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ESTIMATION OF PROPULSION AND DRAG FORCE IN FRONT CRAWL STROKE

[1)]SHUJI SHIMONAGATA, [1)]MASAHIRO TAGUCHI, [1)]SHOUICHIROU TABA, [2)]MIYUKI AOYAGI

[1)]Faculty of Sports and Health Science, Fukuoka University, Fukuoka, Japan
[2)]Goto College of Medical Arts and Science, Kanagawa, Japan

ABSTRACT

The purpose of this study was to clearly show the relationship among the swimming velocity(V_0), the maximum propulsion(P_0) and the active drag force(Da_0) in the front crawl stroke. The subjects were 14 men's front crawl swimmers. The subjects were towed with the active drag system in a streamline position and the subjects swam 8 maximal trials (5 trials with added resistance, and 3 trials in tow by active drag system). The V_0, P_0 and Da_0 were calculated by an exponential function of velocity. The calculated V_0 was 1.68 ± 0.11m/sec, P_0 was 150.12 ± 29.98 N, and Da_0 was 64.85 ± 16.53 N. The relationship between V_0 and the velocity calculated from 100m best time was a linear relation ($r=0.81$, $p<0.01$). The relationship among P_0, Da_0 and V_0 was a significant correlation ($V_0 = 1.387 + 0.004\ P_0 - 0.005\ Da_0$). This result clearly showed that swimming performance depended on the propulsion and the active drag. Consequently the swimming velocity was expressed by the function of the propulsion and the active drag, and it was shown that the swimming velocity progressed with increasing the propulsion and decreasing the active drag.

Key words: front crawl stroke, propulsion, active drag, swimming velocity

INTRODUCTION

In competitive swimming, it is important that swimmers exerted more propulsion and less drag force for improving the performance. In the previous studies, many investigators had tried to estimate these forces. Most studies measured drag forces by towing swimmers through the water passively in a prone position. This drag force was commonly referred to as the passive drag(Clarys et al., 1974). Clarys et al showed that the passive drag can be well approximated by the general fluid force, and that the passive drag can be calculated by body size and shape. In contrast, early measurements suggested the indirect calculations of the drag force on a moving swimmer (active drag) based upon changes in oxygen consumption with additional drags(Di prampero et al., 1974, Clarys, 1979). The results of these studies indicated that active drag was much higher than passive drag. More recently, Toussaint et al(1988) developed the method of calculating active drag directly by using the MAD system, and Kolmogorov and Duplisheva (1992) proposed other direct method of measuring active drag (a velocity perturbation method).These studies mentioned the magnitude of active and passive drag, and reported that elite swimmers have lower active drag than average-level swimmers due to better technique. Magel(1970) measured propelling force by using the tethered swimming test. Magel suggested the method to determine the portion of the propulsive force exerted by legs and arms in the four competitive swimming styles.

The mechanical power output, active drag and passive drag during swimming were estimated independently in previous studies. However the interrelationship among propulsion, active drag and

Table 1. Individual data for age, height, weight, and personal best time on 100m free style

	Age(year)	Height(m)	Weight(kg)	100m Best time(sec)
1	20	1.82	70.0	52.9
2	20	1.77	63.0	56.2
3	21	1.74	72.0	52.7
4	21	1.80	77.0	53.5
5	21	1.77	69.0	55.5
6	21	1.62	55.0	57.0
7	21	1.67	59.0	56.6
8	21	1.78	72.0	57.0
9	19	1.70	65.5	56.9
10	22	1.75	68.0	58.5
11	22	1.67	67.5	59.0
12	19	1.75	66.5	59.0
13	19	1.71	61.0	55.4
14	21	1.70	58.0	58.5
Mean±S.D.	20.57±1.02	1.73±0.06	65.96±6.16	56.34±2.14

passive drag should be controverted, because the performance was determined by the interaction of these components.

The purpose of this study was to define the relationship among the swimming velocity, propulsion and drag force in the front crawl stroke by using the active drag system.

