**Reliability and stability of performances in 400-m swimming and 1500-m running**

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1. Abstract

Purpose: To assess the reliability and stability of performances in 400-m freestyle swimming and 1500-m track running competitions in order to establish the number of samples needed to obtain a stable pacing profile. Coaches, athletes and researchers can use these methods to ensure sufficient data is collected before race strategies are made or research conclusions drawn. Method: Lap times were collected from 5 World and European Championship finals between 2005 and 2011 resulting in the capture of data from 40 swimmers and 55 runners. A cumulative mean for each lap was calculated starting with the most recent data. The number of races needed for the cumulative mean to stabilise to within 1% was calculated. Typical Error for each lap was calculated for athletes who had competed in more than 1 final. Results: International swimmers produced more reproducible performances than runners in three of the four laps of the race (p<0.01). Variance in runners lap times significantly decreased by between 1.7-2.7% after lap 1 whereas variance in swimmers lap times tended to increase by between 0.1 to 0.5% after lap 1. To obtain sufficient data to establish a stable profile, at least 10 400-m swimmers and 44 1500-m runners must be included in the sample. Conclusions: When examining relative lap times, researchers should use total time as the normalising factor because individual laps demonstrate considerable variability. A stable race profile was observed from the analysis of five events for 1500-m running and three events for 400-m swimming where the cumulative lap time was stabilised to ±1% of the mean. Swimmers and their coaches can rely more on recent performance data to predict likely tactics of opponents due to the reduced variation between events.

Keywords:

Typical error, cumulative mean, pacing profile

1. Introduction

Pacing is the goal directed distribution and management of effort across the duration of an exercise bout.[1](#_ENREF_1) Pacing strategies used in real and simulated competition can be negative, positive, all-out, even or parabolic J-, reverse J- and U-shaped[2](#_ENREF_2) and are a popular current topic in the sport science literature.[3](#_ENREF_3) Investigations of pacing profiles across a variety of sports have been determined using a range of methods including laboratory trials,[4-6](#_ENREF_4) the collection of real time data[7](#_ENREF_7) and the use of retrospective data.[8-10](#_ENREF_8)

The use of retrospective data provides researchers, athletes and coaches with access to large amounts of timing data that is relatively cheap and easy to obtain. However when using data collected over a number of years it is important to establish whether the data are reliable and stable. This gives the investigator confidence that statistical inferences obtained using this data are real. It is also beneficial for coaches and athletes to know the most effective pacing profiles that have occurred during elite races and how reproducible these profiles were in order to assist preparation for competition especially tactical plans and expectations.[5](#_ENREF_5),[9](#_ENREF_9) By analyzing an athlete’s pacing profile and that of their opponents, coaches can develop training programmes to suit a planned race strategy as well as learn about pacing.[11](#_ENREF_11) Race strategies could be developed based on the predictability of opponents’ recent pacing profiles in order to minimize the additional physiological strain of working to someone else’s pace during a race.[12](#_ENREF_12)

Pacing strategies during world record performances in 200-m freestyle swimming, 800-m running and 1500-m speed skating can differ markedly, despite the events being of almost identical race duration.[13](#_ENREF_13) Event duration significantly affects the pacing strategies adopted by elite performers in both running and swimming competitions, with a fast finish (‘end-spurt’) on the final lap tending mainly to be seen in events longer that 200-m swimming and 800-m running.[9](#_ENREF_9),[10](#_ENREF_10) In addition to the differing physical environment, middle-distance running and swimming also differ in the degree of interaction between athletes. Pool swimming races are performed in separate lanes for the entire race, whereas runners will come into closer contact, resulting in a greater tactical component, increasing the potential for variability in pacing within- and between events. So, despite 400-m freestyle swimming and 1500-m running events being of similar duration, it would be interesting to compare the number of competitions that need to be collected retrospectively in both events before the data is sufficiently stable to enable a valid comparison of pacing strategies. In addition, research in these middle-distance events has not previously reported within-subject repeated measures pacing data. Researchers, coaches and athletes could use these methods to ensure they collect sufficient pacing data when analyzing performance, developing plans for training and competition.

