LOAD-VELOCITY SLOPE CAN BE AN INDICATOR OF THE ACTIVE DRAG IN FRONT CRAWL SWIMMING

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The purpose of this study was to investigate the relationship between swimming load-velocity slope and the active drag (Da) in front crawl. 19 female and 22 male swimmers were recruited and performed three 25 m front crawl sprints with different external loads (1, 3, 5 kg for females and 1, 5, and 9 kg for males) assigned by a robotic resistance device. The mean swimming velocity was plotted against the external load to establish the load-velocity profile for each swimmer. Da was obtained by the velocity perturbation method. The relationship between the load-velocity slope and Da was assessed using the Pearson correlation coefficient, which showed a very large correlation (r = 0.84, $p < 0.001$) and an extremely large correlation (r = 0.93, $p < 0.01$) for female and male swimmers, respectively, indicating that the load-velocity slope is an indicator of Da in front crawl swimming.

KEYWORDS: velocity perturbation method, freestyle, resistive force.

INTRODUCTION: Load-velocity profiling in swimming has been conducted in the last several years to estimate the maximum velocity (V0) and maximum resistance load (L0) that swimmers can withstand. Swimmers are usually required to swim three semi-tethered swimming trials with different external isotonic loads, and by establishing a linear regression line on the velocity plot against the load, both V0 (the velocity at 0 kg load) and L0 (the load at 0 m/s velocity) can be mathematically computed. It has been reported that, in front crawl swimming, load-velocity profiling is a reliable method (Olstad, Gonjo, Njøs, Abacherli, & Eriksrud, 2020) and that both V0 and L0 are related to sprint swimming performance (Gonjo, Njøs, Eriksrud, & Olstad, 2021). These previous studies assumed that the load-velocity slope should theoretically be related to the resistive force swimmers obtain from the water during a free-swimming condition (active drag: Da). However, albeit logical, this assumption has not been verified. Due to complex unsteady flow phenomena around the body during swimming, it is challenging to quantify Da for many practitioners. Establishing the possibility of the load-velocity slope as an index of Da is practically useful for many coaches and swimmers. It would enable practitioners to assess swimmers' maximum velocity, propulsive force production ability, and Da through V0, L0 and slope in a single testing protocol and device. In other words, it would contribute to establishing comprehensive performance monitoring method. The purpose of the present study was therefore to investigate the relationship between load-velocity slope and Da in front crawl swimming.

METHODS: A total of 41 swimmers (19 females and 22 males) who were all specialised in front crawl swimming participated in the present study (Table 1). The swimmers had a minimum of five years of experience in competitive swimming, trained at least seven times and 15 h per week and competed at the national level in 50 m front crawl. The study was approved by the local Ethical Committee and the National Data Protection Agency for Research in accordance with the Declaration of Helsinki. All swimmers were given detailed verbal and written explanations of the purpose, procedures and risks associated with the experimental testing, and participants or the legal guardian (for minors) provided written informed consent before participation.

Table 1. Age, height, body mass and performance level of the swimmers

n	Age (years)	Height (m)	Body mass (kg)	50 m front crawl	
				Best record (s)	FINA point
Males (22)	19.4±3.5	1.87±0.07	80.6±9.8	23.7±0.8	633.0±58.8
Females (19)	18.1±1.7	1.73±0.05	65.2±4.7	26.9±0.7	628.6±54.5

The participants performed their individual warm-up on land and in water for up to 60 minutes. After the warm-up, they performed three 25 m front crawl sprints with maximal effort with different external loads (1, 3 and 5 kg for females and 1, 5 and 9 kg for males). Swimmers started each trial with a push-off from the wall without underwater kicking. The rest period between each trial was six minutes. The external load was added to the swimmers using a portable robotic resistance device 1080 Sprint (1080 Motion AB, Lidingö, Sweden), which was also used to measure the swimming velocity and tethered force during each trial with a sampling frequency of 333 Hz.

Swimmers wore an S11875BLTa swim belt (NZ Manufacturing, OH, United States) around their pelvis and connected to the machine through a fibre cord. The resistance setting for the 1080 Sprint was isotonic mode, and the eccentric velocity (backward velocity) limit was 0.05 m/s to avoid swimmers being moved back due to the external load.

