ASSESSING THE ACTIVE DRAG IN SWIMMING USING THE KINEMATIC AND DYNAMIC PARAMETERS

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Original scientific paper
UDC: 797.2:577.3
Received: March 10, 1998
Accepted: November 17, 1998

Abstract:

In front crawl swimming at maximum exertion and in swimming at maximum exertion with different forms of artificially created additional resistance, certain kinematic and dynamic parameters can be measured and the active drag, assuming that there is an equal power output in all cases can be estimated. Seventeen highly trained male swimmers, all over 16 years of age and specialised in front crawl swimming participated in this study. The pretraining mean (SE), of the height and the body mass of the subjects were 180.6±4.7 cm, and 74.3, ±7 kg.

The mean active drag at maximal swimming velocities ranged from 64.94 N to 76.37 N in front crawl swimming. It was found out that the forces of the active drag, calculated from the measured kinematic and dynamic parameters in front crawl sprints at maximum exertion and front crawl swimming at maximum exertion with different forms of artificially created additional resistance, were not significantly statistically different. It was concluded that the forces which objectively measure the active drag could be calculated on the basis of the variables defined in the research by using the formula

$$R = F_u \cdot (v_2 \cdot v_1^2) \ / \ v_1^3 - v_2^3$$

Key words: swimming, active drag, additional resistance

Zusammenfassung:

MESSEN DES AKTIVEN WIDERSTANDS BEIM SCHWIMMEN MITTELS KINEMATISCHER UND DYNAMISCHER PARAMETER

Angenommen, dass die Kraftausprägung in allen Fällen gleich sei, können beim Kraulen mit maximalem Kraftaufwand, sowie beim Schwimmen mit maximalem Kraftaufwand zur Überwindung verschiedener Formen der zusätzlichen artifiziell erschaffenen Belastung, gewisse kinematische und dynamische Parameter gemessen und der aktive Widerstand bewertet werden.

Diese Untersuchung umfasste 17 auβerordentlich gut trainierten Schwimmer, über 16 Jahre alt, deren Hauptdisziplin Kraul sei. Die Mittelwerte (SE) der Körperhöhe und Körpermasse am Anfang der Trainingsperiode waren 180.6±4.7cm bzw. 74.3±7 kg.

Das Mittelwert des aktiven Widerstands bei maximaler Geschwindigkeit des Kraulschwimmens variierte zwischen 69.94 N und 76.37 N.

Die Ergebnisse zeigen, dass sich die Kräfte des aktiven Widerstands, die aus den während Kraulens mit maximalem Kraftaufwand, sowie Kurzstreckenkraulens mit maximalem Kraftaufwand und verschiedenen Formen der artifiziell erschaffenen Zusatzwiderstands gemessenen kinematischen und dynamischen Parametern gerechent wurden, statistisch nicht bedeutend unterscheiden.

Es wurde festgestellt, dass aufgrund der für diese Untersuchung definierten Variablen und mittels der Formel

$$R = F_u \cdot (v_2 \cdot v_1^2) \ / \ v_1^3 - v_2^3$$

diejenigen Kräfte gerechnet werden können, die den aktiven Widerstand objektiv messen.

Schlüsselwörter: Schwimmen, Kraul, aktiver Widerstand, Zusatzbelastung

Introduction

When swimming, the human body develops a propulsive force on the surrouding water and the surrounding water exerts an active drag force on the human body. Various methods were applied to determine the active drag. Hollander et al. (1985) tested it using the Measurement of Active Drag (MAD) system. Di Prampero et al. (1974) measured it indirectly from O_2 consumption. Nomura et al. (1994) determined it by using the reel-up system.

Kolmogorov and Duplischeva (1992) estimated it by using additional hydrodynamic body techniques. In that study, the authors presumed that in swimming there is a relationship between the mechanical power output of the swimmer, the active drag, the hydrodynamic force coefficient and the maximal swimming velocity.

In our study, a similar approach which involved different additional loads was carried out to determine the relationship between the power output, the active drag, the hydrodynamic force coefficient and the maximal swimming velocity applied to the maximal freestyle swimming stroke.

The main purpose of the research was to measure certain kinematic and dynamic parameters of front crawl swimming at maximum exertion and front crawl swimming at maximum exertion with different forms of artificially created additional resistance. In both cases the research was conducted on the same swimmer in order to calculate the active drag in front crawl swimming and front crawl swimming with four different artificially created forms of additional resistance, and to compare them.