METHODS

Subjects, apparatus and data collection

A towing apparatus (active drag system) which can measure the propulsion and drag force was placed on the edge of the pool side (Figure 1). The subjects were 14 front crawl swimmers, ages 18 to 22 years(Table 1). The measurements were obtained by three methods (Figure 2). In the first method, swimmers were towed 20m with the active drag system in the streamline position(TST, Figure 2A). In the second method, swimmers were towed in the front crawl movement(TFC, Figure 2B). The towing velocity had seven stages(velocity range from 0.8m/sec to 2.2m/sec) in TST and three stages(velocity range from 1.8m/sec to 2.4m/sec) in TFC. In the third method, swimmers made their maximum effort of semi-tethered swimming(STS) progressing against the submaximum load(Figure 2C). The swimming velocity in STS had five stages (velocity range from 0m/sec to maximum swimming speed). The velocity and tension data were recorded on a personal computer with transmitted speed of 50Hz. The value of TST for each speed was determined as the average tension for five second during a steady speed. The values of TFC and STS for each speed were calculated from the mean data obtained during four stroke cycles.

Statistical analysis

The passive drag(Dp) was determined by the relationship between the tension and the velocity in TST. The Dp was regressed as an exponential function of the velocity(V) in TST expressed by

$$Dp = kp\ V^{np} \qquad (1)$$

Where the kp is the coefficient of Dp and the np is the exponential coefficient. The active drag(Da) and total propulsion (P_0) were calculated from the relationship between tension(Tr) and velocity(V) obtaining from TFC and STS. These relationship were expressed in following equations;

$$Tr = P_0\{1-(V/V_0)^{na}\} \quad (2)$$
$$Da = P_0-Tr-Dp \quad (3)$$

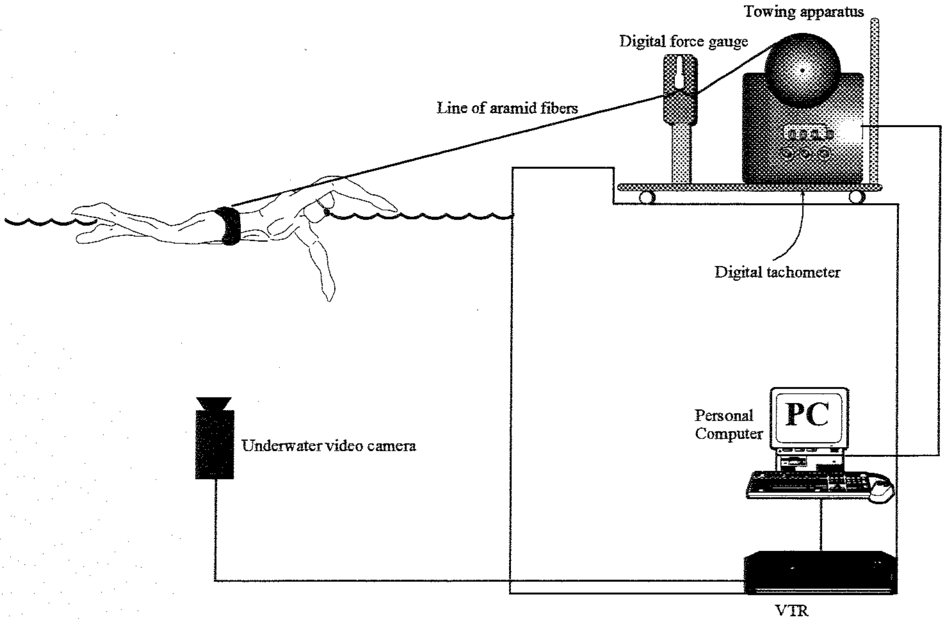

Figure 1. Schematic of the active drag system for measurement of each force during swimming

