THE USE OF PASSIVE DRAG TO INTERPRET VARIATION IN ACTIVE DRAG MEASUREMENTS

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This study investigated if a measure of mean passive drag could explain the huge differences in propulsive force required by different swimmers to swim at a similar high velocity. Nineteen elite male and female national freestyle swimmers were subjects. The subject's mean active and passive drag was measured at each swimmer's top swimming pace. Stepwise regression analysis was used in the analysis. Passive drag was accepted into the equation to calculate mean propulsive force, prior to velocity being rejected. The correlation coefficient for the relationship between mean propelling force and mean passive drag was 0.77. This was statistically significant at the $p<0.001$ level and explained 59% in the variance of mean propulsive force that swimmers need to produce to reach their top swimming pace. Clearly, a measure of the swimmer's passive drag does provide an explanation for the huge differences in propulsive force required by swimmers to be competitive in the free swim aspect of races.

KEY WORDS: Biomechanics, swimming, passive drag, active drag, propulsive forces

INTRODUCTION: The Australian Institute of Sport (A.I.S.) has developed protocols and equipment based on the velocity perturbation method developed in Russia by Kolmogorov et al. (2000) in which the active drag force that opposes the swimmer's motion may be computed at the swimmer's top swimming pace. In constant velocity unaided swimming, the propulsive force applied by the swimmer to the water is equivalent but opposite in direction to the active drag force applied by the water to the swimmer. Unlike the measurement of propulsive forces generated by athletes in many other sports to create and sustain movement and which can be measured directly, propulsive forces in swimming cannot be readily measured by a direct method. However, active drag measurement provides knowledge of the forces generated by swimmers to propel themselves through the water.

The A.I.S. method of assessing active drag as reported by Alcock et al. (2007) relies on towing the swimmer through water at a constant pace that is five percent greater than the top swimming velocity of the subject. The towing velocity is kept at a five percent higher constant velocity by a powerful dynamometer while the swimmer provides a maximum effort to swim with the tow. The dynamometer is mounted on a force platform that measures the force (total Y component of force from the force platform) applied to the swimmer by the dynamometer to maintain this higher velocity. Assuming equal power applied by the swimmer to the water for propulsion in both the unaided and the active drag towing trial, the propelling force at the swimmer's top swimming velocity may be computed using the towing force recorded from the force platform. While the propelling force so obtained is an oscillating parameter which is characteristic of the swimmer's stroke mechanics, it is more productive in this project to report the active drag or propelling force by a mean force over the whole stroke. The A.I.S. had been monitoring swimmers and obtaining the mean propulsive force generated by swimmers to attain their top swimming velocity. It became apparent that there were vast differences in the propelling force required by swimmers at similar swimming velocities. In an attempt to understand the reason for these differences, the A.I.S. entered a project to monitor both active and passive drag for swimmers at the swimmer's top swimming velocity, with the prospect to interpret such differences in mean propelling force from the mean passive drag values.

METHODS: Data Collection: Nineteen Australian swimmers (11 males and 8 females) were tested in the A.I.S. aquatics laboratory. The calibre of the swimmer was such that each had the ability to reach the final in at least one of the three freestyle events (50 m, 100 m and 200 m) at the Australian National Open Swimming Championships. All testing included only the Australian crawl swimming stroke. The testing included a number of tests sections.

The first part of the testing involved obtaining the top swim velocity of each swimmer. Here the subject was instructed to swim at their maximum velocity through a 10 m interval with a swim-in 10 m interval to build up to maximum pace, before reaching the start of the timing interval. The timing of each trial was performed utilising a video system (50 hertz) which included two cameras, with one focused on the start and the other at the end of the timing interval. Each camera's view included vision of an elapsed electronic timing clock, synchronised in each camera view and accurate to a hundredth of a second, to assess the time taken to swim the 10 m interval and hence enabled the calculation of the subject's mean swimming velocity. Three such trials were conducted on each swimmer and the trial with the quickest time was chosen to represent the swimmer's maximum pace.

The second part of the testing involved obtaining a measurement of passive drag for each subject at the swimmer's top swimming velocity. Prior to testing, the subject was instructed how to attain the streamline position, arms extended in front of the head (no breathing), that they were to adopt during the tow. The towing was performed with a device that attached to the second finger of the subject through a non stretch Kevlar cable linked to the dynamometer. The swimmer was thoroughly familiarised with the towing activity prior to any testing. Seven trials were conducted on each subject at a velocity equal to the swimmer's top swimming pace. The force required to tow each swimmer was sampled by computer over a 10 m interval. A trigger was used by the testers to indicate to the data capture computer and video timing system when the subject reached the start and also the end of the 10 m towing interval. Force data (total Y component from force platform) was collected by the computer on a 12 bit analogue to digital board at a sampling rate of 500 hertz. One second of kinetic data was collected prior to the starting signal and six seconds of data was captured after the signal. Both the start and end trigger signals were also collected by the computer as a separate channel of data, from the analogue to digital board, in order to enable the force data to be processed during only the 10 m timed interval. The mean value for the passive drag force over the 10 m interval was recorded for each trial. The two extreme mean trial scores were eliminated in the statistical analysis leaving five means for the calculation of the subject's mean passive drag force.