An attempt was made to prove the presumption that the mechanical work of swimmers swimming without artificially created additional resistance is equal to his mechanical work when swimming with artificially created additional resistance.

Methods

Subjects

Seventeen highly trained male swimmers volunteered to be the subjects for this study. All subjects were 16 years of age or older and were specialised in front crawl swimming. The pretraining mean (SE), the height and the body mass of the subjects were 180.6±4.7 cm, and 74.3±7 kg. Each subject was informed of all the risks and stresses associated with the project and gave a written consent to participate.

Apparatus

Our team was successful in developing an additional form of load called a "boat", which creates additional resistance with the following characteristics:

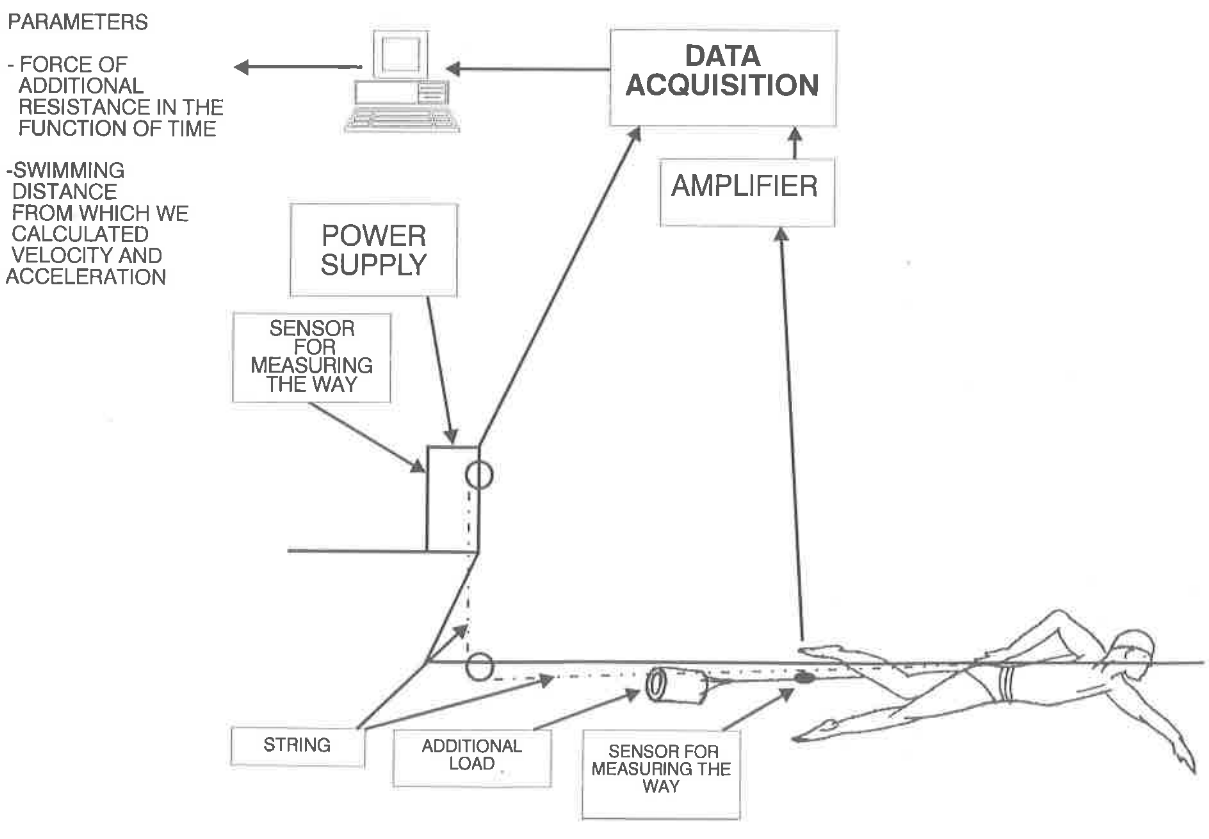
1. The following conditions are fulfilled: stroke velocity is not lower than the one during competition, the stroke curve or the body position does not differ from the one during competition, the usual swimming technique is not disturbed by additional resistance in any other way.

2. It is simple and cheap to use.

3. It allows a partial brake on swimming over any distance.

4. The amount of additional resistance can be adjusted.

Figure 1: Scheme of the system of measuring drag forces.