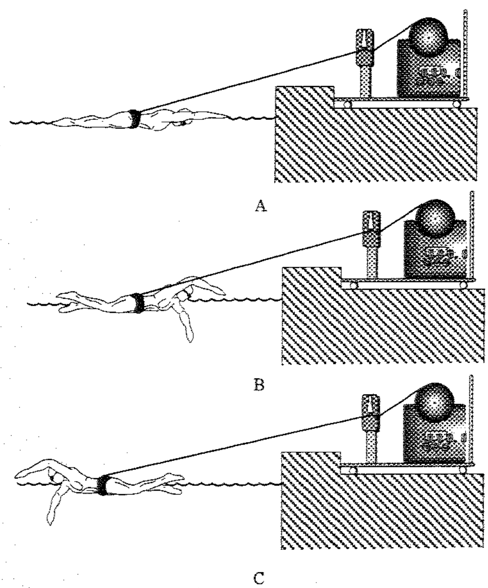

Figure 2. Experimental setup for the measurement of each force during swimming

A: Swimmer was towed with the active drag system in the streamline position, B: Swimmer was towed in the front crawl movement, C: Swimmer made his maximum effort of semi-tethered swimming progressing against the submaximum load

Table 2. Individual values of active drag force and passive drag force

	kp	np	P_0(N)	V_0(m/sec)	na	Da_0(N)	Dp_0(N)
1	28.81	2.13	206.58	1.82	1.63	103.49	103.00
2	34.30	2.01	170.23	1.69	1.78	71.54	98.59
3	33.32	2.03	170.72	1.84	2.07	56.15	114.46
4	34.79	2.05	191.79	1.81	1.84	74.68	117.11
5	22.93	2.15	127.30	1.72	2.07	54.00	73.21
6	25.28	2.36	157.78	1.61	1.74	80.56	77.13
7	21.07	2.20	116.52	1.75	2.09	44.49	72.03
8	35.38	1.97	167.58	1.53	1.35	86.14	81.34
9	29.30	2.19	145.53	1.71	2.11	51.06	94.47
10	31.26	1.66	119.46	1.54	1.66	55.37	64.09
11	22.15	2.22	119.07	1.59	1.73	56.74	62.43
12	28.52	1.81	123.58	1.65	1.86	52.82	70.76
13	43.61	1.78	166.99	1.71	1.85	54.00	113.09
14	19.80	2.42	118.48	1.49	1.60	66.84	51.65
Mean±S.D.	29.32±6.70	2.07±0.22	150.12±29.98	1.68±0.11	1.81±0.22	64.85±16.53	85.24±21.36

Where the V_0 is the calculated maximum velocity and the na is the exponential coefficient of Da. In this study, it was assumed that the Da was an additional drag force that occurred by human movements during front crawl stroke, and it was defined the Da_0 and the Dp_0 as the Da and Dp on the V_0 respectively.

RESULTS

The individual values of passive and active drag force in the front crawl stroke were presented in Table 2. The mean value of the coefficient(kp) of Dp was 29.32 ± 6.70(mean ± S.D.) and the mean value of the exponential coefficient(np) was 2.07 ± 0.22.

The relationship among the Da, tension and velocity was shown in Figure 3. The mean value of the Da_0 was 64.85 ± 16.53(N), Dp_0 was 85.24 ± 21.36(N), P_0 was 150.12 ± 29.98(N), and the V_0 was 1.68 ± 0.11(m/sec). The mean value of Da_0 was 76% of the mean value of Dp_0, and the significant correlation between of them was not found($r=0.24$). The relationship between V_0 and the velocity calculated from the 100m best time was a linear relation ($r=0.81$, $p<0.01$). The Da_0 was tend to increase with increasing the P_0($r=0.71, p<0.01$). The relationship between P_0 and V_0, and the relationship between Da_0 and V_0 were not significant correlations($r=0.56$, $r=0.02$, respectively). However the relationship three components among T_0, Da_0 and V_0 was a significant correlation ($V_0=1.387+0.004\ P_0 -0.005\ Da_0$; $r=0.84, p<0.01$).

DISCUSSION

In the previous studies, Toussaint et al(1988) estimated the active drag by using the MAD system, Kolmogorov and Duplisheva(1992) measured the power and resistance by using a velocity perturbation method, and Magel(1970) measured the propelling force by using the tethered swimming test. Although these studies calculated the hydrodynamic indicators(kp, np, ka, na) and propelling force, the interrelation among propulsion, resistance and power during swimming was indicated scarcely. This depended on the complex nonlinear relationships among these components. In order to define the interrelations among these components,relating factors are discussed further in following 4 topics;

