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INVESTIGATION OF ARM AND LEG CONTRIBUTION TO PROPULSION AND PERCENTAGE OF COORDINATION IN BREASTSTROKE SWIMMING

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Abstract

The Indirect Measurement of Active Drag (IMAD) was used to study the contribution of the legs and arms to propulsion in breaststroke swimming. Contrary to MAD (Measuring of Active Drag) system, the IMAD can be used for all strokes and therefore enabled us to study the breaststroke swim to estimate not only the percentage of leg and arm contribution to propulsion but also the percentage of swimmers' arms and legs co- ordinations. The method revealed that the best coordination was 84.02 % and that the contribution of arms and legs in propulsive force were 43.80% and 56.20% respectively, showing that the swimmers received leg contribution better than arm contribution in propelling.

Keywords: legs and arms contribution, percentage of coordination, breaststroke swim

1. Introduction

Few researchers dedicated research on determination of arm and leg contribution to propulsion and percentage of coordination in breaststroke swimming. It is well known that the breaststroke is the fastest style regulated by FINA. The peak speed of the breaststroke is even faster than that of the front crawl, due to the synchronous pull/push with both arms. Yet since speed drops significantly during the recovery phase, it is overall slightly slower than the front crawl. In breaststroke swimming legs and hands play the important role in propulsion equally. However, it is unclear how many percentage legs may cause an increase in swimming speed.

Shahbazi, (2007 and 2008) and Shahbazi et al., 2006 studies, by using the indirect measurement of active drag (IMAD), reported well these percentages in front and back crawl and butterfly swims. Breaststroke is a simple stroke to swim as it needs both high coordination and style.

Breaststroke is the slowest of the four official styles in competitive swimming. The fastest breaststroke swimmers can swim about 1.57 meters per second. Although it is the slowest of the four competitive strokes, it is commonly agreed that it is by far the most difficult to do correctly. It is mandatory to know if you are aspiring to be a lifeguard. It is also often the hardest to teach to rising swimmers after butterfly due to the importance of timing and the coordination required to move the legs properly.

In the breaststroke, the swimmer leans on the chest, arms breaking the surface of the water slightly, legs always underwater and the head underwater for the second half of the stroke. The kick is sometimes referred to as a frog kick because of the resemblance to the movement of a frog's hind legs. However, when done correctly it is more of a "whip kick" due to the whip-like motion that moves starting at the core down through the legs.

The body is often at a steep angle to the forward movement. This slows down the swimmer more than any other style. Professional breaststrokers use abdominal muscles and hips to add extra power to the kick, although most do not perfect this technique until the collegiate level. This much faster form of breaststroke is referred to as "wave-action" breaststroke and fully incorporates the whip-kick.

A special feature of competitive breaststroke is the underwater pullout. From the streamline position, one uses the arms to pull all the way down past the hips. As the arms are pulling down, one downward dolphin kick is allowed (as of the 2005 season), though still optional (However, any upward motion with the dolphin kick is strictly forbidden, and will result in a disqualification). This is followed by the recovery of the arms to the streamline position once more, and then a kick. The pullout at the start and after the turns contributes significantly to the swimming times. Therefore one way to improve the swimming times is to focus on the start and the turns.

2. Materials and methods

Early measurements of active drag involved indirect calculations based on changes in oxigen consumption with additional drag loaded onto the swimmer Di Prompero et al., (1974), Clarys (1978, 1979). Methods for the direct measurements of active drag have been introduced, namely the Measuring Active Drag system (MAD: Toussaint et al., (1988) and the velocity perturbation method Kolmogorov and Duplisheva (1992). MAD system measures the momentary propulsive arm force during a front crawl swimminig-like activity. At 0.8 meter under the water surface of a 25 meters indoor swimming pool (water temperature 27 C) a 23 meters tube is positioned with help of vertical ropes attached to a second tube on the botton of the pool. On the tube fifteen grips are attached at a distance of 1.35 m apart, which is the estimated stroke length during free swimming. One end of the tube is fixed to the wall of the swimming pool via a force transducer. The other (loose) end is used for calibration by means of weight applied to the pipe via a pulley system. Despite the length of the entire system the resonance frequency appears to be high (20 Hz).

Velocity perturbation method involves changing the maximal swimming velocity using added drag by a hydrodynamic body of known resistance towed by the swimmer Kolmogorov and Duplisheva (1992). To prevent turbulance, produced behind swimmer, the hydrodynamic body is placed at 3.5-4.5 times the swimmer length. Swimming speed, V, and resistance force, R, are measured during both swims. The assumption has been made by authors that the power output during swimming without the hydrodynamic body is equal to the power output delivered when swimming with the hydrodynamic body. However, not all power generated in swimming can be used to overcome drag.