The third part of the testing involved obtaining a measurement of active drag for each swimmer at the subject's top swimming velocity. Each swimmer was familiarised with the active drag tow which was performed to obtain the swimmer's mean active drag at the subject's top swimming pace. The tow attachment to the swimmer was connecting to the belt worn around the waist and attached anterior to the body. Five trials were conducted with each swimmer at a tow velocity that was 5% faster than the subject's top swimming pace. The swimmer swam at top pace with the tow (no breathing). The first trigger for the collection of data occurred at the beginning of a stroke (right hand entry) and the kinetic data was captured for four complete strokes as denoted by a second trigger. The force data collected in these trials represented the additional force required to tow the swimmer at the subject's 5% higher velocity beyond that required at the swimmer's top pace. The active drag or propulsive force measurement for the swimmer's maximum speed was then able to be computed under the assumption that an equal effort was produced by the swimmer in both the free swim maximum effort unaided trials and in the active drag trials. The mean value for the active drag force over the four complete strokes was recorded for each of the five trials. The five mean trial scores were utilised to obtain the subject's mean propulsive force.

Data Analysis: The top swimming pace for each swimmer was obtained as the fastest of three free swim trials. The raw kinetic data in the seven passive tows was smoothed with a Butterworth digital low pass filter with a cut off frequency of 5 hertz. The mean passive drag force was computed over the 10 m interval for all seven trials and the two trials with extreme values were excluded from further analysis. The force obtained from the five active drag tows were smoothed as above and the active drag computed for each trial prior to obtaining a mean propulsive force value for each of the five trials. From the above five passive drag trials per subject, a single force value representing mean passive drag was obtained by averaging over the five trials. A single value representing mean propulsive force per subject was similarly obtained from the five active drag trials.

A stepwise regression SPSS package using propulsive force as the dependent variable and swim velocity and mean passive drag as the independent variables was carried out. A significance value of 0.05 for acceptance and 0.10 for rejection was chosen for the regression equation.

RESULTS:

Subject	Gender	Speed ($m.s^{-1}$)	Mean Propulsive Force (N)	Mean Passive Drag Force (N)
1	M	1.90	161.7	77.2
2	M	1.92	226.4	81.9
3	M	1.92	151.0	85.3
4	M	1.85	235.7	71.3
5	M	1.91	256.5	88.3
6	M	1.89	302.2	84.5
7	M	1.92	325.3	84.6
8	M	2.02	237.2	100.0
9	M	1.98	204.9	81.6
10	M	1.83	184.3	64.8
11	M	1.89	286.4	73.7
12	F	1.72	163.7	49.9
13	F	1.76	127.4	52.5
14	F	1.71	77.5	47.5
15	F	1.74	164.6	51.0
16	F	1.69	171.3	43.9
17	F	1.61	95.3	37.9
18	F	1.64	89.3	40.7
19	F	1.64	100.1	38.4

The correlation coefficient for swim velocity with mean propulsive force was 0.738, for mean passive drag with mean propulsive force was 0.766 and correlation coefficient between the two independent variables (velocity with mean passive drag) was 0.977. The significance level for the both independent variables with the dependent variable was $p<0.001$.

In the regression equation mean passive drag was accepted into the equation first. Velocity was rejected from the equation. The reason for the rejection of velocity was probably because of the high correlation between mean passive drag and velocity. This indicated that there was relatively little further information that velocity could add to the equation.

DISCUSSION: It was revealed in A.I.S. active drag testing that male swimmers of approximately the same ability sometimes had vastly different mean propulsive force characteristics. In fact two male swimmers who were participating in the same testing session recorded identical top swimming velocities. These swimmers were tested in active drag analysis and the mean propulsive force over four whole strokes for one swimmer was found to be twice the value of the other swimmer's mean propulsive force. Such differences in effort for athletes that perform to the same level of performance are rarely seen in other sports unless there are huge size differences in the athletes. This then raised the question as to why one swimmer needed to exert twice the propelling force to swim at the same velocity as the other swimmer. Was it possible that a measure of some other parameter may be able to explain the difference? The obvious parameter to investigate was passive drag as it theoretically incorporated many of the anthropometric characteristics of the swimmer.

It is common knowledge that the force required to swim at a set velocity is a function of velocity squared. Therefore velocity itself must be highly related to the mean propulsive force produced by a swimmer. The researchers investigated the relationship between the dependent variable mean propulsive force and independent variables mean passive drag and swim velocity. Velocity was itself an additional independent variable that was known to relate to the mean propulsive force so that a comparison between the relationships of both independent variables and the dependent variable would be of interest. The regression analyses revealed that mean passive drag was slightly more highly correlated to mean propulsive force than was velocity. Mean passive drag was included in the regression equation to derive mean propulsive force but velocity was rejected because of the high correlation between velocity and mean passive drag. The project did however identify mean passive drag to be a slightly better predictor of mean propelling force than was swim velocity in a maximum swim effort. Mean passive drag was shown to account for close to 60% of the variance in the mean propulsive force generated by a swimmer at a maximum swim velocity.

CONCLUSION: This study identified that mean passive drag and mean velocity were both significantly related to mean active drag and hence mean propulsive force. Mean passive drag was in fact more highly related to mean propulsive force than was swim velocity. Therefore mean passive drag was identified to be a good indicator of why some swimmers need to generate much greater propulsive forces than do other swimmers that travel at relatively similar velocities. The differences in the mean propulsive force required by swimmers to travel at maximum velocity can to some extent be explained in the measurement of their mean passive drag at a similar velocity. Surely individuals that require considerably more force and power to swim at a set pace are at a greater disadvantage than those that require considerably less force and power. As passive drag reflects the level of propulsive force required for a swimmer to swim at top pace, then passive drag may be a good indicator of the future capabilities of a subject's swimming ability, as passive drag is to a limited extent dependent upon non adjustable anthropometric characteristics of the individual concerned.

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