THE RELATIONSHIP BETWEEN BACKSTROKE SWIMMING SPRINT PERFORMANCE AND LOAD-VELOCITY PROFILES

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The study investigated relationships between backstroke sprint swimming performance and variables extracted from load-velocity profiles. Thirteen male swimmers performed 50 m backstroke and semi-tethered swimming with three progressive external loads. From 50 m backstroke, race time (T_{50m}) swimming velocity (v_{50m}), stroke length and frequency were obtained. From semi-tethered swimming, maximum load (L_0) and velocity (v_0), slope and L_0 normalized to body mass (rL_0) were computed. Large to very large significant relationships were found between v_{50m} and all variables derived from the load-velocity profiling. Similar relationships were found between T_{50m} and v_0, L_0 and slope, but not with rL_0 ($r = -0.530$, $p = 0.062$). These findings indicate that load-velocity profiling is a practical method to predict and assess sprint backstroke performance and swimming velocity, and to assess propulsive force production and velocity capabilities related to backstroke sprint performance.

KEYWORDS: semi-tethered, race analysis, performance prediction, strength, technique.

INTRODUCTION: Competitive swimming is performed using either alternating (front crawl and backstroke) or simultaneous (butterfly and breaststroke) techniques. To achieve a high swimming velocity, the propulsive force should be maximized, and the resistive force should be minimized. A load-velocity profile can help coaches and practitioners analyse and compare swimmers' velocity and strength capabilities (Olstad, Gonjo, Njøs, Abächerli, & Eriksrud, 2020). This is done by estimating the theoretical maximum swimming velocity (v_0) when the load is zero and the maximum resistive load (L_0) that the swimmer can generate when the velocity is zero. Load-velocity profiling may also be used for establishing requirements for free swimming performance, and the slope (steepness of the regression line) could explain performance determinants in relation to propulsion and drag (Gonjo, Njøs, Eriksrud, & Olstad, 2021).
Load-velocity profile parameters have previously shown strong relationships with sprint performance for male front crawl (Gonjo et al., 2021) and butterfly (Gonjo, Eriksrud, Papoutsis, & Olstad, 2020) swimming. Whether similar relationships exist for backstroke is unknown. Since front crawl and backstroke are both alternating strokes, it could be hypothesized that a similar relationship between sprint performance and load-velocity profile parameters could exist. However, faster speed is usually achieved in front crawl due to a higher stroke rate (SF). The purpose of the present study was therefore to investigate the relationship between backstroke sprint performance and parameters derived from the load-velocity profiling to identify factors that are related to performance among national elite swimmers.

METHODS: A total of 13 male backstroke swimmers qualified for the national senior championship in the 50 m backstroke participated in this study; age 19.4 ± 3.0 yrs, height 188.3 ± 4.4 cm, body mass 82.0 ± 8.4 kg, 50 m backstroke personal record 26.5 ± 1.1 s, FINA (Fédération Internationale de Natation) points 591.8 ± 71.9 corresponding to 80.5 ± 4.8% of the current world record. The study was approved according to the Declaration of Helsinki by the local Ethical Committee and the National Data Protection Agency for Research. All participants were given detailed verbal and written explanations of the purpose, procedures and risks associated with participation. Participants or the legal guardian (for minors) provided written informed consent prior to participation.

Participants first performed their individual warm-up procedures on land and in the water for ~ 45 min. Thereafter, each participant performed a simulated 50 m backstroke race in a 25 m long swimming pool. Each race was captured by the AIM race analysis system (AIMsys Sweden AB, Lund, Sweden) consisting of five above and five underwater cameras placed at the side of the pool. The system automatically detects the two-dimensional head displacement and the timing of the beginning of each arm pull motion based on an image processing technique and machine learning process with a sampling frequency of 50 Hz. Detailed calibration algorithm for the system has been described in (Haner, Svärm, Ask, & Heyden, 2015). The mean velocity (v_{50m}), stroke length (SL), and SF were calculated for each swimmer using the head displacement and stroke timing data obtained by the AIM system. All stroke cycles apart from the first and last cycle in each lap were used to minimize potential effects of transition strokes (from underwater to surface swimming) and turn and finish preparation. Gonjo et al., 2020 investigated the accuracy of the system and the average errors between the AIM system and 2D-DLT results were 0.003, 0.635, and 0.362 % for SF, SL, and v, respectively. The system was synchronized with an electronic Omega timing system (Swiss Timing, Bienne, Switzerland) providing the finishing time for the 50 m backstroke (T_{50m}).
Following ~ 30 min of recovery, each swimmer performed three 25 m semi-tethered backstroke trials with maximal effort from an in-water start without underwater kicking to generate their individual load-velocity profile. An external load was added to the swimmers using a portable robotic resistance device, 1080 Sprint (1080 Motion AB, Lidingö, Sweden) in the order of 1, 5 and 9 kg with six minutes of rest between each trial. Two swimmers were not able to complete the distance with 9 kg and performed an additional attempt with 7 kg (used for calculations). The device also measured the swimming velocity during each trial with a sampling frequency of 333 Hz. A swim belt, S11875BLTa (NZ Manufacturing, OH, United States), was attached around the participants' pelvis and connected to the device through a fibre cord. Three stroke cycles around mid-pool were selected from each trial to calculate the mean velocity. The mean velocity was plotted against the external load to establish the load-velocity profile for each swimmer as a linear regression line, as further described in Gonjo et al. (2021). The regression line was used to determine v_0 which represents the theoretical maximal velocity when the load is zero, L_0 which represents the theoretical maximal load when the velocity is zero and slope which is the steepness of the regression line and is calculated as $-v_0/L_0$. The coefficient of determination (R^2) was also calculated and L_0 was also normalized to body mass (rL_0).
Normality of all variables was tested with the Shapiro-Wilk test and confirmed. The relationship between T_{50m} and v_{50m} during the 50 m backstroke race was assessed with the load-velocity profile parameters v_0, L_0, rL_0 and slope with Pearson correlation coefficient (r). The Statistical Package for Social Sciences (SPSS) version 28.0 (IBM Corp, Armonk, NY, United States) was used for the correlation analysis with the significance level of $p < 0.05$. Correlation threshold values of 0.1, 0.3, 0.5, 0.7, and 0.9 were interpreted as small, moderate, large, very large, and extremely large correlations, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009).