A stable profile is found when performances become consistent between events. A number of methods have been used to achieve this aim including the use of coefficient of variation and limits of agreement,[14](#_ENREF_14) t-tests between data from one event compared to a number of previous events[15](#_ENREF_15) and 90% confidence limits.[10](#_ENREF_10) An alternative method of identifying stable data has been developed by Hughes *et al*[15](#_ENREF_15) in the context of match play in a variety of racket and team sports and this method would appear suitable for use in other contexts such as pacing profile stability as it is able to produce the minimum number of races needed before data stabilises. Data used in retrospective studies in pacing varies widely in scope from lap times collected at a single event[16](#_ENREF_16) to lap times collected over 85 years[9](#_ENREF_9) and a number of studies have used multiple recent events to provide their data.[8](#_ENREF_8),[10](#_ENREF_10) However none of these studies have justified their choice of data collection period or demonstrated that they have used enough data to provide a stable and reliable pacing profile with which to analyze pacing changes.

Using 400-m swimming and 1500-m running as example events, the current study aims to a) establish the reliability of middle-distanceswimming and track athletics lap data of international-standard competitors, and b) to determine the number of races required to be analyzed before a stable pacing profile can be established within an acceptable error margin for the benefit of investigating pacing and planning training and race strategies.

1. Methods

*Data Collection*

Data were collected from five major international competitions between 2005 and 2011 in both 400-m swimming and 1500-m running events. In total 40 performances were analyzed from five international 400m freestyle swimming final competitions. Split times from the final in each championship were included from the Ligue Européenne de Natation (LEN) European Championships in 2008 and 2010 and the Federation Internationale de Natation (FINA) World Championships in 2007, 2009 and 2011. Data was freely available in the public domain from the Omega Timing results service (www.omegatiming.com) and was anonymised before publication. For 1500-m running, video recordings were obtained from public websites of 5 athletics final events. Videos were included from the 23rd and 24th Olympiads (Athens 2004 and Beijing 2008), the International Association of Athletics Federations (IAAF) World Championships in 2009 and 2005, and the European Athletics Championships in 2010. Videos were only used when a static camera view of the start/finish line existed as athletes crossed the line on every lap during the final of the 1500-m event. In total 60 performances were analyzed from these five events. It is worth noting that a static camera view of the start/finish line was not available for the IAAF 2011 or 2007 World Championships or the European Athletics Championships in 2006. The videos were uploaded into Dartfish TeamPro v5 (Dartfish, Switzerland) and each athlete’s lap times measured using a frame by frame playback method.[17](#_ENREF_17)

*Within-subject pacing profile reliability*

Hopkins *et al.*[18](#_ENREF_18) suggested reporting the typical error to demonstrate within-subject reliability. Data from each athlete’s first recorded event was used as trial one and from their second as trial two. Eleven swimmers had competed in more than one championship final (with a mean time between finals of 20.5 ± 13.3 months). Twelve runners had competed in more than one championship final (24.9 ± 18.9 months between finals). Trial one to trial two data were then compared using Hopkins’ reliability spreadsheet[19](#_ENREF_19) and the typical error (TE) and coefficient of variation (CV) reported. A two-way ANOVA with repeated measures on lap was used to analyze changes in variation between the laps and sports.

*Stability of the pacing profile*

The stability of the pacing profile was analyzed using the cumulative mean method [15](#_ENREF_15) to calculate the number of races needed before the cumulative mean stabilises itself to within set error margins (NE). Lap times for each finalist were added in reverse chronological order and added to a cumulative mean. The point at which the cumulative mean entered and remained within a set % error range was identified. Error percentages of 10%, 5% and 1% were calculated for each lap. The NE needed for each lap to remain within a 1% range was identified.