Recently, a new Indirect Measurement of Active Drag has been introduced [10,11]. This method enabled us to find out the drag force in four competion strokes Shahbazi and Sabbaghian (2005), Shahbazi (2006), Shahbazi (2007), Shahbazi et al., (2008), Shahbazi (2008), Shahbazi and Shahbazi (2008). In this method swimmer is considered as a lumped particle of mass M, moving in the direction of X axis. The swimmers were encouraged to swim a 10m distance from still position as fast as they could and at the end of this distance they ciesed swimming and glided as afa as they could. The time of 10m swim and the glided distance were inserted in the established formulae to estimate the propulsive force, which at maximum velocity is equal to the drag force.

2.1. Formalism

In order to estimate the propulsive force, swimmer was assumed as a lumped particle moving along horizontal direction. According to Shahbazi and Sanders (2002, 2004) a general equation of motion has been considered;

$$F_P - (C_1 v - C_2 v^2) = M\, dv/dt \qquad (8)$$

Where F_P is the swimmer's propulsive force, C_1 and C_2 are the resistive force coefficients and, v and M are swimmer's velocity and mass respectively. In fact, Eq. (8) shows that the swimmer experiences two types of drag forces; one proportional to v and the other proportional to v^2. As the swimmer reaches his/her limit speed V_L after a while, then $dv/dt = 0$ and we get for propulsive force

$F_P = (C_1v - C_2v^2)$ (9)

2.1.1. Drag force proportional to v

The equation of motion is

$F_P - C_1v = M\ dv/dt$ (10)

At limit speed; $v = V_L$ the acceleration becomes zero and we will have for propulsive force

$F_P = C_1 V_L$ (11)

Inserting Eq. (11) into Eq. (10) we get

$C_1(V_L - v) = M\ dv/dt$ (12)

In integral form;

$$\int_0^t (C_1/M)dt = \int_0^v dv/(V_L - v) \quad (13)$$

Integrating both sides of Eq. (13) and considering; at t=0, v=0 then

$$(C_1/M).t = -Ln[(V_L - v)/V_L] \quad (14)$$

Equation (14) in exponential form;

$$(V_L - v)/V_L = \exp(-C_1 t/M) \quad (15)$$

Solving Eq. (15) for v, we get

$$v = V_L(1 - \exp-(C_1 t/M)) \quad (16)$$

Equation (16) shows that the behavior of the body velocity in water from still position is exponential and depending upon the maximum (limit) velocity of the swimmer and varies with time. After a certain time, the exponential term vanishes and the instantaneous speed equals the limit speed. Solving Eq. (16) for V_L;

$$V_L = v/(1 - \exp-(C_1 t/M)) = v(1 + \exp-(C_1 t/M)) \quad (17)$$

Combining Eq. (17) and Eq. (11) yields the propulsive force

$$F_P = C_1 v(1 + \exp-(C_1 t/M)) \quad (18)$$

Equation (18) shows how the propulsive force varies with time until the exponential term vanishes and equals the drag force. As approximation, v has been considered as mean velocity in order to get propulsive force variation profile.

2.1.2. Determination of C_1

At gliding phase, since there is no propulsive force, Eq. (10) becomes;

$-C_1 v = M\ dv/dt$ (19)

Putting Eq. (19) in an appropriate form for integrating, we have;

$$-\int_0^t (C_1/M)dt = \int_{v_L}^{v} dv/dt \quad (20)$$

Integrating yields;

$$v = V_L \exp(-C_1 t/M) \quad (21)$$

Equation (21) shows that when time increases the velocity decreases exponentially and finally tends to zero. Replacing *v* by dx/dt and integrating, we get;

$$X = (V_L M/C_1)(1-\exp(-C_1 t/M) \quad (22)$$

X is the glided distance and when *t* increases then the exponential term vanishes and *X* tends to; $V_L M/ C_1$ from which C_1 can be extracted as;

$$C_1 = V_L M/X \quad (23)$$

Inserting the value of V_L into Eq. (17) we will have

$$C_1 = Mv/X(1+\exp(-C_1 t/M)) \quad (24)$$

Expanding the exponential term and solving for C_1 yields;

$$C_1 = 2Mv/(X+vt) \quad (25)$$

In fact the term *vt* in Eq. (25) is nothing but the 10 meters distance swum by the swimmers, therefore C_1 is in its final form as;

$$C_1 = 2Mv/(X+10) \quad (26)$$

2.1.3. Drag force proportional to v^2

The equation of movement becomes;

$$F_P - C_2 v^2 = M\, dv/dt \quad (27)$$

Repeating the previous procedure we get;

$$(C_2/M)\, dt = dv/(V_L^2 - v^2) \quad (28)$$

Integrating Eq. (28), and considering that at *t*=0, *v*=0, then we get

$$(C_2 t/M) = \frac{1}{2} V_L \ln \frac{v+V_L}{v-V_L} \quad (29)$$

In exponential form, Eq. (23) becomes

$$V_L - v = (v+V_L)\exp(-2C_2 V_L t/M) \quad (30)$$

Rearranging Eq. (30) we can get;

