BIOMECHANICAL ANALYSIS OF ACTIVE DRAG IN SWIMMING

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Active drag measurement through an entire swimming stroke was computed from the swimmer's maximum sprint speed and the assistive force required to tow the swimmer at a slightly higher known velocity. The mean values of the active drag obtained were similar to those previously reported (Male 95 & 83 N, Female 73 & 69 N in freestyle and butterfly). A graph of time against active drag for butterfly highlighted the propulsion and recovery phases. The within stroke drag fluctuations in freestyle were less than in butterfly. The active drag graph combined with synchronised video would enable the swimmer's technical efficiency to be evaluated throughout the stroke cycle. This method could be used to identify aspects of the swimmer's stroke that corresponded with changes in the swimmer's active drag.

KEY WORDS: active drag, swimming, biomechanics, drag force, freestyle, butterfly

INTRODUCTION:

According to Newton's Laws of Motion the mean propulsive force exerted by a swimmer on the water is equal to the mean drag force exerted by the surrounding water on the swimmer when moving at any constant velocity. Consequently, the maximum velocity a swimmer can attain is achieved when their maximum propelling force is in equilibrium with the drag force opposing the forward movement. To enable an athlete to swim faster, the swimmer must either increase the propulsive force, reduce the drag force, or do both.

Since active drag is a determinant of maximum speed, an understanding and quantification of how technique relates to drag force is important for coaches and scientists in their pursuit of improved performance. Hollander *et al*., (1985) developed a system to measure active drag (MAD-system). Here swimmers pushed on fixed pads with each hand stroke of a freestyle swimming action. The pads were attached to a 23 metre long bar, submerged 0.8 m below the water surface and fixed to a force transducer at one end of the pool. The transducer quantified the force that the swimmer exerted on the bar to propel themselves forward. The force was time integrated to give a mean drag force. The problems which arose from the MAD-system were that it did not evaluate the contribution of the kick (athletes held a pull buoy between their legs) nor could it be applied to investigate any other stroke beside freestyle. There are also questions asked as to how well the freestyle action was duplicated when the swimmer used the MAD system.

Kolmogorov and Duplischeva (1990) developed a system to measure active drag in all swimming strokes, in almost a free swimming condition. Subjects swam twice with maximum effort, once swimming free and once towing a hydrodynamic body that created an additional, known resistance. The difference in speed attained in the two conditions was used to compute active drag. The investigators also measured passive drag at the free swimming velocity with the swimmer in a streamlined position. The investigators reported paradoxical results in that when the results for active and passive drag were compared, active drag was less than passive drag in three of the strokes (all except breaststroke). The proposed reason for this phenomenon was explained by the intra-cyclic velocity fluctuations that occur during the swimming strokes. However the investigators were unable to directly measure these fluctuations with their current method.

Active drag is constantly changing throughout a stroke due to movements of the athlete's body, changes in the flow of the water around the body and because of the various propulsive and recovery phases within the stroke. Previous studies have reported active drag as a single mean value. However the benefit of representing active drag by a single value to represent this fluctuating parameter, as opposed to a constantly changing value within the swimming cycle, is questionable. Therefore, the aim of this study was to develop a method by which active drag could be monitored throughout an entire swimming stroke.

METHODS:

The method used in this research was similar to the Kolmogorov and Duplischeva perturbation method except that the swimmer was assisted rather than resisted. Two subjects participated after giving informed consent. The female was an Olympic medal winner and the male was a member of the Australian national swimming squad. The swimmers were towed by a flux vector dynamometer mounted on a Kistler force platform at 2 m/s for butterfly and 2.2 m/s for freestyle. Competition analysis conducted by the Australian Institute of Sport revealed these athletes reached almost 1.8 m/s in butterfly and 2.0 m/s in freestyle races. Thus 2.0 m/s and 2.2 m/s were selected respectively to increase maximal speed by approximately 10%. This was considered to be a small enough increase that it would not affect stroke mechanics, yet fast enough so that the athlete could not overtake the swim assistance force in any phase of the stroke. A tachometer validated the speed of the dynamometer. The athlete was attached to the dynamometer tow rope with an Eyeline belt, with the rope attachment pulling at the waist from the front of the body. Excess belt material was tucked in behind the belt to minimise any effect on drag. The rope was also pulled in without a swimmer or belt attached so as to obtain a measurement used to compensate for any force associated with the equipment on which the swimmer was towed.

