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ESTIMATION OF ACTIVE DRAG USING AN ASSISTED TOW OF HIGHER THAN MAX SWIM VELOCITYTHAT ALLOWS FLUCTUATING VELOCITY & VARYING TOW FORCE

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The purpose of this study was to identify if an improved active drag profile could be obtained when estimating active drag using the A.I.S. method of assisted towing, if the tow velocity permitted intra stroke velocity fluctuations that were initiated by the propulsive actions of the swimmer, as opposed to using a tow of constant velocity. When the tow velocity did allow such fluctuations the active drag profile of the swimmer appeared to be less complicated and more accurately representative of the swimmer's actual active drag profile than when a tow of constant velocity was used. There appeared to be very little difference in the active drag profile of the swimmer with a tow that incorporated the intra stroke velocity fluctuations, whether the mean velocities were used in the computation or whether the velocity parameters at the various intervals were used.

KEY WORDS: biomechanics, swimming, active drag, assisted tow, fluctuating velocity.

INTRODUCTION: A swimmer's capability to swim faster is depended upon the ability of the swimmer to either generate an increase in mean propulsive force such as to exceed the mean drag force presently acting on the swimmer's motion or to reduce the mean drag force on the body through better streamlining technique or do both. Research has indicated that active drag increases and decreases exponentially with a progressive increase or decrease in the swimmer's mean velocity (Mason et al., 2010). When the mean active drag and the mean maximum propulsive force that the swimmer generates reach equilibrium, the swimmer attains their mean maximum swim velocity. At any constant swim velocity, mean active drag is equal in magnitude to the mean propulsive force exerted by the swimmer. Knowing the magnitude of the mean active drag as well as the shape and magnitude of the fluctuating active drag parameter opposing the forward motion, provides information that may be useful to evaluate the swimmer's mean propulsive force and provide information about the intra stroke fluctuating propulsive forces produced by the swimmer.
The Measure of Active Drag (MAD) system, developed in the Netherlands, provided a method to measure a swimmer's active drag at different velocities (Toussaint et al., 2004). However, questions have arisen as to whether the swimming actions used in the MAD system truly represented the swimmer's propulsive actions when Swimming. The Velocity Perturbation Method (VPM) using a resisting force to decrease the swimmer's velocity, provided the capability to compute an estimate of mean active drag. However, the estimate of active drag was only at one velocity, the swimmer's maximum swim velocity (Kolmogorov & Duplishcheva, 1992). Similarly, an assisted towing method developed at the Australian Institute of Sport (A.I.S.) was also used to estimate the parameter representing the active drag force on the swimmer at the swimmer's maximum swim velocity (Alcock et al., 2007). Both these two later methods used to estimate active drag were dependent upon the assumption that the swimmer applied equal power while swimming at their maximum velocity during both the free swim and during the assisted/resisted condition. The A.I.S. assisted method towed the swimmer at an increased but set velocity using a dynamometer. The force selected on the dynamometer to tow the swimmer was set at a high level so as to ensure the tow velocity was maintained at that selected level, thereby resulting in a constant tow velocity. The actual towing force used to pull the swimmer would however fluctuate with the swimmer's propulsive actions and this force was measured using a force platform upon which the dynamometer was mounted. This measured fluctuating towing force was used in a computation to estimate the active drag parameter at the swimmer's maximum swimming velocity. A criticism of the A.I.S. method was that in normal free swimming the swimmer has

intra stroke fluctuations in velocity. Without these velocity fluctuations during the assisted towing, the swimmer may not as readily replicate the actions that may occur in normal swimming or the forces produced may vary slightly from those where fluctuations do occur. The aim of this present study was to develop a method to estimate the active drag of the swimmer using the A.I.S. method but which allowed for intra cyclic stroke velocity of the swimmer to fluctuate with the variations in drag force.

