DETERMINATION OF ARM AND LEG CONTRIBUTION TO PROPULSION AND PERCENTAGE OF COORDINATION IN BUTTERFLY SWIMMING

Morteza Shahbazi-Moghadam

School of Physics, University of Tehran & Centre for Aquatic Research and Education, the University of Edinburgh Scotland, UK

The Indirect Measurement of Active Drag (IMAD) was used to study the contribution of the legs and arms to propulsion in butterfly swimming. Contrary to MAD (Measuring of Active Drag) system, the IMAD can be used for all strokes and therefore enabled us to study the butterfly 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 78.% and that the contribution of arms and legs in propulsive force were 92% and 66% and in velocities were 98% and 88% respectively, showing that the swimmers received arm contribution better than leg contribution in propelling and velocity.

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

INTRODUCTION: Few researchers dedicated research on determination of arm and leg contribution to propulsion and percentage of coordination in butterfly swimming. It is well known that the butterfly is the fastest style regulated by FINA. The peak speed of the butterfly 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. Butterfly swimmers have a top speed of 2.18 m/s (4.87 mph), slightly under freestyle at 2.35 m/s (5.25 mph), over backstroke at 2.04 m/s (4.57 mph), and well over breaststroke at 1.84 m/s (4.11 mph). In butterfly swimming hands play the main role in propulsion 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 breaststroke swims. Butterfly is a difficult stroke to swim as it needs both stamina and style.

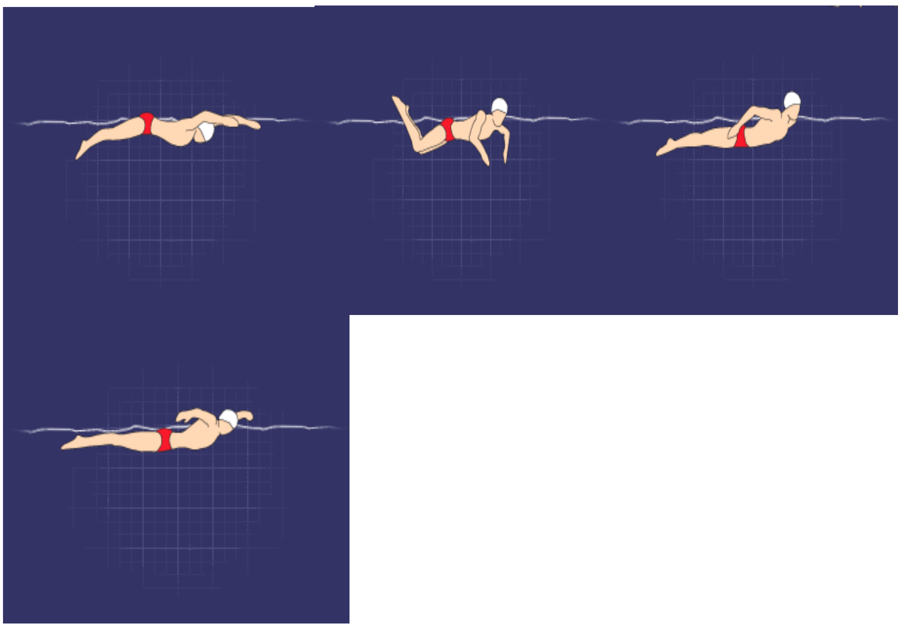

Figure 1. The four main phases in butterfly swim; start position, pre-thrust, thrust and flying phases in which the maximum drag is produced in third phase.

