycle and cycle-run transitions combined. Between-athlete variation in these times in each race was 5.2, 5.6 and 7.8 s, or ~0.1% of the mean total time of 115 min. (c) Analysis of reliability between all possible pairs of races showed no substantial effect of time between pairs (14-567 days). (d) Reliability between pairs of races held in normal environmental temperatures was better than when at least one of the pair was held in hot conditions (typical variations of 1.6% and 2.0% respectively). (e) The top 10% of triathletes, who averaged 3.4% faster than the average triathlete, had substantially smaller variations than the other triathletes for total time (1.1%) and for each of the three stages (swim, 1.2%; cycle, 1.3%; run, 2.5%). In triathlons where drafting in the cycle stage is permitted, variation in total time of the top triathletes is probably determined by the run alone and is therefore ~0.8%. CONCLUSIONS. (a) Factors that affect performance of individual elite triathletes act largely independently in the three phases. (b) No worthwhile gains in performance are possible in the transitions. (c) Elite triathletes' performance is remarkably stable over a 19-month period. (d) The outcome of a triathlon staged in a hot environment is somewhat less predictable than normal. (e) The smallest important change in race time for a top triathlete (half the variation in total time) is ~0.5%, which in current triathlons has to be achieved via changes of at least 1.2% in running speed.

KEYWORDS: competition, error, race, reproducibility, testing, variability.

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Introduction

Anyone with a serious interest in the performance of top-level athletes should appreciate the importance of the smallest worthwhile change in performance: the change that makes a meaningful difference to an athlete's chances of winning. Knowledge of this change is needed when assessing athletes with a performance test either to make decisions about meaningful changes in an individual or to research strategies that might affect performance (Hopkins, 2004).

For athletes who compete as individuals and who win by achieving the best time, distance or other score, analysis of reliability (reproducibility or variability) of competitive performance provides an estimate of the smallest worthwhile change (Hopkins et al., 1999). Performance of the individual athlete always shows random variation from competition to competition. Enhancements or impairments of performance affect an athlete's chance of winning only if they are greater than about half the magnitude of this random variation. As yet, the only fully published data on variability of competitive performance are for junior swimmers (Stewart and Hopkins, 2000), elite swimmers (Pyne et al., 2004) and non-elite runners (Hopkins and Hewson, 2001) More studies on the variability of competitive performance are needed. We address here the question of the magnitude of variability in performance time of top triathletes.

Methods

We searched the Web for official result times of international Olympic-distance triathlons. At the time, the practice of drafting (riding in packs during the cycle stage) was not permitted. We arbitrarily limited data to the races in a 19-month period, as shown in Table 1. To contribute to the analysis of reliability, athletes had to compete in and finish at least two races. The numbers of such athletes and their race times are shown in the table. For these athletes, overall mean times (min) were: swim, 19.5; cycle, 59.8; run, 35.1; and total, 115.0.

We derived estimates of variability in times of individual athletes from race to race using procedures described previously for competitive runners (Hopkins and Hewson, 2001). Briefly, we applied the mixed linear modeling procedure (Proc Mixed) of the Statistical Analysis System (Version 8.2, SAS Institute, Cary, NC) to log-transformed times and derived a within-athlete coefficient of variation (standard deviation expressed as a percent of the mean) along with their 90% likely (confidence) limits. The within-athlete coefficient of variation represents the typical percent variation in performance of an athlete from race to race after statistically controlling for differences in mean times of each race.

Table 1. Olympic-distance triathlons and triathletes analyzed in this study.

Venue	Date	Athletes analyzed	Total time[a] (min)
Japan1	13 Apr 97	23	110.5 ± 1.6
Japan2[b]	6 Jul 97	32	115.4 ± 4.4
Sweden	26 Jul 97	56	112.3 ± 2.4
Bermuda[b]	21 Sep 97	37	121.3 ± 4.6
Australia1	26 Oct 97	48	116.6 ± 2.7
Australia2	16 Nov 97	52	113.1 ± 3.4
Japan	12 Apr 98	51	115.9 ± 3.7
Australia3	26 Apr 98	48	114.8 ± 2.9
New Zealand	1 Nov 98	39	111.8 ± 2.8

[a]Mean ± standard deviation.
[b]Performed in a relatively hot environment (>30°C).