METHODS: Eight (3 male; 5 female) national level freestyle swimmers participated in the study. Three were members of the Australian swimming team and two were members of other national teams. Each of the subjects completed all the tests required in a single individual testing session. The subjects were given sufficient rest between test trials so that fatigue would not be an issue. Firstly, subjects completed three maximum free swim velocity trials over a 10 m interval, starting from 25 m out and the velocity was measured over the interval 15 m to 5 m out from the wall. The velocity was determined using video cameras with a resolution of 0.02 s. The middlemost velocity trial was utilised to determine the subject's maximum swim velocity. Three passive drag tests were then completed at the swimmer's maximum velocity with the force selection on the dynamometer set high at 550 newtons, to ensure a constant tow velocity. Six active drag tests were then completed with a mean tow velocity equal to approximately 5% greater than the maximum swim velocity. The first three trials were completed with a high dynamometer force selection of 550 newtons which resulted in a near constant tow velocity. The next three trials were completed with a low force selection on the dynamometer which resulted in the swimmer being towed and having a mean velocity equivalent to 5% greater than swimmer's maximum swim velocity, but allowing for intra stroke velocity fluctuations. To enable the mean velocity, which was to be 5% greater than the swimmer's maximum swim velocity in these last three trials, the actual tow velocity selection on the dynamometer was set at the level of the mean passive drag force while the velocity selection on the dynamometer was set to 15% to 20% greater that maximum swim velocity. The dynamometer priorities velocity until the selected force is overtaken.

The equipment used in the active and passive drag testing consisted of a motorised towing device or dynamometer that can tow a swimmer over a range of constant velocities if the towing force was selected high or at fluctuating velocities when the tow force on the dynamometer was selected low. The towing dynamometer was mounted on a Kistler force ™ platform which enabled the force required to actually tow the subject to be monitored. The eight component force signals from the force platform were captured by computer at a 500 Hz sampling rate. Only the Y component was utilised and was smoothed with a 8 Hz low pass digital filter. The dynamometer provided an output towing velocity signal which was also collected and smoothed. Four complete stroke cycles were captured for analysis and extra data on either side of these strokes was also collected to allow for smoothing. The mean velocity of the towing device was also monitored for accuracy with the video camera system.

In the passive drag testing the tow rope was attached to the swimmer by way of a loop through which the subject's fingers could grasp. Following passive drag familiarisation, three passive drag trials were completed at the subject's constant maximum swim velocity. The subject was towed through the water ensuring a shallow laminar flow over the body. Finally, in the active drag testing the rope was attached to a belt around the swimmer's waist. The six active drag trials were completed at a five percent greater velocity than the swimmer's maximum swim velocity to ensure that a force was always applied by the towing dynamometer. The swimmers were instructed to swim at maximum effort for each of the trials. The detailed equations used to determine active drag from the recorded towing force that represented active drag at the swimmer's maximum velocity are described in previous articles by the researchers (Alcock, et al. 2007).

Active drag F_1 & F_2 are defined as follows: $F_1 = 0.5C . \rho . A . V_1^2$ & $F_2 = 0.5C . \rho . A . V_2^2 - F_b$

NB. Active Drag F_1 relates to free swimming and F_2 relates to the assisted tow condition.

where ρ is water density, A is the frontal surface area of the swimmer & Fb is the force needed to pull the athlete at the increased speed as measured with the force plate, V_1 is the swimmer's maximum swim velocity and V_2 is the increased tow velocity.
If we assume an equal power output in both the free swimming and the assisted swimming conditions: $P_1 = P_2$ and therefore $F_1 . V_1 = F_2 . V_2$
Through substitution of F_1 and F_2 we get: $0.5C . \rho . A . V_1^3 = 0.5C . \rho . A . V_2^3 - F_b . V_2$

Rearranging the formula to find C: $$C = \frac{F_b \cdot V_2}{0.5\rho \cdot A \cdot \left(V_2^3 - V_1^3\right)}$$

Substitution of C gives the following formula for active drag: $$F_1 = \frac{F_b \cdot V_2 \cdot V_1^2}{V_2^3 - V_1^3}$$

In the case of constant velocity both V_1 and V_2 are considered as constants to derive the variable force parameter representing active drag.
In the case of the fluctuating velocity trials, both V_1 and V_2 are variable velocity parameters.
To establish the variable velocity parameter to represent velocity for the maximum velocity free swimming, an identically shaped curve was chosen to that representing the velocity during towing, but with a reduced mean, equivalent to the mean maximum swim velocity.