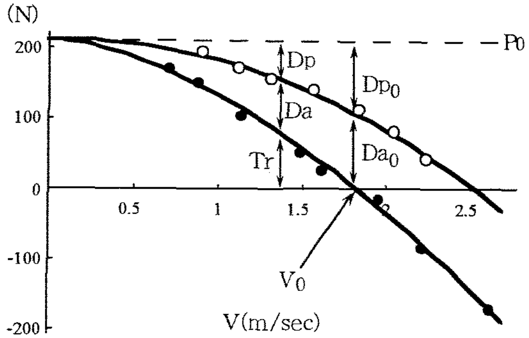

Figure 3. Tension(Tr), active drag(Da) and passive drag(Dp) in relation to swimming velocity

Relationship between estimated and actual maximum swimming velocity

It was considered that the method used in the present study was satisfactory to determine the propulsion and drag forces during swimming because the estimated value of the maximum swimming velocity was very similar to the actual swimming velocity.

Passive Drag

Karpovich(1933) used a towing machine to determine the mean value of kp and np. The mean value of kp was 30.5 $\pm$ 3.9 and the mean value of np was 2.04 $\pm$ 0.04. Miyashita(1978) used a swimming flume to assess the values of passive drag. The value of kp was 24.4 and the value of np was 1.91. Clarys et al(1974) calculated the coefficient of passive drag using the Netherlands Ship Model Test Basin. The kp and the np of the passive drag in the present study coincided well with the results of earlier studies. It was indicated that the active drag system is suitable to measure the each drag force.

Propulsion and active drag in front crawl stroke

Magel(1970) estimated the propulsive force that a swimmer could exert against a measuring device at zero velocity on tethered swimming test. Similarly, the present study defined a propulsive force that a swimmer could generate at zero velocity as the maximum propulsion. Magel showed that the propelling force in front crawl stroke was 131.3 $\pm$ 12.7(N) during a maximum 20 second tethered swim. In this study, the maximum propulsion was 150.12 $\pm$ 29.98(N). The correlation coefficient between the maximum propulsion and maximum velocity was not significant. This result suggested that the factor of determining the maximum swimming velocity was not only the propulsion.

The value of active drag in front crawl stroke was 64.85 $\pm$ 16.53(N) in this study. In the previous studies, the value obtaining by indirect methods as reported by Di Prampero (1974) was from 28.42 to 88.79(N) and the value evaluating from the MAD system by Toussaint was 79.38 $\pm$ 7.84(N). The correlation between the active drag and maximum velocity was not significant, therefore this result showed that the swimming performance could not be evaluated by only the active drag force.

Interrelation between propulsion and drag

In the previous studies, the swimming performance was estimated by the propulsion or drag force respectively. In the present study, the relationship between the maximum swimming velocity and propulsion, and the relationship between the maximum swimming velocity and active drag were not significant. However, the interrelation among the maximum swimming velocity, propulsion and active drag showed a highly significant coefficient(Figure 4). This result clearly showed that the swim-

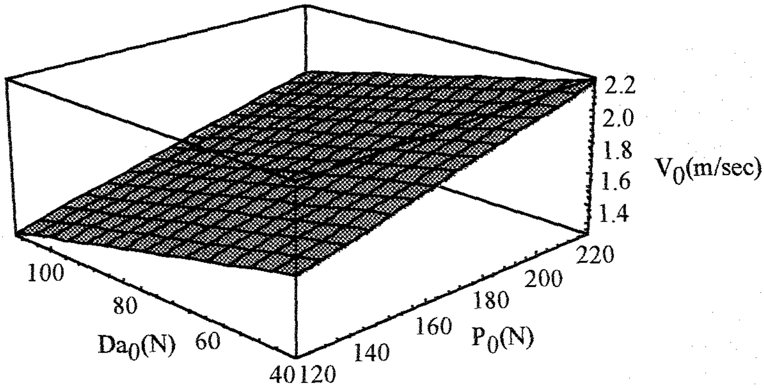

Figure 4. Three dimensional relationship among Propulsion(P_0), active drag(Da_0), maximum velocity(V_0)

ming performance depended on the propulsion and active drag. Consequently the swimming velocity progressed with increasing the propulsion and decreasing the active drag.

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