A sensor for measuring the way was developed in the form of a very accurate potentiometer, a portable mechanism with a wheel and a roll of wire cable, meant to be attached to the object of measurement (Figure 1.). All rotating parts were made of plastics due to the requirement of minimal moments of endurance. A more accurate tracking of the measured object's movement was done as follows: the maximum length which could be measured by the apparatus was 30 m. The tension range of the signal was 0 to 5 V. Before an act was measured, the apparatus' measure was taken. (We intend to develop the apparatus so that it would be possible to measure the distances up to 100 m.)

Force was measured by a resistance strain gauges transducer called a load cell which translates the input of mechanical energy (strain) into equivalent electrical signals. The spring component was made from aluminium alloy (low mass) to minimize the effects of inertia. To reduce sensitivity to bending moments, an H - section column spring component with strain gauges close to the load axis was chosen. To provide inherent compensation for thermal output, a Whetstone full-bridge circuit and self-temperature compensating strain gauges were used. The load cell was also protected against moisture.

The measured data was processed on an IBM PC computer using the Turbo Pascal programme language. The input data was obtained from an analog-digital converter in the form of two sequences of digital data: the first sequence for force and the second for distance. Time was defined by the appearance of a particular measurement in the sequence. By using splines, continuous and distinguishable functions for both the force and the displacement were derived in the time domain. From these two functions velocity, acceleration, power and work were evaluated by differentiation and integration according to the principal laws of physics. In addition, both the average and the extreme values of these quantities could be computed.

Procedures

During the partly tethered swimming, the swimmer dragged the additional load about 20 cm under the water surface. This load gave the swimmer additional hydrodynamic resistance the amount of which could be adjusted.

Each subject performed five maximal exertions of the front crawl stroke over 18 m: once without a "boat", once with an open "boat", once with a half-opened one, once with the closed one and once with a bigger "boat".

Although the additional loads were attached to the swimmers, their swimming velocities did not fall more than 15% below the maximum.

Rest intervals between each performance by the same subject were always over 5 minutes.

By dragging additional loads, the force of additional resistance was created. We measured that force in the function of time and the distance swum, from which we calculated both the velocity and the acceleration. The average measuring time was never more than 7 seconds.

The maximal values of these parameters were achieved in the swimmer's actions which are not logically related to usual swimming (for example: by pushing with the feet off the swimming pool wall, etc.). As a result, we started to measure the parameters only when the swimmers were 2.5 metres away from the wall. There was the possibility of a measuring error, so that is why the maximal values of parameters are not completely correct. Still taking into account the physical and the measuring conditions to determine the average force values in a certain time interval (that defines stable measuring conditions), the average velocity of a swimmer is metrically correct and interesting for the issue.

Active drag

Active drag was determined by the use of an additional hydrodynamic body technique.

If the force caused by the swimmers' artificially created additional resistance is such that it does not change the swimming conditions, and if a swimmer is swimming at maximal velocity, we can presume that the mechanical work of a swimmer swimming without any artificially created additional resistance is equal to his mechanical work when he swims with artificially created additional resistance.

We could prove this presumption by calculating the mechanical work of a swimmer when swimming without artificially created additional resistance and comparing it with the mechanical work of the same swimmer - this work being calculated when swimming with different forms of additional, artificially created resistance. The problem is that this presumption cannot be experimentally proven so far. We do not know how to measure the propulsion, the change of kinetic energy of the water and the forces, which are opposite to the movement. The only exception is force, which is opposite to the movement, and which is caused by a swimmer's artificially created additional resistance.

Let us assume that the mechanical work of a swimmer, swimming without any artificially created additional resistance at maximal velocity is equal to his mechanical work when swimming with artificially created additional resistance at maximal velocity (mechanical power output is also equal in both cases).

Active drag relates to swimming conditions according to:

$$F_1 = {}^1/_2\, C \cdot \rho \cdot S \cdot v_1^2$$
$$F_2 = {}^1/_2\, C \cdot \rho \cdot S \cdot v_2^2 + F_b\,,$$

in which ρ is the density of water and S a characteristic surface area (m^2) of the swimmer, F_b is the added drag due to the hydrodynamic body.