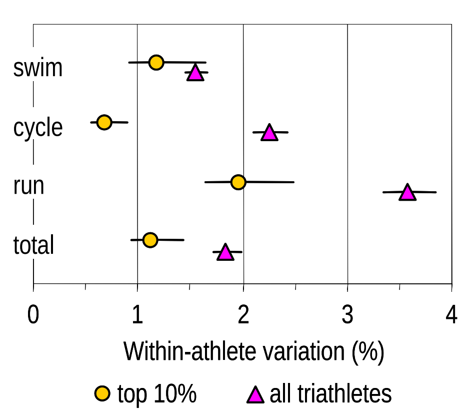
Variability in each phase of the triathlon contributes to variability of the total time. If an athlete's performance in each phase is independent of that in the other phases, the variability of the total time should be equal to the square root of the sum of the variances representing variability in each phase. On the other hand, if an athlete's performance in each phase was fully dependent on that in each other phase, the variability of the total time should be equal to the linear sum of the standard deviations. We estimated the variability in total time by combining the variabilities in each phase independently and dependently, for comparison with the observed variability in total time.

The above analyses were performed for all data and for subgroups of the top 10%, 20%, and 50% of the triathletes, identified by ranking the least-squares means of each athlete's total time across all races. This ranking procedure adjusts each athlete's race time for the mean duration of the race and for the races the athlete did not enter, and thus it is a more accurate way to rank the athletes than simply averaging raw times (Hopkins and Green, 1995).

To examine the effect of time between races on within-athlete variability, we computed variability for every possible pairwise combination of races; we then plotted the resulting coefficients of variation against the time between the races. The effect of environmental temperature on variability was investigated by labeling separately the points on the plots representing races that were paired with one of the two races held in the hottest conditions (>30°C, as provide in the official race results). Unweighted least-squares lines were fitted to these points and to the points representing the pairs of all other races. Confidence limits for these lines and their comparisons were not derived, owing to the lack of independence of the points.

Differences between coefficients of variation representing race-to-race variability were considered substantial if their ratio was greater than 1.10. The rationale for this decision is as follows: the smallest worthwhile change in performance is proportional to the variability (Hopkins et al., 1999); sample size in studies aimed at quantifying a mean change is inversely proportional to the square of the magnitude of the change (Hopkins, 2000); therefore a ratio of 1.1 represents an increase in sample size of a factor of 1.21 (1.1^2), or a 21% increase.

Figure 1. Typical variation in a triathlete's swim, cycle, run, and total performance time averaged over all nine triathlons for all triathletes and for the top 10%. Bars are 90% confidence limits.



Results

Typical within-athlete variation in performance times from race to race is shown in Figure 1. The variations in the figure for all athletes are: swim, 1.6%; cycle, 2.3%; run, 3.6%; and total, 1.8%. When combined independently or dependently, the variations of the three phases yielded predicted variations in total time of 1.6% or 2.6% respectively.

Total race time of the top 10% of athletes was 3.4% faster than that of the mean for all athletes. For these top athletes, the within-athlete variations shown in Figure 1 are: swim, 1.2%; cycle, 1.3%; run, 2.5%; and total, 1.1%. The predicted variations in total time were 1.0% or 1.6% respectively for independent or dependent variabilities in the three phases. Variability of performance of the top 20% of athletes was little different from that of the top 10%, but the variability of the top 50% was substantially greater.

Transition times were available for three venues (Table 2). Mean transition time was 89 s for the swim-cycle and cycle-run transitions combined. The between-athlete variation in time is equivalent to ~0.09% of the mean total race time of 115 min. Within-athlete variation over the three races was a little less (4.6 s, or 0.07%).

Table 2. Total transition times in the three races with such data recorded.

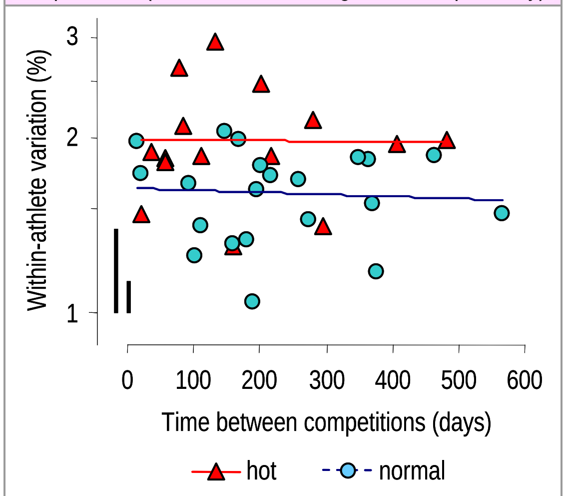
Venue	Mean ± SD (s)	Range (s)
Sweden	84 ± 5.2	72 – 96
Australia1	66 ± 7.8	42 – 83
Australia2	114 ± 5.6	104 - 127

For the analysis of within-athlete variation between all pairs of races, the mean sample size was 19 (range 6-32). A plot of within-athlete variation (Figure 2) showed no substantial effect of time between pairs over the range of 14-567 days. Typical variation between pairs of races held in normal environmental temperatures (mean 1.6%) was less overall than when at least one of the pair was held in hot conditions (mean 2.0%). The extra random variation added to an athlete's performance time in the heat is given by $\sqrt{(2(2.0^2-1.6^2))}$ = 1.6%.