For both velocity and force data, the horizontal component was extracted by detecting the angle between the water surface and the fibre cord using the height of the device from the water surface (1 m), the length of the cord at each sampling time and the trigonometric functions. Mid-pool three stroke cycles were selected in the dataset, from which the mean velocity and tethered force over the three cycles were computed. The mean velocity was plotted against the external load to establish the load-velocity profile for each swimmer, as described in Gonjo et al. (2020), to obtain V0 and L0. The slope of the load-velocity regression line was then acquired as -V0/L0.

Da was computed using the velocity perturbation method (VPM) proposed by Kolmogorov and Duplishcheva (1992). For this analysis, V0, mean force and velocity data from a semi-tethered swimming trial were used. Under the assumption that the power output of swimmers is equal between free-swimming and swimming with the external load, Da was calculated as:

$$Da = \frac{F \cdot VL \cdot V0^2}{V0^3 - VL^3} \qquad (1)$$

Where *F* is the mean tethered force measured at the trial with the external load, *V0* is the maximum free-swimming velocity estimated from the load-velocity profiling, and *VL* is the mean velocity swimmers achieved with the external load. Both *F* and *VL* were obtained from 3 kg and 5 kg trials for females and males, respectively. These loads were selected based on a preliminary study which showed that Da calculations with VPM were more reliable when using 3-5 kg external loads compared with lighter or heavier loads.

The normality of both slope and Da data were checked with the Shapiro-Wilk test and confirmed. Furthermore, no data outliers were detected by ROUT method (Motulsky & Brown, 2006) with Q = 1%. Therefore, the relationship between Da and the load-velocity slope was assessed by the Pearson correlation coefficient (*r*). All statistical tests were performed using GraphPad Prism 9.3.1 (GraphPad Software, San Diego, CA, USA). The statistical significance level for the Shapiro-Wilk test and the correlation analysis was set at p = 0.05. For correlation data interpretation, *r* = 0.1, 0.3, 0.5, 0.7, and 0.9 were defined as the threshold for small, moderate, large, very large, and extremely large correlation, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009).

RESULTS: The individual load-velocity profiling showed high coefficient of determination (R^2 = 0.99 ± 0.02). The mean V0, L0, slope obtained from the load-velocity profiling were 1.82 ± 0.07 m/s, 19.67 ± 5.07 kg and -0.098 ± 0.024 m/s/kg for males, and 1.62 ± 0.08 m/s, 12.00 ± 1.88 kg and -0.137 ± 0.020 m/s/kg for females, repsectively. The male and female swimmers showed Da of 81.95 ± 23.42 N and 49.59 ± 9.02 N in VPM. An extremely large and a very large correlation were observed for male and female swimmers, respectively (males; r = 0.93, p < 0.001, females; r = 0.84, p < 0.001, Figure 1).

