Propulsion model for front crawl swimming

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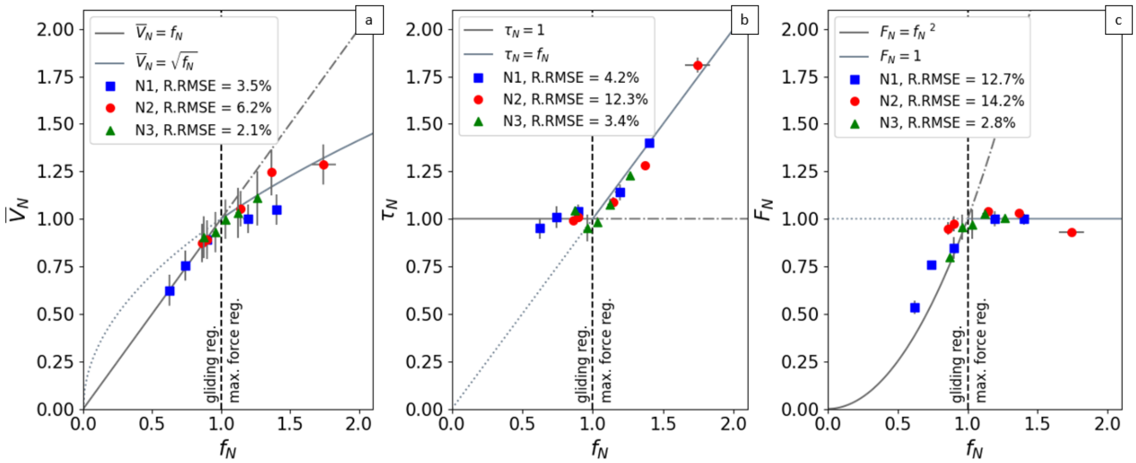
Front crawl swimming is characterized by an alternate propulsion of the arms with air recovery. The relationship between the stroke frequency f and the average velocity of the swimmer $\overline{v}$ appears to be a key parameter to understand performance. Indeed, for long distance races, swimmers do not seem to use their minimal f, suggesting they do not use their highest propulsive force $\tilde{F}_P$ [2]. By looking at the evolution of $\overline{v}$ with f, one can highlight two regimes separeted by a critical frequency f_{crit}. When $f \leq f_{crit}$, $\overline{v} \propto f$ while once $f \geq f_{crit}$, $\overline{v} \propto \sqrt{f}$. A model was proposed by Carmigniani *et al.* [1] to explain this evolution. The balance of forces on the swimmer's body gives $k_b\overline{v}^2 = 2\tau_p\tilde{F}_P$ with τ_P the relative propulsion time and k_b a constant. It is assume that for a given $\overline{v}$, a swimmer control τ_P and $\tilde{F}_P$ to minimize his energy consumption. Thus, when $f \leq f_{crit}$, $\overline{v}$ increase with $\tilde{F}_P$ ($\tilde{F}_P \propto f^2$) and $\tau_P = \tau_0$ is constant. Once $f \geq f_{crit}$, $\tilde{F}_P = F^*$ is constant and maximum and $\overline{v}$ increase with τ_P ($\tau_P \propto f$). The non-dimensionnal version of these relationships is: while $f_N \leq 1$, $v_N = f_N$, $\tau_N = 1$ and $F_N = f_N^2$ and once $f_N \geq 1$, $v_N = \sqrt{f_N}$, $\tau_N = f_N$ and $F_N = 1$ with $f_N = f/f_{crit}$, $v_N = v/\overline{v}(f_{crit})$, $\tau_N = \tau_P/\tau_0$ and $F_N = \tilde{F}_P/F^*$. the model has been tested on three swimmers during a 5x25m with progressive speed. F_N, τ_N and f_N were measured using swimming paddles instrumented with force sensors and inertial motion units. v_N was measured by a set cameras calibrated in 3D. N1 is a male international-level swimmer, N2 is a male national-level swimmer and N3 is a female national-level swimmer.



a) $\overline{V}_N$ as a function of f_N. b) τ_N as a function of f_N. c) F_N as a function of f_N.

All the swimmers show both regime. N1 has been far below the $f_N = 1$ transition ($f_{N,min} \approx 0.6$), increasing v_N mainly with F_N while N2 far above ($f_{N,max} \approx 1.8$), increasing v_N mainly with τ_N. N3 stayed around it suggesting less capacity to variate F_N or τ_N.

References

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