Power Requirements for Swimming a World-Record 50-m Front Crawl

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Peak performances in sport require the full deployment of all powers an athlete possesses. How factors like mechanical power output, technique, and drag, each in itself but also in concert with each other, determine swimming performance is the subject of inquiry in this case study.

At constant speed, a swimmer is subjected to the resistive forces of water, that is, drag \( F_d \) depending on a drag factor \( K \) and the swimming speed squared \( v^2 \); see Equation 1. In order to overcome these resistive forces the swimmer has to generate power \( P_d \), ie, force times velocity) according to

\[
P_d = F_d \cdot v = K \cdot v^2 \cdot v = K \cdot v^3
\]  

In swimming, \( P_d \) is not equal to the total mechanical power \( P_o \) a swimmer has to deliver: The generation of propulsion in a fluid always leads to the loss of mechanical power that will be transferred in the form of kinetic energy from the swimmer to the fluid. Thus, in competitive swimming 2 important mechanical-power terms of the total power \( P_o \) can be discerned: power used beneficially to overcome drag \( P_d \) and power lost in giving water a kinetic-energy change \( P_k \). Hence,

\[
P_o = P_d + P_k
\]  

The ratio between the useful mechanical power spent to overcome drag \( P_d \) and the total mechanical power output \( P_o \) is defined as the propelling efficiency, \( e_p \),

\[
e_p = \frac{P_d}{P_o} = \frac{P_d}{P_d + P_k}
\]  

Combining Equation 1 with Equation 3, it appears that swimming speed depends on power output, a drag factor, and propelling efficiency:

\[
v = \sqrt[3]{\frac{P_o \cdot e_p}{K}}
\]  

These theoretical considerations will be put to use by predicting individual power requirements for swimming a world record in the 50-m freestyle based on experimental data obtained with the MAD system (see Figure 1), in which the swimmer pushes off from fixed pads with each stroke. These 16 push-off pads,
placed 1.35 m apart, are attached to a 22-m-long, highly rigid aluminum rod that is mounted 0.8 m below the water surface. The rod is connected to a force transducer enabling direct measurement of push-off forces. Subjects use their arms only for propulsion; their legs are floated with a small buoy. If a constant swimming speed is maintained, the mean propelling force equals the mean drag force. Hence, swimming 1 lap on the system yields 1 data point for the speed-drag curve (see Figure 2).

Figure 1 — System to measure active drag (MAD system).

Figure 2 — Drag dependent on speed for subject JK.