The butterfly stroke has three major parts, the pull, the push, and the recovery. These can also be further subdivided. From the initial position, the arm movement starts very similarly to the breast stroke. The pull movement follows a semicircle with the elbow higher than the hand and the hand pointing towards the center of the body and downward. The push pushes the palm backward through the water underneath the body at the beginning and at the side of the body at the end of the push. The swimmer only pushes the arms 1/3 of the way to the hips, making it easier to enter into the recovery, making the recovery shorter and making the breathing window shorter. The recovery swings the arms sideways across the water surface to the front, with the elbows straight. The arms should be swung forward from the end of the underwater movement, the extension of the triceps in combination with the butterfly kick will allow the arm to be brought forward relaxed yet quickly. In contrast to the front crawl recovery, this arm recovery is a ballistic shot. The leg movement is similar to the leg movement in the front crawl, except the legs are synchronized with each other, and it uses a wholly different set of muscles. The shoulders are brought above the surface by a strong up and medium down kick, and back below the surface by a strong down and medium up kick. A smooth undulation fuses the motion together. The feet are pressed together to avoid loss of water-pressure. The feet are naturally pointing downwards, giving downwards thrust, moving up the feet and pressing down the head. The aim of present study was to determine the contribution of arms and legs and also the percentage of coordination in butterfly swim.

METHODS: Seven male swimmers at national level (aged 18±1 yr; weight 66.68±10.89 kg; height 175.59±14.35 cm) volunteered for this study. The mean best time for the subjects in the 100-m butterfly stroke, short course, was 62.5±2.45 sec. The subjects swam butterfly under three conditions: (a) arms only with no bounding in legs, (b) legs only, and (c) full stroke. At a constant speed and using the arms only, the mean propelling force equals total drag at any given speed. In IMAD method (Shahbazi and Sanders 2002, 2004; Shahbazi et al., 2006; Shagbazi, 2007 and 2008), there is no special system but a tape-meter, a start-stop watch and appropriate formulae extracted from theoretical mathematical modeling.
The swimmers were requested to start swimming a 10 m long distance from still position by whistling as fast as they could and then at the end of the 10 m distance, again by whistling, they ceased swimming but gliding as far as possible. The time of 10m swim and the glided distance were used in the formulae (Shahbazi and Sanders, 2002, 2004) 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. The mean propulsive force is given as:

$$F_P = (C_1 V_L + C_2 VL^2) \quad (1)$$

V_L is the maximum velocity that the swimmer can reach in 10 m swim; C_1 and C_2 are the hydrodynamic coefficients to be obtained by:

$$C_1= 2MV/(X+Vt) \quad (2)$$

X is the glided distance, V is the average velocity in 10 m swim, and

$$C_2= X/M \quad (3)$$

The maximum velocity (limit velocity) can be obtained by:

$$V_L=0.5\{C_1/C_2+ [(C_1/C_2)^2+(4MV/C_2t)]^{½} \} \quad (4)$$

RESULTS AND DISCUSSION: By measuring time of 10m swim with a precision of 10^{-2} s. and the glided distance with a precision of 10^{-2} m and using above formulae, the individual values for maximum swimming speed, hydrodynamic coefficients, drag force, and the relation between these variables for all subjects were obtained. In the second, third, and forth columns of the Table 1 the full stroke, arm only (with no leg support), and leg only forces, applied by subjects are presented. In column 5 of the Table 1 the sum of the arm and leg only forces is presented as theoretical force. In fact we considered as if these two forces were applied in the same direction (direction of velocity). In column 6 the difference between theoretical and real forces are presented. In column 7 of Table 1 the percentage of force which has not been used for increasing the swimmer velocity is presented. From these data the percentage of the arms and legs coordination can easily be achieved and is presented in column 8.

In columns 2, 3, and 4 of Table 2 the mean velocities of full stroke, arms and legs only are presented. In columns 5 and 6 the percentage of arms and legs are presented using their velocities and in column7 and 8 the percentage of arms and legs contributions are presented by using IMAD method. 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; an amount of ΔF (in Table 1) is used in stabilizing the trunk in the full stroke. Subject No.3 (75.2 kg) had the highest coordination (78.3%) and stabilizing in full stroke swim. Subject No.1, (85 kg), although 10kg heavier, showed significant coordination (73.8%). On the other hand, with less full stroke force he had significant mean velocity.

