COMPUTATION OF A SWIMMER'S PROPULSIVE FORCE PROFILE FROM ACTIVE DRAG PARAMETERS WITH FLUCTUATING VELOCITY IN ASSISTED TOWING

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The purpose of this research was to identify a mathematical formula to compute a swimmer's realistic intra stroke propulsive force profile at the swimmer's maximum mean swim velocity. The intra stroke active drag profile and intra stroke fluctuating velocity profile of the swimmer at maximum mean swim velocity were able to be computed using the assisted towing method, while still allowing the swimmer's usual intra stroke velocity fluctuations to occur. The computation had only these two profiles and a measure of passive drag at the swimmer's maximum mean swim velocity to utilise in the formula. Previously, the whole body propulsive force profile had been more easily computed using a constant velocity tow. However, allowing a fluctuating velocity tow provided a more realistic and accurate measure of the swimmer's true intra stroke propulsive force profile.

KEYWORDS: swimming, resistance, propulsion, technique coaching.

INTRODUCTION: From a biomechanical perspective, much has been done to assist the swim coach in eliminating problems with a swimmer's technique during starts, turns and relay changeovers. This has been made possible using equipment incorporating various types of force transducers that interface between the swimmer's body and a rigid surface. Examples of this occur in instrumented starting blocks and instrumented turning walls. However, the same level of biomechanical assistance has not readily been available to assist coaches in stroke technique correction during the free swimming phases of the sport. This is as a consequence of an impossible task to directly measure the forces that are produced by the swimmer during free swimming. Coaches rely upon video feedback from underwater cameras and direct observation to subjectively assess whether the actions of the swimmer are technically sound. The swimmer's stroke mechanics are judged purely by the coach's pre conceived views on how the stroke should be performed, without the capability to utilise any quantifiable objective parameters to assist them in their judgement. There is a real need in the sport for biomechanics to provide the coach with objective, quantifiable information about the propulsive forces that are produced during swimming, in conjunction with underwater video of the swimmer's actions, to enable objective decisions to be made concerning changes to the swimmer's stroke mechanics for performance enhancement.

It has long been recognised that swimming speed was related to the propulsive actions of the swimmer and the active drag which opposed the swimmer's forward movement. Up until the 1970's it was believed that the mean active drag on a swimmer could be estimated by a measurement of mean passive drag. Passive drag involved the towing of the swimmer while the swimmer maintained a streamline position. The swimmer was towed at the swimmer's maximum mean swimming velocity, while measuring the mean force required in maintaining this tow velocity. It was in the late 1970's that scientists recognised the problems with using the mean passive tow force as an estimate of active drag and attempted to assess the active drag profile utilising tethered swimming, by measuring the force on the restraining cable. This force profile was considered as being equivalent to the propulsive force that occurs during free swimming. Research (Mason et al., 2009) identified that measurement of the restraining force obtained during tethered swimming was not closely related to the propulsive force produced by the swimmer. A major step forward in the practical estimation of mean active drag over a range of swim velocities was made with the Measurement of Active Drag (MAD) system (Hollander et al., 1986) in which the swimmer progressed down the pool, while pulling and pushing on paddles under the water which were attached to rigid vertical rods connected in turn to a long horizontal rod which transferred the force to the pool wall through a force transducer. This provided a measurement of mean active drag through a range of swim velocities. A major criticism of the MAD system was how well the actions of the swimmer related to real swimming and the fact that the feet were not used and were kept buoyant using a pull-buoy. The next major step forward was with the Velocity Perturbation Method (VPM) (Kolmogorov & Duplishcheva,1992). The VPM estimated a measure of mean active drag using a resisted method, but only estimated the mean active drag at the swimmer's maximum swim velocity. This method relied on two assumption; 1) that the swimmer exerted equal power in both the free swim condition and when being resisted, and 2) that the swimmer maintained a consistent mean velocity through all trials. The calculation of mean active drag was based upon the free mean swim velocity versus the resisted mean swim velocity. A system by which active drag was assessed was developed at the Australian Institute of Sport (Alcock, & Mason, 2007). The Assisted Tow Method (ATM) approach was based on similar assumptions as the VPM; however, the protocol involved assisting rather than resisting the swimmer. A powerful dynamometer was used to tow the swimmer at a constant velocity equal to five-percent greater than the swimmer's mean maximum swim velocity. A force platform, upon which the dynamometer was mounted, measured the varying force profile required to tow the swimmer. As was the case of the VPM, the active drag of the swimmer could only be computed at the swimmer's maximum mean swimming velocity. The ATM produced an active drag profile that varied throughout the stroke. Most of the initial research using the ATM involved the use of a constant velocity tow. Here the active drag is able to be calculated and is considered to be positive. With a constant velocity tow, the propulsive force produced by the swimmer is the mirror image of active drag about the mean active drag value. However, coaches are not familiar with the active drag concept but definitely do understand propulsion. Using the propulsive force profile, an analysis system that incorporates both that profile alongside underwater video images of the swimmer's stroke mechanics is able to be used to assist the coach in stroke correction. Recent research (Mason et al., 2011) revealed the benefits of towing the swimmer whilst allowing for intra-stroke velocity fluctuations. This however resulted in having to compute the propulsive force profile from the active drag profile, knowing only the active drag and fluctuating velocity profiles together with the passive drag constant at maximum mean swimming velocity.