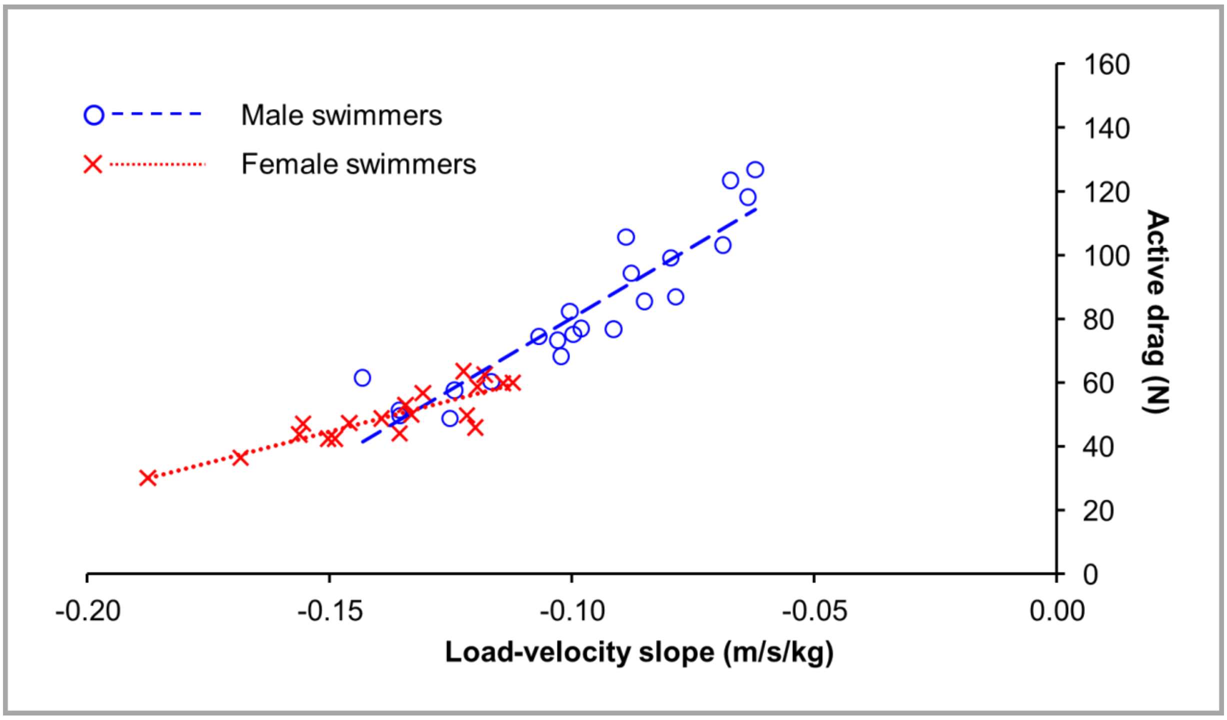

Figure 1. The relationship between the load-velocity slope and active drag

DISCUSSION: The present study investigated the relationship between the load-velocity slope and Da computed using VPM by Pearson correlation coefficient. The significant relationship between the load-velocity slope and Da is not surprising given the theoretical backgrounds of the load-velocity profiling: In theory, L0 reflects the tethered force in a fully-tethered condition. This means that, for example, swimmers with a large L0 and a flat load-velocity slope (i.e. small V0) have the ability to exert a large propulsive force at zero velocity, but as the velocity increases, they are not able to transfer the ability to actual propulsion. As Da was reported in previous studies to be proportional to the square or the cube of the velocity, it was assumed that Da was the main source of the loss in propulsive ability and the slope was an indicator of Da. The significant positive correlation coefficients (with the slope always being a negative value) in the present study shows that the load-velocity slope is indeed an indicator of Da, i.e. the flatter the slope, the larger Da.

It is important to note that VPM used in the present study was somewhat different from the original VPM that requires swimmers to perform with pulling an object with a known additional resistive force. Furthermore, the present study estimated the maximum free-swimming velocity from the load-velocity profiling rather than actually measuring it. Nevertheless, Da for both males and females in the present study showed similar values as the original VPM study by Kolmogorov and Duplishcheva (1992) who reported Da of 82.79 ± 35.90 N and 53.17 ± 11.70 N for males and females whose level was similar to the swimmers in the present study. These similarities indirectly imply that the slight modification in the method did not critically affect the outcomes.

As the present study only assessed the relationship between the load-velocity slope and Da in front crawl swimming, the relationship should also be explored in other swimming strokes. Furthermore, it would be of interest to investigate the longitudinal change in the load-velocity slope due to growth or training intervention. Furthermore, as Da is a force, employing force-velocity relationship instead of load-velocity relationship, as has been widely done in on-land sports (Cross, Brughelli, Samozino, & Morin, 2017), might be beneficial to make a stronger direct link between Da and the semi-tethered swimming method. As swimming load-velocity profiling can be used to assess the swimming velocity (V0), maximum tethered force and Da (in the form of L0 and slope) altogether, it is potentially a great practical tool to monitor the longitudinal performance change as well as the source of the performance improvement or deterioration.

CONCLUSION: There is a very or extremely large relationship between the load-velocity slope and Da in front crawl swimming, meaning that the slope is an indicator of Da with steep and flat slopes showing small and large Da, respectively.

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