If we assume that the swimming power both with and without additional resistance is equal in both cases

$P_1 = P_2$ and

$P_1 = F_1 . v_1$ and $P_2 = F_2 . v_2$

than we get the following equation:

$$^1/_2\, C \cdot \rho \cdot S \cdot v_1^3 = {}^1/_2\, C \cdot \rho \cdot S \cdot v_2^3 + F_{b2}v_2\,,$$
$$c = F_{b2}v_2 / {}^1/_2 \cdot \rho \cdot S \cdot (v_1^3 - v_2^3)\ ,$$

and if we substitute c in equation than:

$$F_1 = F_b . v_1^2 . v_2 / v_1^3 - v_2^3$$

The final result of the mathematical approximation is the following formula:

$$R = F_u \cdot (v_2 \cdot v_1^2)\ /\ v_1^3 - v_2^3$$

The active drag, calculated with the help of kinematic and dynamic parameters, measured by maximal effort input swimming and maximal effort input swimming with different artificially created additional resistance, which do not change the swimming conditions, should always be equal. The active drag can be calculated using the above formula. We mastered the necessary technology to measure the swimming velocity and force, which is a consequence of the artificially created additional resistance.

Proving that the active drag calculated from the parameters measured during swimming with maximal effort exertion and swimming with maximal effort exertion with different artificially created additional resistances, which do not change the conditions of swimming, is always equal, also supports the presumption that the mechanical work of a swimmer swimming without artificially created

Table 1: Arithmetic means of average velocities and average forces of additional resistance over a defined time interval

	Velocity (m/s ±SD)	Frequency (cm/min ±SD)	Force of additional resistance(N ±SD)
Front crawl sprint without additional resistance	1.712 ±0.84*	55.70 ±5.03*	0
Front crawl sprint with the first additional resistance	1.618 ±0.88	54.76 ±5.24	9.7 ±0.99
Front crawl sprint with the second additional resistance	1.616 ±0.08	54.32 ±4.92	12.47 ±1.13
Front crawl sprint with the third additional resistance	1.588 ±0.08	54.07 ±4.67	13.12 ±0.92
Front crawl sprint with the fourth additional resistance	1.408 ±0.10	55.20 ±8.66 no difference	37.62 ±4.90

* $p \leq 0.05$ Significant difference

Table 2: Arithmetic means of forces of the active drag:

Variable	Mean ±SD (N)	Minimum (N)	Maximum (N)
FAKT 1	76.37 ±27.19	34.35	147.12
FAKT 2	70.75 ±37.15	35.13	197.61
FAKT 3	75.03 ±25.74	39.09	140.31
FAKT 4	64.94 ±37.51	30.94	164.59

* $p \leq 0.05$ Significant difference

additional resistance is equal to his mechanical work when he swims with artificially created additional resistance, which means that in both cases the effective power of a swimmer is equal.

Data processing

Given the defined variables of the research, using the formula

$$R = F_u \cdot (v_2 \cdot v_1^2) \ / \ v_1^3 - v_2^3,$$

we calculated four forces of the active drag:

R1 = the force of the active drag, calculated from parameters measured during front crawl sprint and front crawl sprint with the smallest artificial additional resistance.

R2 and R3 = forces of the active drag, calculated from parameters measured during front crawl sprint and front crawl sprint with artificial additional resistance.

R4 = force of the active drag, calculated from parameters measured during front crawl sprint and front crawl sprint with the greatest artificial additional resistance.

For all the measured and calculated parameters, basic statistical parameters were calculated and normal distribution was tested.

We tested the t-test statistical significance of the differences between the research variables measured or calculated during front crawl sprint both with and without artificially created additional resistance.

Results

All variables are normally distributed.

In addition, from t - tests the following is evident:

- the forces of active drag do not significantly differ statistically between each other (see Table 2);

- the average velocity of swimming over a chosen time interval, in swimming front crawl sprint without artificially created additional resistance does significantly differ statistically from average velocities measured over a corresponding time interval, by maximal velocity of swimming with all four artificially created additional resistance levels (see Table 1);

- the stroke frequency over a chosen time interval in front crawl sprint without artificially created additional resistance does significantly statistically differ from frequencies of pulls, measured over a corresponding time interval, by maximal effort swimming with the first three artificially created additional resistance levels (see Table 1);

- the stroke frequency over a chosen time interval, using front crawl sprint without artificially created additional resistance, does not significantly differ statistically from stroke frequency measured over a corresponding time interval, by maximal effort swimming with the fourth-greatest, artificially created level of additional resistance (see Table 1);

Discussion

If we compare the absolute values of active drag forces obtained during this research, it is evident that the mean values varied from 65 N to 76 N. Using the values of both the passive and active resistance levels from other authors, we can establish the following:

1. The values of active drag forces obtained in our study are similar to the values of passive resistance. Values of passive resistance do vary from 40 to 90 N at a velocity of 1.6 m/s according to the findings of Clarys (1981), who collected the findings of different authors. Within these limits, the values of passive resistance also vary, according to Bednarik (1991). The findings of various authors collected by Miller (1981), show that the active drag is greater than the passive one, but the differences varied from 1.3 to 3 times

greater active drag. However, other authors (Hollander, 1985; Toussaint, 1988) who have assessed the active drag with a MAD system found that the active drag was even less than the passive one.