METHODS: Three senior nationally ranked freestyle swimmers (1 male and 2 females) participated in this investigation. After a warm up, the swimmers completed three maximal free swim trials over a 10 m interval and the mean swim velocity was calculated. Following the free swim trials, a passive drag measurement was obtained at maximum swim velocity as well as three maximal assisted swims in order to determine the active drag profile. During these three trials, participants were towed by a flux vector dynamometer mounted directly on a calibrated Kistler™ force platform (Kistler Instruments Dimensions: 900 x 600mm Type Z20916) (Figure 1). The trials were completed with the mean tow velocity equal to five-percent greater than the maximum mean free swim velocity. The trials were completed such as to allow normal swimming velocity fluctuations to occur (Mason et al., 2011). During each trial, continuous velocity data were captured from the dynamometer and continuous force data from the force platform. The captured data was processed to compute active drag profiles. Trials were simultaneously video recorded using three genlocked cameras at 50 Hz.

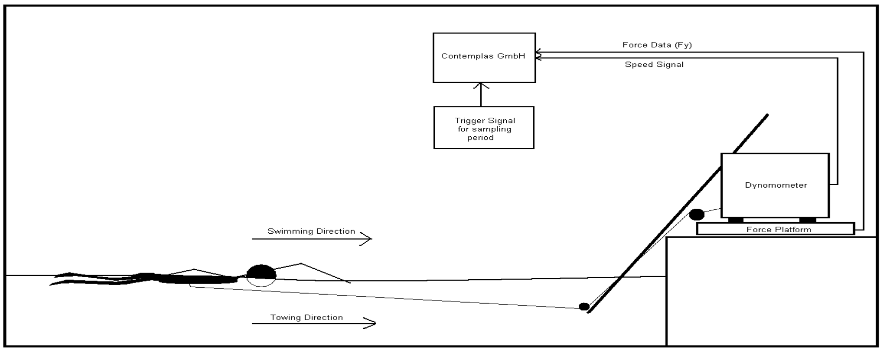


Figure 4: Assisted towing method set up.