1. Results

*Within-subject pacing profile reliability2*

There were no significant differences in total times between trial 1 and 2 in either running (p=0.18) or swimming events (p=0.66). The mean total times were 216.08 ± 2.30s and 217.67 ± 3.03s for 1500-m run and 225.86 ± 2.33s and 225.48 ± 2.54s for the 400-m swim in trials 1 and 2 respectively. The TE values for within-subject reliability were low and can be seen in Table 1. The reliability of swimming times, both individual laps and total time, is greater than running times. Figure 1 shows the CV between two performances from the same athlete at different events. There was a significant interaction between lap number and sport (p=0.001). Post hoc tests between sports showed that variation was greater in running than in swimming in laps 1 (p=0.001), 2 (p=0.01) and 4 (p=0.01) but not different in lap 3 or total time. Post hoc tests within sports showed that swimming laps tended to become less variable during the race (p=0.06), however lap 1 in running was significantly more variable than laps 2,3 and 4 (p=0.005).

*Stability Results for 400m swimming*

Analysis of Figure 2(a-d) shows that it is necessary to collect data from at least ten individuals to stabilise lap 1 in 400m swimming and that less data is needed to stabilise laps 2-4 (Table 2). In addition it would be necessary to have a cumulative mean that remains within the allowed fluctuation parameters for one additional race after this number to ensure complete stability. Eight athletes contest the finals in major swimming events which means that it is necessary to collect data from at least three swimming events to stabilise the pacing profile to 1% error. Collecting more than three events does not affect the profile stability.

*Stability Results for 1500-m running*

The 1500-m stability analysis demonstrates that it is necessary to collect data from at least 44 individuals to stabilise all four laps in this event (Figure 3c). As twelve athletes contest the finals in major events this means that it is necessary to collect data from at least four running events to stabilise the pacing profile to 1% error. In addition it would be necessary to have a cumulative mean that remains within the allowed fluctuation parameters for one additional race after this number to ensure complete stability and the analysis confirms this when a fifth race is added and the profile remains stable. Table 2 summarises the N(E) for the individual laps in 1500-m running.

1. Discussion

The findings of this study suggest that in international standard competitors, within-subject reliability for 400-m swimming times is greater than 1500-m running for individual lap times despite both events being of similar duration. Laps 1, 2 and 4 in the 1500-m running events were found to demonstrate greater variation than the corresponding laps in the swimming events. These differences between exercise modalities might be due to a number of factors such as a higher degree of tactical racing in the first lap in track athletics when the athletes will jostle for position, the manner of the start being different to swimming (i.e. dive start in swimming) and differences in kinetic energy production and loss and mechanical efficiency between the two sports.[13](#_ENREF_13) It would appear that elite swimmers vary their pace to a lesser extent than elite runners at the beginning of a race. The differences in variability measured between exercise modalities reduced as the races progressed, which may be due to pacing becoming more tightly controlled as competitors in either sport attempt to protect their remaining metabolic resources to achieve their best performance by the end of the race. This shows that swimmers and their coaches have greater opportunity to predict the potential strategies of their opponents than runners can and could therefore incorporate this knowledge when planning race strategies and training interventions. This could take some uncertainty out of an athlete’s mind at the start of an event.

The change in variance of velocity profiles as the race progresses seems to be opposite in running and swimming. Swimmers in the 400-m event demonstrated a high degree of consistency in the first 100-m of the race with the variance tending to increase as the race progressed. A similar pattern in elite swimmers was reported when analysing between-subjects mean and standard deviation times for the 400-m freestyle event.[10](#_ENREF_10) CV calculated from their data results in values of 1.54%, 1.29%, 1.60% and 2.12% for the four 100-m race segments respectively when using data collected from nine international events. This is very similar to the pattern of change shown in Figure 1 and in both cases CV rose by about a third from lap 1 to lap 4. This is likely to be an indication of fatigue and deterioration in mechanical efficiency as the race progresses. However this contrasting pattern to runners might also be due to swimmers not having to compete for space in their lane at the start of the race, which will mean they are able to self-select a more optimal pace for the entire event earlier in the race than track and field runners can. In middle distance running, athletes are more influenced by external factors and their pace may be dictated by the pace of the running pack to maintain a tactically advantageous position. Again this re-confirms that performance in 400-m swimming is more predictable than 1500-m running and therefore better planning and projections can be made when designing training interventions in order to race specific opponents which should help athletes to balance the potentially negative consequences of enforced pacing regimes[12](#_ENREF_12) with the benefits of drafting in reducing aerodynamic drag in runners (Brownlie et al 1987)