RESULTS: Table 1 shows numerical results for all variables obtained from the load-velocity profiling and the 50 m backstroke test while Table 2 shows the correlations between 50 m backstroke performance and parameters obtained from load-velocity profiling.

Table 1: Variables obtained from the load-velocity profiling and the 50 m backstroke tests.

	L_0 (kg)	rL_0 (%)	v_0 (m/s)	Slope (-m/s/kg)	R^2	T_{50m} (s)	v_{50m} (m/s)	SF (cycles/min)	SL (m/cycle)
Mean ± SD	18.51 ± 3.60	22.62 ± 4.34	1.63 ± 0.10	−0.09 ± 0.02	0.99 ± 0.01	27.37 ± 1.26	1.64 ± 0.06	47.65 ± 3.57	2.08 ± 0.11

SD = standard deviation; L_0 = estimated maximum load from the load-velocity (LV) slope; rL_0 = estimated maximum load as a percentage of body mass; v_0 = estimated maximum velocity from the LV slope; Slope = steepness of LV regression; R2 = coefficient of determination of the LV regression line; T_{50m} = time for the 50 m backstroke test; v_{50m} = mean free-swimming velocity during 50 m backstroke; SF = stroke frequency for the 50 m backstroke; SL = stroke length for the 50 m backstroke.

Table 2: Correlations between 50 m backstroke performance and load-velocity profiling variables.

	v_{50m}	SF	SL	L_0	rL_0	v_0	Slope
T_{50m}	−0.667*	-0.455	0.191	-0.721**	−0.530	−0.708**	-0.634*
	0.013	*0.118*	*0.531*	*0.005*	*0.062*	*0.007*	*0.020*
v_{50m}		0.754**	−0.364	0.731**	0.613*	0.774**	0.681*
		0.003	*0.222*	*0.005*	*0.026*	*0.002*	*0.010*
SF			−0.885**	0.377	0.486	0.383	0.390
			< 0.001	*0.204*	*0.092*	*0.197*	*0.188*
SL				-0.032	−0.276	0.009	-0.087
				0.918	*0.362*	*0.978*	*0.778*
L_0					0.818**	0.701**	0.974**
					< 0.001	*0.008*	*< 0.001*
rL_0						0.550	0.878**
						0.052	*< 0.001*
v_0							0.624*
							0.023

*Numbers in plain font (upper row) and italics (lower row) show correlation coefficients and p-value, respectively. T_{50m} = time for the 50 m backstroke; v_{50m} = mean free-swimming velocity during 50 m backstroke; SF = stroke frequency for the 50 m backstroke; SL = stroke length for the 50 m backstroke; L_0 = estimated maximum load from the load-velocity slope; rL_0 = estimated maximum load as a percentage of body mass; v_0 = estimated maximum velocity from the load-velocity slope; Slope = steepness of load-velocity regression; *p < 0.05; **p < 0.01.*

An overview of the distribution of load-velocity profiles for all participants is presented in Figure 1. The left panel of the figure illustrates individual data for absolute load (L_0), and the right panel for L_0 normalized to body mass (rL_0).