The assisted swim commenced 30 m out from the end of the pool and force platform data was captured from the first hand entry for four full strokes (four hand entries for butterfly and eight for freestyle) after the swimmer passed the 20 m mark. The Fy force (in the towing direction) and a trigger pulse, to indicate the start and end of data capture, were sampled at 500 Hz. In the 10 m period before data capture the dynamometer reached the required speed while the athlete accelerated to a maximum speed and found stroke rhythm. A visual aid was placed at the bottom of the pool at 20 m so the athlete could identify when data capture commenced as they were instructed not to breathe for five full stroke cycles after this point. This was done to control for any variations in drag that may have resulted from the breathing process. Five trials were performed and the total Fy component of force was used for analysis of the drag force. A Butterworth low pass digital filter was used to reduce noise when graphing the data. A cut off frequency of 5 Hz was used given that the difference between the mean of the raw and filtered data was less than 0.01 N.

Active drag is related as follows: $F_1 = 0.5C.\rho.A.V_1^2$ and $F_2 = 0.5C.\rho.A.V_2^2 - F_b$

where ρ is water density, A is the frontal surface area of the swimmer & F_b is the force needed to pull the athlete at the increased speed, as measured with a force plate.

If we assume an equal power output in both the free swimming and the assisted swimming conditions: $P_1 = P_2$ and therefore $F_1.V_1 = F_2.V_2$

then substitution of F_1 and F_2 gives: $0.5C.\rho.A.V_1^3 = 0.5C.\rho.A.V_2^3 - F_b.V_2$

Rearranging the formula to find C: $C = \dfrac{F_b.V_2}{0.5\rho.A.(V_2^3 - V_1^3)}$

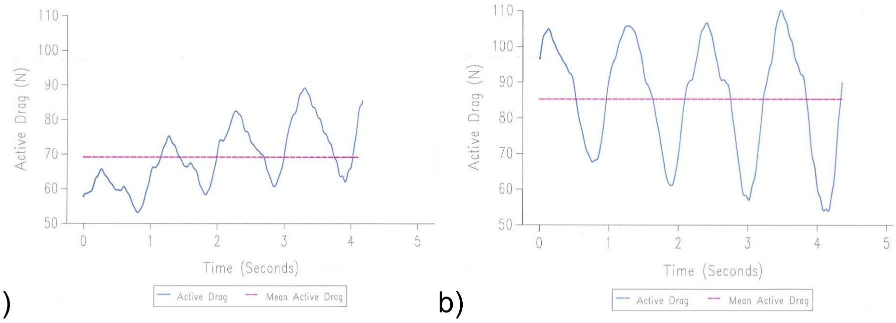
then substitution of C gives the following formula for active drag: $F_1 = \dfrac{F_b.V_2.V_1^2}{V_2^3 - V_1^3}$

The swimmer's maximal unaided velocity was determined by the average of five maximal 10 m sprints with a rolling start, which were timed using magnetic timing gates.

RESULTS:

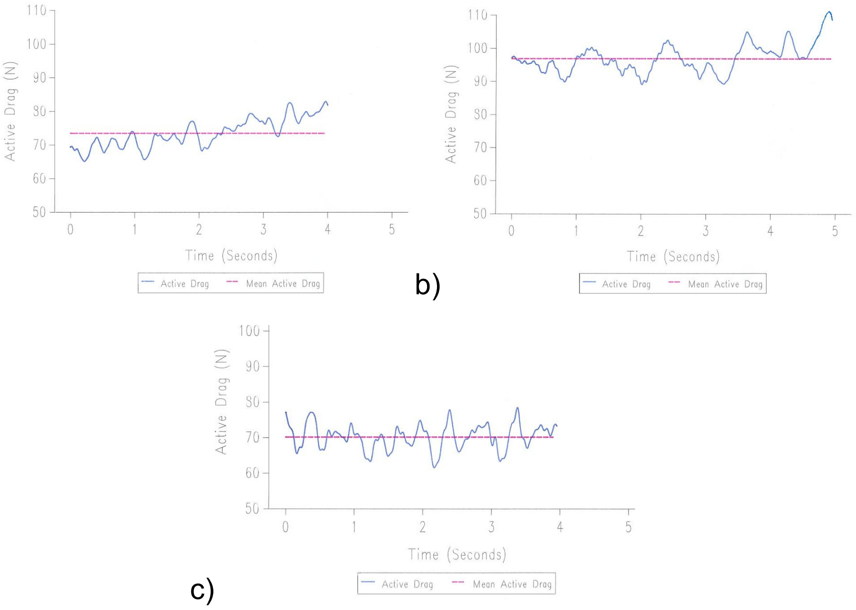
The mean active drag of five trials for freestyle was 73.39 ± 2.46 N for the female and 95.83 ± 2.86 N for the male. In the butterfly the female experienced 69.55 ± 3.12 N of active drag and the male 83.12 ± 3.46 N. The small standard deviations observed indicated the reliability of the method and that the system was capable of obtaining repeatable results.

