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Force-velocity-endurance relationship: development of a mathematical model and validation of the IFLET test *

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Introduction. Force production capacities during brief maximal efforts are constrained by a force-velocity relationship, a negative linear function characterized by theoretical maximum force (F_0) and velocity (V_0) [1]. For longer efforts, the intensity-duration relationship is mathematically described by an asymptotic decay function, the asymptote being the critical intensity [2]. Changing the force and velocity produced during an exercise *e.g.* by manipulating cadences in cycling, modifies the intensity-duration relation [3]. When the effort is prolonged, alterations in force and velocity capacities may also be different. Unfortunately, a unified force-velocity-time relationship as a representation of biomechanical and bioenergetical capacities of exercise performance has never been modeled. The aims of this study were to develop a mathematical model of a force-velocity-time relationship and to validate a test to determine the model parameters.

Methods. Based on the assumptions that *i*) the force-velocity relationship is linear and remains so when fatigued and that *ii*) both the force and velocity capacities decrease over time following an exponential decay function, a mathematical model has been developed. It is defined by 6 parameters being initial force (F_{0_i}) and velocity (V_{0_i}) capacities, the critical force (F_{0_c}) and velocity (V_{0_c}) capacities and the time constants for force (τ_F) and velocity (τ_V) decay. 16 participants realized the IFLET test on two separate days to test the reliability. It consists in a modified cycling 3-min all-out exercise during which the flywheel was instantaneously braked every 30 s so that the participant had to re-accelerate, thus allowing regular evaluation of the force-velocity capacities. The mean force and velocity of each pedal stroke was computed and used to fit the model's parameters.

Results. The goodness of the fit of the model from experimental data was excellent (all $r^2 > 0.93$). F_{0_i} and V_{0_i} presented no systematic bias, excellent ICC (> 0.9), and very low SEM ($< 5\%$). F_{0_c} and V_{0_c} demonstrated very good reliability (ICC > 0.8) and low SEM (5.4 and 7.6 %, respectively). τ_F and τ_V showed good reliability (ICC > 0.75) but higher SEM ($\sim 20\%$). Overall, when looking at the $F(v, t)$ surface, independently of the parameters mentioned above, the relative and absolute reproducibility was very good to excellent.

Discussion. This is the first time that a model describes the force capacity considering both velocity and time simultaneously. This model fitted very well with experimental data obtained during the IFLET test, a 3-min all-out sprint interspersed exercise which also showed very good test-retest reliability. Applications of this approach could be numerous in the evaluation of physical capacities as well as for performance application through training or the optimization of human-material interactions.

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