Computations: When active drag is estimated with a constant tow velocity then propulsion is the mirror image of active drag. If this were not the case, the velocity would fluctuate.
v=Velocity Profile (a function of time) positive value.
A=Active Drag Profile (a function of time) negative value – As *P* and *A* directly oppose one another the *A* is considered a negative as velocity is positive in the direction of propulsion.
P=Propulsion Profile (a function of time) positive value.
m=Passive drag force (considered as equivalent to a constant mass).
In the fluctuating velocity trials *v*, *A* and *P* all vary throughout the stroke cycle. However there is a relationship between all three. $v = \int \frac{P+A}{m} dt$

$$mv = \int Pdt + \int Adt$$

$$\int Pdt = mv - \int Adt$$

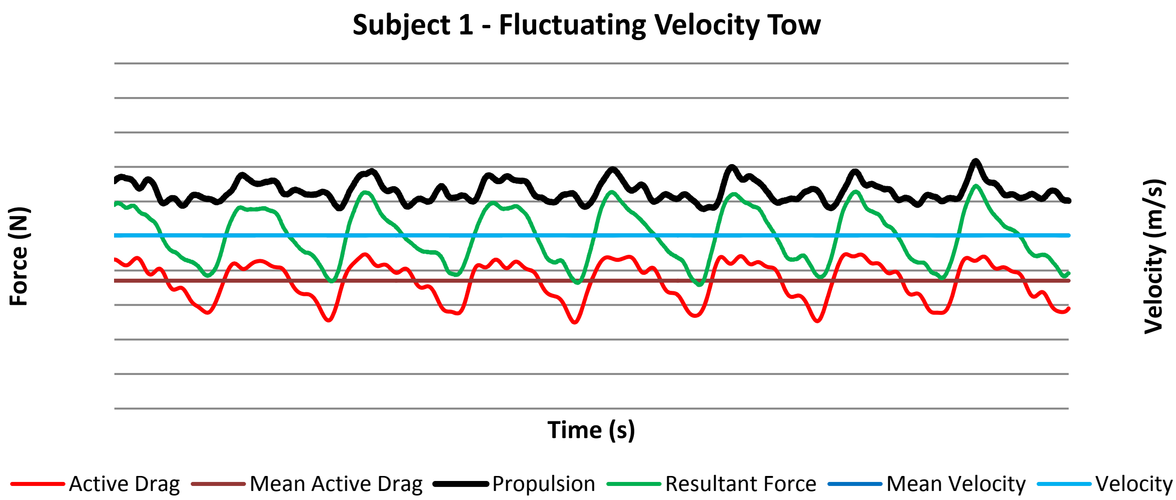
Since $\frac{d}{dt}\int Pdt = P$

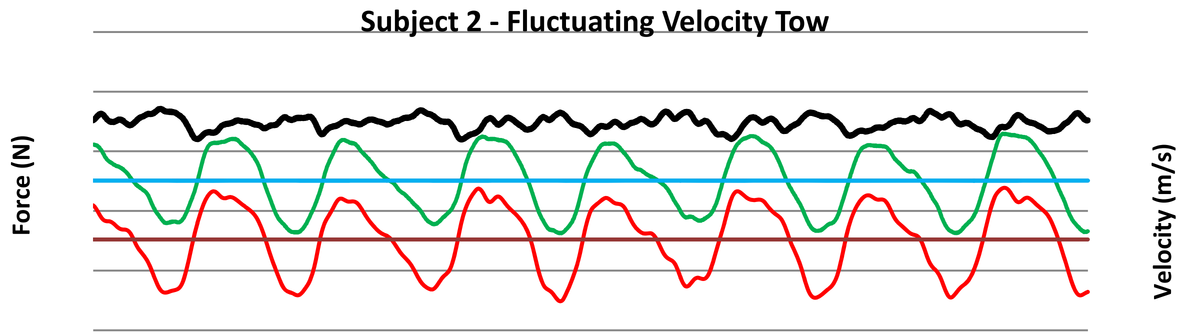
Then $P = \frac{d}{dt}(mv - \int A\,dt)$