The active drag in butterfly was less than freestyle, probably due to the greater energy expenditure required to perform the butterfly stroke and the lower maximal unaided velocity. The male had a significantly greater active drag than the female, most probably due to differences in anthropometry. In both butterfly and freestyle, the five trials of one athlete were almost identical. The athletes were consistent in their stroke and each had their own unique curve.



a) b)

Figure 1. Time versus active drag (N) of (a) the female and (b) the male athlete for four butterfly strokes at maximal unaided velocity. 0 seconds corresponds with the 1^{st} hand entry.



a) b)

c)

Figure 2. Active drag (N) of (a) the female and (b) the male for four freestyle strokes at max unaided velocity when towed at 2.2 m/s, and c) the female athlete when towed at 2.0 m/s.

DISCUSSION:

The mean active drag force experienced by the two elite swimmers in this study are in agreement with values previously reported by Hollander *et al*., (1985) and Kolmogorov & Duplischeva, (1990). However since the active drag is constantly changing it was considered more appropriate and meaningful to represent the active drag with a graph rather than with a single number represented by the mean of the parameter.

Figure 1 shows the relationship between active drag and four butterfly strokes, clearly indicating the propulsion and recovery phases of each stroke. There are points on the graph in both the propulsion and recovery phases where active drag momentarily plateaued, possibly due to kicking actions. The active drag resulting from a freestyle technique depicted a smaller range than the butterfly, indicating the intra-cyclic velocity fluctuations were not as pronounced in freestyle. Future studies should adopt a video synchronisation technique to allow for identification of different aspects of the stroke with the corresponding component of the graph. This would allow for variations in an individual's stroke to be monitored to see how this affects drag forces, and may be used as an assessment of the efficiency in the different stroke mechanics used.

An interesting aspect seen in Figures 1, 2a and 2b was that active drag increased over time during each trial. Fatigue was not considered to be a factor as it was assumed elite athletes could easily repeat five 15 m sprints. Instead it was thought the athlete could be "over-swimming". By this what is meant is that the swimmer was attempting to swim faster than they were capable, in an attempt to keep up with the dynamometer and as a result was becoming less efficient with each stroke. If this was the case, one of the assumptions in this method of active drag assessment, that the swimmer's power output in the free and assisted swims was equal, was therefore violated. The athletes' maximal speeds on the day of testing were 1.8 m/s for the female and 1.76 m/s for the male in freestyle meaning the towing speed of 2.2 m/s increased their maximal speed by approximately 20%. Subsequently the investigators pulled the female at 2 m/s for freestyle. The result of this 2 m/s assisted tow supports the theory of over-swimming, as the active drag of the same athlete no longer increased during the trial (Figure 2c). Future studies employing this methodology should be aware of the importance of determining an athlete's maximum speed on the day of testing and not from competition analysis data when athletes usually perform at or near personal best levels. An increase in assisted swimming speed of 5 – 10% is recommended.

There are a number of limitations associated with this method of assessing active drag. Firstly, since it must be assumed that there is a constant power output in both the unaided and assisted conditions, then a measure of active drag can only be valid at the athlete's maximum speed. This has implications for measuring active drag for distance swimmers as the stroke mechanics in a full out sprint and a distance endurance effort differ.

Secondly the current method only allows intra-athlete comparisons as active drag is not only affected by stroke mechanics but also anthropometry. In order to calculate the value of C (the dimensionless coefficient of drag) we must first calculate A (the frontal surface area of the swimmer). The difficulty with calculating A is that like active drag, it is constantly changing. In addition even if the frontal surface area of the athlete could be assessed throughout the stroke, some parts of the body, while contributing to the frontal area, will not be contributing to the drag as these parts are moving backward to propel the body forward. For example, when the arms are pulling through the water in the propulsion phase of a stroke the arms are counteracting the drag force and not contributing to it. Consequently, knowing when to include certain body areas and when to exclude them to get an accurate measure of C would be difficult. Kolmogorov & Duplischeva (1990) used a ratio between passive and active drag to express an efficiency index of an athlete's technique. Given the difficulties of finding A and C, this may be considered as the preferred method for inter-athlete comparisons.

CONCLUSION:

The method presented here provides a simple way of measuring active drag at maximum swimming speed throughout the entire swimming stroke, for both freestyle and butterfly. It provides an easy way to evaluate the efficiency and effectiveness of the swimmer throughout the stroke cycle with respect to small changes in technique. Synchronising this data with video would allow for identification of those aspects of the stroke that correspond to changes in active drag on the graph. The principles and system used here should also hold true for breaststroke and backstroke.

Active drag varies considerably throughout a stroke; therefore expressing it as a varying parameter on a graph, with active drag plotted against time, is probably more beneficial to a coach or scientist than expressing it as a single mean value. Since the athlete's propulsive force is equal to the drag force, this information could also be used to investigate the force profile of a swimmer throughout an entire swimming stroke.

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