Discussion

We performed this study primarily to determine the smallest worthwhile change in performance for top triathletes. The analyses also revealed interesting and useful information about the stability of performance time between races and about the contributions of each of the three phases and the transitions to performance time.

Figure 2. Within-athlete variation (log scale) in performance between all pairs of the nine triathlon competitions, plotted against time between the competitions. Pairings and regression lines are shown for pairs of competitions held in normal environmental temperatures and for pairs with at least one of the pair in hot conditions. Bars are standard deviations representing expected sampling variation for the smallest and largest sample sizes (6 and 32, left and right bars respectively).



The triathletes who were in the top 10% overall were substantially less variable in their performance than the average international triathlete. Less variability for faster subgroups of athletes in competitions has been observed in previous studies (Stewart and Hopkins, 2000; Hopkins and Hewson, 2001; Pyne et al., 2004) and presumably reflects more consistent preparation, pacing, or motivation from race to race. The smallest worthwhile change in performance is about half the typical race-to-race variation (Hopkins et al., 1999), so for our top triathletes this change is ~0.5×1.1 = 0.5% of total race time.

A surprise finding was that random changes in times for each of the phases were largely independent of each other. It follows that any factors that normally affect a triathlete's performance in competitions must act predominantly in only one phase. For example, changes in endurance fitness, such as maximum oxygen uptake, either have a substantial effect on only one of the phases or are inconsequential on any phase relative to whatever other factors affect performance. It is therefore likely that any single strategy aimed at enhancing a triathlete's total performance time by the minimum target of 0.5% would have to focus on only a single phase.

Before the recent change to permit drafting in the cycle phase, it was possible in principle to achieve the minimum gain of 0.5% in any phase; indeed, it may still be possible to achieve worthwhile gains in the swimming and cycling stages in a triathlon where a hilly course reduces the effect of drafting. The necessary gain in speed would depend on the duration of the phase. The duration of the swim phase is about one-sixth of the total duration, so a 0.5% enhancement in overall time would require a 3% (=6×0.5%) enhancement of swimming speed–an unrealistic target at the top level. Corresponding enhancements in cycling and running speeds would be 1.0% and 1.6%, which are more achievable. Now that drafting is allowed, it is reasonably clear that the medal winners have to leave the water in time to join the first cycling pack, because these riders generally stay together in the cycle phase and achieve a lead that is difficult for other riders to overcome in the running phase. The best triathletes therefore now have to be fast enough in the swimming phase to join the first pack in cycling phase, and they should focus performance-enhancing strategies on the run phase. If we assume that the only contribution to variation in total time now comes from the run phase, and that the within-athlete variation in the run phase of the top athletes is similar to what we observed (2.5%), the variation in total time becomes 35/115×2.5% = 0.8%; the smallest worthwhile change in total time becomes ~0.5×0.8 = 0.4%, and this change has to be achieved by a change of ~0.5×2.5% = 1.2% in running speed.

There is also no substantial achievable gain in the transitions, because the variation in transition time represents <0.1% of the total time. In triathlons where drafting is permitted, the variation in the swim-cycle transition might be large enough in principle affect the athlete's chances of getting into the first pack. However, most of the variation in the transition is due to within-athlete random variation, and it is difficult to imagine how an athlete could modify such variation to improve a transition time.

Another noteworthy finding is the remarkable stability of performance of triathletes at international level. Indeed, as can be seen in

Figure 2, there was no indication in this sample of any increase in variability even over 19 months, implying that athletes hold their form for at least this period. The error bars in the figure show that the scatter in the within-athlete variation is due mainly to sampling variation in the estimates, rather than to true differences in variation between races.

Finally, it is reasonably clear that performance was more variable for triathlons staged in the hottest conditions. The variability added by the heat is enough to substantially disadvantage some athletes relative to others. It is possible that aggressive acclimation strategies would reduce this variability to an inconsequential level, but some athletes may be inherently more disadvantaged in the heat, no matter how well acclimated they become.

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