# Pacing strategy and competitive performance of elite female 400-m freestyle swimmers

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**Introduction.** Pacing strategy in endurance events has a substantial impact on performance. Here we characterize pacing and identify its parameters for optimal performance in 400-m swimming. **Methods.** Swimrankings.net and other websites provided 50-m split and final race times for 381 swims of 20 elite female swimmers in over 150 national and international competitions between 2004 and 2016. Plots of lap time vs lap number indicated that each pacing profile could be characterized by five parameters derived from a general linear model: linear (slope) and quadratic (curvature) coefficients for the effect of lap number to characterize the overall trend; coefficients representing deviations from the trend in the first and last (eighth) laps; and the standard error of the estimate, summarizing lap-to-lap variability and other deviations from the trend. Analyses of log-transformed lap time provided values of parameters for each swim in percent units. Race time was then plotted against each parameter for each swimmer's best swim to characterize the associated pacing profiles. In separate plots for all the swims of each swimmer, a quadratic was fitted to help identify the value of the parameter associated with the swimmer's optimum performance and to determine the deviation of the swimmer's mean time from her optimum. **Results.** In the analysis of the best swims of each swimmer, the pacing profiles all displayed negative quadratic curvature, with the fifth lap being the median slowest. The first and last laps were faster than predicted by the quadratic by 5.6 ± 1.1 % and 1.6 ± 1.1 % respectively (mean ± SD), and the lap-to-lap variability was 0.6 ± 0.3 %. The best swimmer (Kathleen Ledecky) had the most curvature, the slowest first lap and the lowest lap-to-lap variability. There were otherwise no clear associations between ability of the swimmers and the pacing parameters. Relationships between parameters and race time in the scatterplots of each swimmer's swims were also generally unclear, suggesting that swimmers usually compensated for changes in one parameter with changes in another. However, some plots showed a U shape or linear trend that allowed tentative identification of optimum values of the pacing parameters. In these plots it was apparent that nearly half of the swimmers could make moderate (~1%) improvements by changing the curvature of their pacing profile. Small-moderate improvements (~0.7%) might also be possible for one third of swimmers by changing time in the first and last laps by ~1.0%. Only two swimmers could make a substantial improvement by reducing their lap-to-lap variability. **Discussion & Conclusion.** Our study indicates that even pacing is not the best strategy for female elite 400-m swimmers, and that a minority of these swimmers might obtain small-moderate improvements by modifying their pacing profiles. Our studies of 800-m and 1500-m swimmers produced similar findings. The method for identifying possible improvements might be appropriate to assess pacing in other sports with multiple laps, frequent competitions and relatively constant environmental conditions.

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