Table1. Mean±SD of full, arm, and leg forces and the percentage of coordination

Subjects	Full-Stroke F_F (N)	Arms only F_A (N)	Legs only F_L(N)	Theoretical (F_A+F_L)(N)	Difference ΔF (N)	Loss $\Delta F/(F_A+F_L)$	Coordination %
1	72.1±1.65	66.54±3.85	31.09±2,53	97.64±2.85	25.54	26.2%	73.8%
2	72.32±1.57	65.82±3.47	43.79±1.84	113.6±3.92	41.30	36.4%	63.6%
3	68.86±3.92	56.23±2.57	30.33±2.64	75.06±3.33	16.28	21.7%	78.3%
4	55.77±3.6	51.09±1.25	26.92±1.45	78.05±3.95	22.26	28.6%	71.5%
5	44.76±1.48	41.1±0.92	21.05±2.07	62.34±2.33	17.54	28.2%	71.9%
6	49.08±2.66	48.09±1.59	36.46±3.52	83.56±2.96	34.46	41.2%	58.8%
7	41.92±2.24	37.54±1.12	24.52±1.42	62.04±1.95	20.09	32.4%	67.6%

Table 2. Mean±SD of full, arm, and leg only velocities and their % of contributions

Subjects	Full-Stroke V_F (m/s)	Arms only V_A (m/s)	Legs only V_L(m/s)	V_A/V_F %	V_L/V_F %	F_A/F_F %	F_L/F_F %
1	1.41±0.03	1.35±0.02	0.95±0.04	95.8%	67.4%	92.3%	43.1%
2	1.42±0.05	1.4±0.04	1.14±0.03	95.6%	78.6%	91%	66.1%
3	1.44±0.07	1.32±0.03	1.23±0.05	84.3%	76.9%	69.2%	58.5%
4	1.35±0.04	1.29±0.02	1.21±0.03	95. 6%	70.4%	91.6%	48.3%
5	1.33±0.10	1.26±0.03	1.15±0.06	94.7%	70.0%	91.6%	47.6%
6	1.49± 0.06	1.46±0.03	1.33±0.12	98%	88.0%	96%	74.3%
7	1.39± 0.05	1.32±0.02	1.25±0.04	95%	78.4%	89.5%	58.4%

Our results showed that in butterfly swimming the arm forces were significantly higher than leg forces whereas the arms only velocities were predominant in butterfly swimming. Figure 2 shows that there are high correlations between arm forces and swimmer mass (82%) and full stroke (93.8%), while there were no significant correlations with leg forces.

Unfortunately, our subjects were not butterfly swimmers but still the results are satisfactorily acceptable. 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 method has been used to determine the contributions of arms and legs in propulsion and swimmers' velocity. The study revealed that there were significant correlations between swimmers' mass and arm forces, while it was not the case for leg forces. This meant that the swimmers' kicking was mostly used for body stabilizing and swimmers' mass was not much correlated with legs. Arms forces were significantly related with full stroke force. The IMAD reliably and easily revealed the swimmers parameters which could not be achieved with MAD.