The cumulative mean method shows that 400-m swimming lap times stabilise sooner than 1500-m running with 10 and 44 samples needed in the two sports respectively. This may be due to a number of reasons, some of which have been mentioned previously, which affect the variability of speed during the races. For example, the environmental conditions the race is performed in, the number of competitors that compete in international finals (eight in swimming and twelve in running), running lanes are shared for the majority of the race, lane changes and drafting occur in running, the start is different with swimming rapidly attaining racing speed, and there are marked differences in mechanical efficiency and drag forces experienced between the sports. Another point to note is that whilst lap 1 in 400-m swimming took the longest to stabilise compared to the other laps, it was also the most reliable lap within subjects. This may indicate that the swimmer’s time to complete the first lap was consistent between events, but varied between performers to the greatest extent, possibly indicating that factors such as the range of pacing strategies adopted, reaction times and starting ability affected lap 1 to a greater extent than subsequent laps. This study has shown that within-subject reliability can be achieved by analysing five retrospective international events. Based on this analysis, Lap 1 should not be used as the relative marker for 1500-m runners or lap 4 for 400-m swimmers as they were the least reliable of the segments analyzed. Total race time has been shown here to be a more consistent variable across both disciplines and validates the use of this variable to normalise lap times as has been previously used but not explained.[8](#_ENREF_8),[13](#_ENREF_13),[20](#_ENREF_20),[21](#_ENREF_21)

1. Practical Applications

Individual lap times were separately analyzed to allow later comparisons between the four lap times to be made. In using this method the most conservative error range of ± 1% has been used. The current study shows that stable data can be obtained by collecting 400-m swimming data from at least three events over 3--years and 1500-m running data from at least five events over a 5-year period. Researchers, athletes and coaches now have a statistical framework for ensuring lap times are collected from sufficient samples before data is analyzed for research, training or competition purposes. This might include the development of training plans and pacing strategies that relate to an athlete’s prior performance or that of their opponents.

The stability of the pacing profile could differ in other circumstances, for example in heats compared to final races and so these findings are limited to the 400-m freestyle and 1500-m running events in males only. Unlike previous research outliers were not identified and excluded from the data set,[10](#_ENREF_10) which may mean that the number of events required to establish the stability of race profile in the present study is a conservative estimate. In contrast, several performances from the same participants were used to establish the stability of split and overall times in both running and swimming events, which would be expected to overestimate race stability. However, Hughes *et al*.[15](#_ENREF_15) also used repeated measures on the same individual in their analyses to establish normative performance profiles.

1. Conclusion

In international competitors, 1500-m running and 400-m swimming lap times are highly consistent. However there was a contrasting trend found in terms of variations in speed across laps in running and swimming, with runners demonstrating a reduced variation in speed as races progressed, while the opposite occurred in swimming albeit to a lesser extent. Five competitive events for running and three events for swimming must be collected to ensure that the data has stabilised to within 1% margins for time.

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1. References

1. Edwards A, Polman R, *Pacing in Sport and Exercise: A Psychophysiological Perspective*, New York: Nova. 2012

2. Abbiss CR, Laursen PB, Describing and Understanding Pacing Strategies During Athletic Competition*.* *Sports Med*. 2008;**38**:239-239.

3. Hopkins WG*, et al.*, *Novel Training and Other Strategies for Sport Performance at the 2011 Acsm Annual Meeting*. *Sportscience*, 2011. **15**, 1-8.

4. Stone MR*, et al.*, Consistency of Perceptual and Metabolic Responses to a Laboratory-Based Simulated 4,000-M Cycling Time Trial*.* *Eur J Appl Physiol*. 2011;**111**:1807-1813.

5. Foster C*, et al.*, Pattern of Energy Expenditure During Simulated Competition*.* *Med Sci Sports Exerc*. 2003;**35**:826-831.