RESULTS: Both the constant velocity and fluctuating velocity active drag parameters were computed for each of the subjects. In the case of the constant velocity, the values for velocity used in the computation of active drag were the mean velocity values. In the case of the fluctuation velocity a separate value for velocity at each interval of data was obtained from the velocity parameter. Middlemost values for active drag were chosen to represent each subject below.

Table 1
Represents the characteristics of each swimmer's Active Drag obtained using a tow of constant velocity and a tow that included fluctuating velocity

Subject #	Gender	Max swim Speed (ms^{-1})	Mean of ActiveDrag Constant Velocity (N)	Mean of active Drag Fluctuating velocity (N)
1	F	1.75	184	129
2	F	1.61	108	128
3	F	1.69	178	119
4	F	1.71	114	127
5	F	1.66	170	195
6	M	1.83	62	112
7	M	1.82	106	124
8	M	1.82	239	253

Observation of the results for all subjects would indicate that the active drag profile obtained with the fluctuating velocity tow was much smoother, was more repeatable and probably more closely resembled true active drag than did the active drag profile obtained using a constant velocity tow. The researchers believe that the mean value for the active drag profile obtained using a fluctuating velocity tow would more likely represent a true mean value for active drag. The mean value for the active drag profile over all subjects did not appear to be either greater or less with respect to whether it was derived from a constant velocity tow or fluctuating velocity tow. Overall the profiles obtained from the active drag profile obtained using a constant velocity tow appeared to have greater variations in force around the mean active drag value than did the drag profile obtained from fluctuating velocities.

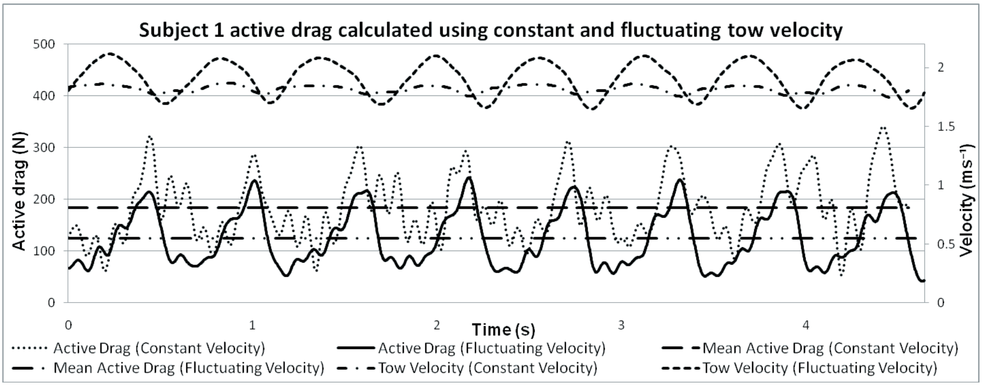

Figure 1: Active drag profile for one subject in the study derived from a constant tow velocity and the active drag profile derived from using a fluctuating velocity. The velocity graphs for both the constant velocity tow and the fluctuating velocity tow are also included.

DISCUSSION: A more precise active drag profile of a swimmer is able to be computed using the A.I.S. method of assisted towing, if a tow velocity is used that incorporates intra stroke velocity fluctuations rather than towing at a constant velocity. The resultant active drag profile appeared smoother and more repeatable than that derived from the constant velocity tow.

CONCLUSION: The present study demonstrated the added value in obtaining an estimation of active drag using the A.I.S. assisted towing method by incorporating a tow that permitted intra stroke velocity fluctuations as opposed to a method that used a tow of constant velocity.

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