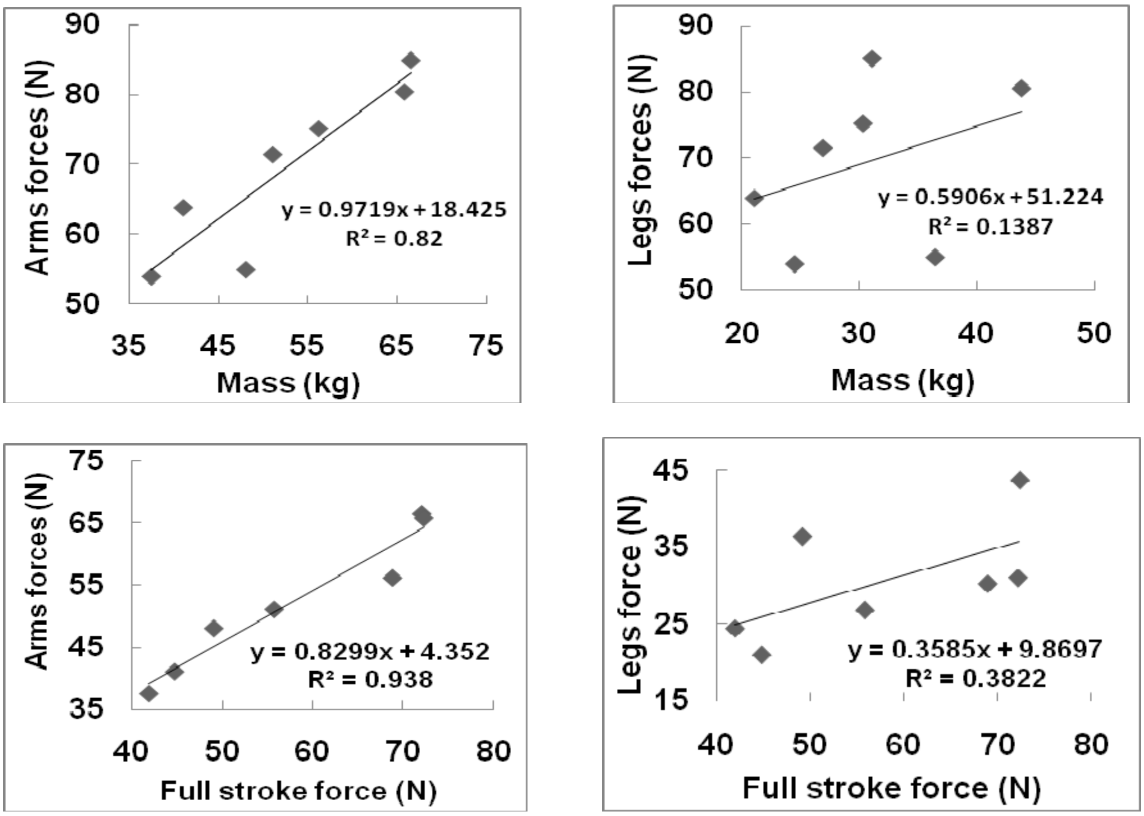

Figure 2. There are high correlations between arm forces and swimmer mass (82%) and full stroke (93.8%), while there were no significant correlations with legs forces.

REFERENCES:

Shahbazi, M.M. (2008). Determination of Arms and Legs Contribution to Propulsive and Percentage of Coordination in Breaststroke Swimming. Proceedings; XXVI International Symposium on Biomechanics in Sports. Seoul, Korea, pp. 228-231.

Shahbazi, M.M. (2007). Determination of Arms and Legs Contribution to Propulsive and Percentage of Coordination in Backstroke Swimming. Proceedings; XXV International Symposium on Biomechanics in Sports. Menzel, H.J. and Chagas, M. H. (eds.). Ouro Preto, Brazil. Pp208-211.

Shahbazi, M.M., Ravassi, A.A., Taghavi, H. (2006). Use of a New Indirect Method in Determining the Contribution of Legs and Hands to Propulsion in Front Crawl. Proceedings; XXIV International Symposium on Biomechanics in Sports. Schwameder, H., Struzenberger, G., Fastenbauer, S., Lindinger, S., Muller, E. (eds). P. 71-74. University of Salzburg- Austria.

Shahbazi, M.M., and Sanders, R.H. (2004). A Biomechanichal Approach to Drag Force and Hydrodynamic Coefficient Assessments. Proceedings; XXIV International Symposium on Biomechanics in Sports. Lamotagne, M. Gordon, G., and Sveistrup, H. (eds). Faculty of Health Sciences, University of Ottawa, Canada. P. 225-228.

Shahbazi, M.M., and Sanders, R.H. (2002). Kinematical Approaches to Hydrodynamic Force Assessments. Pakistan Journal of Applied Sciences. 2(9) 895-902.