$$V_L/v = (1+\exp(-2C_2 V_L t/M))/(1-\exp(-2C_2 V_L t/M)) \quad (31)$$

Equation (31) shows that the swimmer's velocity is again exponential and after a certain time the exponential terms vanish and limit speed is attained. As an assumption, we took the linear terms of exponentials in nominator and denominator, and then we have;

$$V_L/v = (1-(C_2 V_L t/M))/(C_2 V_L t/M) \quad (32)$$

Rearranging, Eq. (32) we get;

$$V_L^{\,2} - vV_L - M / C_2 t = 0 \qquad (33)$$

Solving Eq. (27) for V_L ;

$$|V_L| = 0.5\{v + \sqrt{v^2 + 4Mv/(C_2 t)}\} \qquad (34)$$

The previous approximation could be taken to get the force variation profile.

2.1.4. Determination of C_2

As there is no propulsion force in glide phase, therefore the equation of movement becomes;

$$-C_2 v^2 = M\, dv/dt \qquad (35)$$

The integration yields

$$C_2\, t/M = (1/v - 1/V_L)) \qquad (36)$$

Solving Eq. (36) for v gives

$$v = V_L /(C_2 V_L t + M) \qquad (37)$$

Replacing v by dx/dt and integrating yields finally for glided distance;

$$X = ((M / C_2) \ln(1 + C_2\, V_L t / M) \qquad (38)$$

Since $C_2\, V_L t / M$ »1 then 1 is negligible and we can rewrite Eq. (32) in exponential form as;

$$\exp(-C_2 X / M) = M/(C_2 V_L t) \qquad (39)$$

In most practical cases, $C_2 X / M \le 1$, therefore expanding the exponential term we can rewrite Eq. (39) as;

$$1 - C_2 X / M = M/(C_2 V_L t) \qquad (40)$$

As $M/(C_2 V_L t) \ll 1$, therefore we can have for C_2 ;

$$C_2 = M/X \qquad (41)$$

Now solving equation Eq. (9) by the same procedure, Shahbazi and Sanders (2002) showed that we could have for the swimmer’s velocity the following relationship;

$$v = V_L (1 - \exp - (C_1 + C_2 V_L) t / M) \qquad (42)$$

Equation (42) shows that the behavior of velocity is exponential. Expanding the exponential term and as an approximation staying in linear region, and solving for V_L we get;

$$V_L = 0.5\{C_1 / C_2 + \sqrt{(C_1 / C_2)^2 + (4Mv) / tC_2}\} \qquad (43)$$

Equation (43) can now be used, knowing the values of C_1 and C_2 for propulsive force estimation. in order to estimate the propulsive force resulted from arms only, legs only, and the full stroke. In each step, swimmers swam three times with enough time of rest in between.

3. RESULTS AND DISCUSSION:

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By measuring time of 10m swim with a precision of 10s, and the glided distance with a precision of 10m and using above formulae, the individual values for hydrodynamic coefficients and drag force for all subjects were obtained.

Table1. Measurements of full, arm, and leg forces and the percentage of coordination

Subjects	Full Stroke (N)	Arms only (N)	Legs only (N)	Contribution of Arm %	Contribution of leg %	Coordination %
1	38.27	23.45	26.21	47.22	52.78	70.24 %
2	54.85	27.86	35.75	43.80	56.20	84.02 %
3	40.23	37.98	19.40	66.19	33.81	57.39 %
4	57.15	28.74	32.69	46.44	53.56	87.27 %
5	41.02	32.05	21.64	59.70	40.30	69.11 %
6	34.41	26.65	18.69	58.79	41.21	68.22 %
7	19.50	14.77	12.65	53.87	46.13	59.38 %
8	51.09	38.39	26.56	59.11	40.89	72.89 %

As is indicated in Table 1, IMAD method is capable of yielding the arms and legs forces separately, therefore the percentage of the contribution of arms and legs are calculated. Our results suggest that the whole leg force does not aid propulsion directly and therefore it follows from the present results that partly. Subject No. (2), had the highest coordination (84.02 %%) and stabilizing in full stroke swim. Subject No. (3), showed least coordination (57.39 %).

Our results showed that in breaststroke swimming the arm and leg forces had approximately equally contribution in breaststroke swimming. On the other hand, in the best coordination and high propulsive force, the leg forces were a little higher than arm forces. The method is reliable and simple to use, therefore other researchers can use this method for all other strokes and get fantastic results.

CONCLUSION

The IMAD system has been used to determine the contribution of arms and legs in propulsion. The study showed that the leg and arms had equally contribution and in the best coordination and high propulsion between subject, leg had a little higher contribution than arms.

The IMAD reliably and easily revealed the swimmers parameters which could not be achieved with MAD.

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