6. Edwards AM, Lander PJ, Physiological Responses to Self-Paced Exercise: Effort-Matched Comparisons across Running and Rowing Modalities*.* *J Sports Med Phys Fitness*. 2012;**52**:344-350.

7. Chen I*, et al.*, Identification of Elite Swimmers' Race Patterns Using Cluster Analysis*.* *Int J Sports Sci & Coach*. 2007;**2**:293-303.

8. Corbett J, An Analysis of the Pacing Strategies Adopted by Elite Athletes During Track Cycling*.* *Int J Sports Physiol Perform*. 2009;**4**:195-205.

9. Tucker R*, et al.*, An Analysis of Pacing Strategies During Men's World-Record Performances in Track Athletics*.* *Int J Sports Physiol Perform*. 2006;**1**:233-245.

10. Robertson E*, et al.*, Analysis of Lap Times in International Swimming Competitions*.* *J Sports Sci*. 2009;**27**:387-395.

11. Micklewright D*, et al.*, Pacing Strategy in Schoolchildren Differs with Age and Cognitive Development*.* *Med Sci Sports Exerc*. 2012;**44**:362-369.

12. Lander PJ*, et al.*, Self-Paced Exercise Is Less Physically Challenging Than Enforced Constant Pace Exercise of the Same Intensity: Influence of Complex Central Metabolic Control*.* *Br J Sp Med*. 2009;**43**:789-795.

13. De Koning JJ*, et al.*, Regulation of Pacing Strategy During Athletic Competition*.* *PloS one*. 2011;**6**:15863.

14. Skorski S*, et al.*, Reproducibility of Pacing Profiles in Competitive Swimmers*.* *Int J Sports Med*. 2013;**34**:152-157.

15. Hughes M*, et al.*, Establishing Normative Profiles in Performance Analysis*.* *Int J Perform Anal Sport*. 2001;**1**:1-26.

16. Brown E, Running Strategy of Female Middle Distance Runners Attempting the 800m and 1500m "Double" at a Major Championship: A Performance Analysis and Qualitative Investigation*.* *Int J Perform Anal Sport*. 2005;**5**:73-73.

17. Mytton GJ*, et al.*, Validity and Reliability of a 1500-M Lap Time Collection Method Using Public Videos*.* *Int J Sports Physiol Perform*. 2013:Epub ahead of print.

18. Hopkins WG*, et al.*, Progressive Statistics for Studies in Sports Medicine and Exercise Science*.* *Med Sci Sports Exerc*. 2009;**41**:3-12.

19. Hopkins WG, *Reliability Spreadsheet*. [2010 01/11/2011]; Available from: <http://www.sportsci.org/resource/stats/xrely.xls>.

20. Marcora S, Is Peripheral Locomotor Muscle Fatigue During Endurance Exercise a Variable Carefully Regulated by a Negative Feedback System? *J Physiol*. 2008;**586**:2027-2028.

21. Muehlbauer T*, et al.*, Pacing Pattern and Performance During the 2008 Olympic Rowing Regatta*.* *Eur J Sport Sci*. 2010;**10**:291-296.

10. Figures and Tables

Table 1: Typical Error (±90% Confidence Limits) for within-subject reliability in each lap and in total time

Table 2: Summary of the number of races needed to stablize data for each lap in 400m swimming and 1500-m running

Captions

Figure 1: Within-subject coefficient of variation for within-subject reliability in each lap and in total time. Error bars show standard deviation. *\*Significantly greater variation than the corresponding swimming lap.#Significantly reduced variation than running lap 1.*

Figure 2 (a-d): 400-m swimming laps 1-4 cumulative means by number of individual performances collected(Long dashes and dots = 10% limits; long dashes = 5% limits; short dashes = 1% limits. Circle indicates stabilised data to a 1% limit).

Figure 3 (a-d): 1500-m running laps 1-4 cumulative means by number of individual performances collected(Long dashes and dots = 10% limits; long dashes = 5% limits; short dashes = 1% limits. Circle indicates stabilised data to a 1% limit).