2. In determining the active drag values, much controversy remains. The range of active drag values found varies from values of around 30 N (Toussaint, 1992) to around 108 N as found in the study of Nomura (1994). The different values of active drag achieved could be the consequence of different methods of measurement, estimations of active drag and different subject samples.

3. In the research of Kolmogorov and Duplischeva (1992), active drag was obtained using a similar method to that used in our study. In that research, the values of active drag in the men's front-crawl swimming varied from 45.25 N to 167.11 N. In our research, similar values of active drag were obtained.

The differences between the forces of active drag, calculated on the basis of parameters measured during front crawl sprint and maximal velocity front crawl with different artificial additional resistances, are not really statistically significant. With that we confirmed the hypothesis that active drag can be estimated with the help of artificial additional resistances.

The resulting difference between the subjects (from 34 N to 197 N) was probably due to subject sample. Since some of our swimmers obtained higher values of active drag with lower swimming velocities, we can presume that swimmers had poorer swimming techniques or other parameters influencing the active drag. This is in accordance with the findings of Clarys (1981) and Kolmogorov (1992) who found that body form has only a small effect on active drag, which is mostly determined with body movement. Bigger or smaller active drag mostly depends on a swimmer's technique. A swimmer's movement in water creates different active drag results. The structure of the forces operating during swimming is very complex and measured with difficulty.

We found that active drag forces do not significantly differ in five swimmers. For the other measured persons, the deviation of one or even two active drag forces from others was relatively big. This is probably because the results of this research prove that an increase of additional resistance by only 9 N produces statistically significant changes to the velocity of a swimmer.

The reason that the same measured person produces deviation in particular forces of active drag could be that some individuals may not have swum repetitively with the defined additional maximal resistance engaged and that is why they have not achieved maximal velocity. The second possibility is that a swimmer is not able to produce enough active drag to enable him to function normally in the harder conditions dictated by the artificially created additional resistance. Therefore, a suspicion exists that particular measured persons changed the conditions of swimming because of additionaly created resistance, that deviate significantly from those which are valid for competitive swimming. If that suspicion is well founded, we have not succeeded in the proof. We do not have at our disposal the appropriate technology for measuring. We only ascertained that the velocity of swimming and stroke frequency have, because of additional resistance, significantly changed statistically, but stayed within the range characteristic for competitive swimming (200 m or 400 m freestyle).

In swimming with the greatest artificial additional resistance, swimmers began to swim at a frequency which is within competition limits, but reacted to a greater additional resistance differently than to the other, smaller forms of additional resistance. In their swimming, it was the velocity which decreased most, which is normal, but swimmers swam with a higher frequency of strokes as for smaller additional resistance. This data shows the shortening of the length of strokes and, with that, changes to swimming technique. The swimming technique, whereby the same swimmer swims slower, but with greater frequency than for faster swimming, appears to be atypical. Competitors swim in this way usually when they are exhausted. And they were not exhausted during the measuring procedure lasting 10 seconds. They obviously reacted to greater artificially created additional resistance with atypical swimming technique, with a shortening of strokes and a greater frequency of strokes.

In any case, it is necessary that in the future we also equip the swimmers with a system for the two- or three-dimensional kinematic analyses. It will thereby be possible to precisely determine if the swimming technique with additionally created artificial resistance corresponds to the technique which is characteristic for competitive swimming.

Conclusions

In terms of the research results, we can conclude that the forces of the active drag, calculated from kinematic and dynamic parameters, measured during the front crawl sprint at maximum exertion and the front crawl at maximum exertion with different artificially created forms of additional resistance, do not significantly differ statistically between each other.

Because of those findings, statistically proved by t - test and based on experiments, we can presume that the active drag can be assessed using the following mathematical model:

$$R = F_u \cdot (v_2 \cdot v_1^2) \; / \; v_1^3 - v_2^3,$$

Although our research findings about active drag are substantially consistent with the findings of other authors, we are convinced that we must continue our experiment so that a system for a three-dimensional kinematic analysis is also incorporated. With that, measurements of kinematic parameters would be more precise and the possibility of controlling swimming conditions would improve.

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