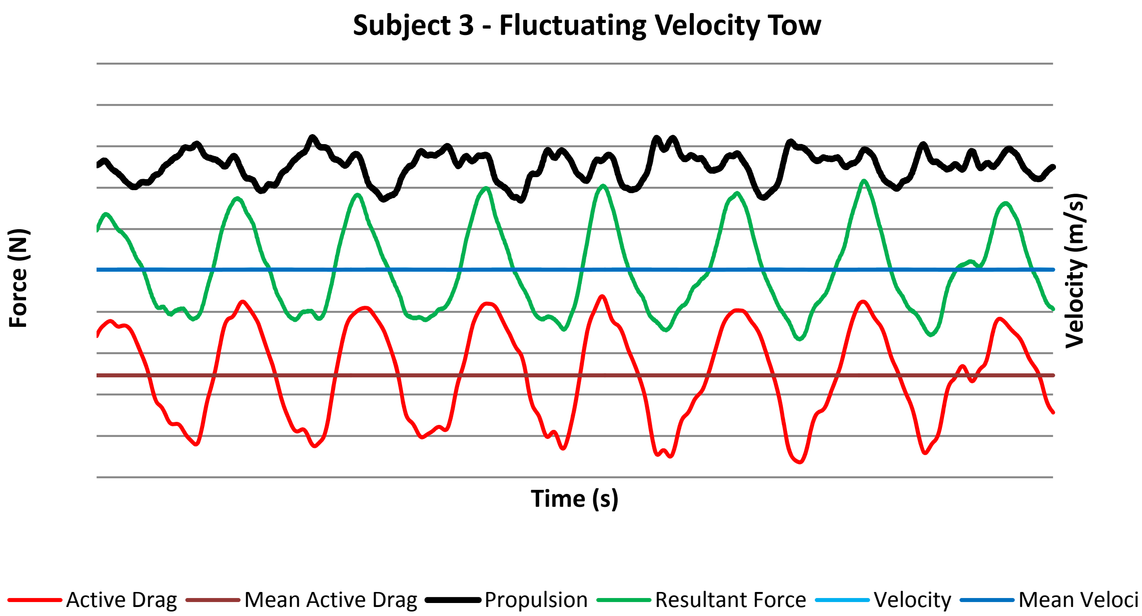
$$P = \frac{d}{dt}(mv) - \frac{d}{dt}\int Adt$$

$$\therefore Propulsion = \frac{d}{dt}(mv) - A$$

RESULTS: Using the equation: ($Propulsion = \frac{d}{dt}(mv) - A$), the propulsive force profile of the swimmer is able to be computed using the ATM approach with a fluctuating intra stroke swim velocity tow. Here the active drag profile was computed and the fluctuating intra stroke velocity measured using the ATM. The mean passive drag quantity had previously been measured. Adding the active drag profile to the propulsive force profile produced a resultant force profile which results in the intra stroke velocity fluctuations. Graphs are provided for all three subjects. In support of the formula, as the resultant force profile crosses from positive to negative or vice versa the velocity profile has a maxima or minima.


Subject 1 - Fluctuating Velocity Tow
Force (N)
Velocity (m/s)
Time (s)
Active Drag
Mean Active Drag
Propulsion
Resultant Force
Mean Velocity
Velocity


Subject 2 - Fluctuating Velocity Tow
Force (N)
Velocity (m/s)


Subject 3 - Fluctuating Velocity Tow
Force (N)
Velocity (m/s)
Time (s)
Active Drag
Mean Active Drag
Propulsion
Resultant Force
Velocity
Mean Veloci

DISCUSSION: The present study demonstrated the use of ATM as a means of measuring the swimmer's fluctuating intra stroke velocity profile and drag profile. This was followed by computation of the active drag profile at the swimmer's maximum swim velocity. The active drag profile, the fluctuating velocity profile and mean passive drag value were used in the computation of the swimmer's propulsive force profile using the previously listed formula.

CONCLUSION: This paper presents a method by which a swimmer's total body propulsive force profile is able to be estimated for free swimming and when combined with video footage of the swimmer's stroke mechanics may be used as a useful tool by the coach to correct free swimming stroke mechanics.

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