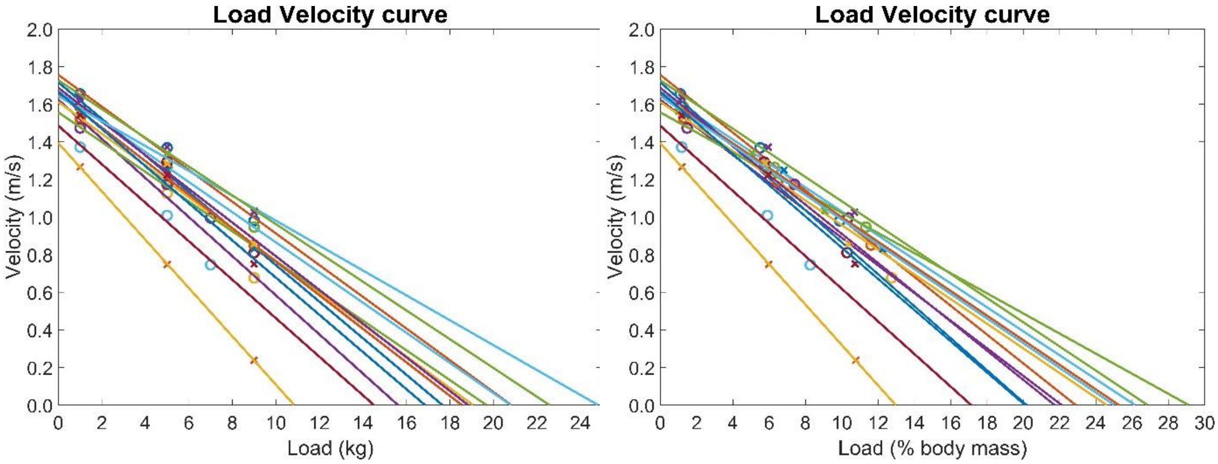

Figure 1: Individual load-velocity profiles for male sprint backstrokes. Absolute load (L_0) in left panel and relative load (rL_0, normalized to body mass) in right panel.

DISCUSSION: The purpose of the present study was to establish relationships between backstroke sprint swimming performance and variables derived from load-velocity profiles. Both T_{50m} and v_{50m} showed large and very large relationships with the load-velocity profile variables L_0, v_0 and the slope. rL_0 on the other hand was largely related to v_{50m}, but not with T_{50m}. This suggests that these variables derived from a load-velocity profile are good indicators of 50 m backstroke performance and swimming velocity.
The very large relationship between L_0 and both T_{50m} (r= -0.721) and v_{50m} (r= 0.731) suggests that the higher L_0 a swimmer can produce a better swimming performance and a higher swimming velocity is attained. A large correlation was also previously found in front crawl for v_{50m} and T_{50m} (r= 0.632 and −0.554) (Gonjo et al., 2021) and in butterfly (r= 0.556 and −0.624) (Gonjo et al., 2020), respectively for male national level swimmers. From the perspective that L0 corresponds to the maximal tethered force obtained during fully tethered swimming, it could be expected that T_{50m} would show a very large relationship with L_0 as a similar relationship was

found during fully tethered backstroke swimming (r= -0.86) (Morouço, Keskinen, Vilas-Boas, & Fernandes, 2011). This can further be explained by the very large correlation between L_0 and v_0 (r= 0.701) in the present study. This shows that for reaching a high v_0, swimmers also need to produce a high L_0. This is contradicting to what was previously found in both front crawl and butterfly where no significant relationship between L_0 and v_0 was present. This implies that in backstroke, swimmers rely more on propulsive force production (L_0), while in front crawl and butterfly swimmers show different strategies to achieve a large v_0. For these strokes, some swimmers achieved a large v_0 based on their ability to generate propulsive force, while others minimize resistive force to achieve a large v_0.
The very large correlation between v_0 and T_{50m} (r= −0.708) and v_{50m} (r= 0.774) also supports the validity of the load-velocity profiling as a 50 m swimming performance and velocity predictor. However, a very small difference between v_0 and v_{50m} was present, 0.58%. The difference in backstroke is smaller than previously reported for front crawl (3.53%) and butterfly (1.88%) and suggests that v_{50m} is less influenced by the start and turn performance than in the two other strokes. One reason for this could be the start procedure where both front crawl and butterfly has an aerial dive, while in backstroke the swimmer starts in the water and consequently achieves less velocity off the start.
The present study assessed the relationship between the load-velocity slope and T_{50m} and v_{50m} in sprint backstroke. The relationship should also be explored for longer pool events and for triathletes and open water swimmers. Furthermore, it would be of interest to investigate the longitudinal change in the load-velocity slope due to training interventions with a focus on assisted and resisted sprint protocols. As the load-velocity profile can be used to assess v_0 independent of the start and turn performance that might influence v_{50m}, it is potentially a valuable practical tool to monitor how v_0 change over time in relation to propulsion and drag

CONCLUSION:
The present study found large to very large significant relationships between v_{50m} and all variables derived from load-velocity profiling; v_0, L_0, slope and rL_0. Large to very large negative relationships were also found between T_{50m} and v_0, L_0, slope, but not with rL_0. These findings indicate that the load-velocity relationship established by semi-tethered swimming is a useful method to predict and assess sprint backstroke performance and swimming velocity and can be used to assess sprint swimming-specific backstroke strength and velocity capabilities.

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