Comparative Analysis of Active Drag Using the MAD System and an Assisted Towing Method in Front Crawl Swimming

Danielle P. Formosa,1,3 Huub M. Toussaint,2 Bruce R. Mason,1 and Brendan Burkett3
1Australian Institute of Sport; 2VU University; 3University of the Sunshine Coast

The measurement of active drag in swimming is a biomechanical challenge. This research compared two systems: (i) measuring active drag (MAD) and (ii) assisted towing method (ATM). Nine intermediate-level swimmers (19.7 ± 4.4 years) completed front crawl trials with both systems during one session. The mean (95% confidence interval) active drag for the two systems, at the same maximum speed of 1.68 m/s (1.40–1.87 m/s), was significantly different ($p = .002$) with a 55% variation in magnitude. The mean active drag was 82.3 N (74.0–90.6 N) for the MAD system and 148.3 N (127.5–169.1 N) for the ATM system. These differences were attributed to variations in swimming style within each measurement system. The inability to measure the early catch phase and kick, along with the fixed length and depth hand place requirement within the MAD system generated a different swimming technique, when compared with the more natural free swimming ATM protocol. A benefit of the MAD system was the measurement of active drag at various speeds. Conversely, the fixed towing speed of the ATM system allowed a natural self-selected arm stroke (plus kick) and the generation of an instantaneous force-time profile.

Keywords: biomechanics, sports performance, net force

A swimmer’s potential to propel their body faster through the water is dependent upon the ability to produce a higher propulsive force and/or the ability to reduce drag forces (Yanai, 2003; Lauder & Dabnichki, 2005). Despite this acknowledged relationship, there is no agreed-upon method to measure active drag, which occurs as a consequence of propulsion when swimming (Kolmogorov & Duplishcheva, 1992; Lyttle et al., 2000). This may be the result of too many unknown factors associated with assessing active drag, a lack of technology, or both. The measurement of active drag (MAD) system and velocity perturbation method (VPM) are the most established methods of assessing active drag; however, for each system, mean active drag was only calculated, therefore ignoring the active drag fluctuations throughout the stroke cycle (Kolmogorov et al., 1997; Toussaint et al., 2004). Representing active drag as a continuous changing force would allow the intracyclic variations within and between individuals to be examined and provide insight into active drag relationships (Formosa et al., 2011). The aim of this study was to compare the established and more cited MAD system with an assisted towing method (ATM) protocol approach to measure active drag in swimmers.

Methods

Nine intermediate (club level) swimmers (3 females, 6 males, aged 19.7 ± 4.4 years) from the Eindhoven training center completed two protocols in randomized order during one testing session: the MAD system and assisted towing method (ATM). Human ethics approval was obtained for protocols used in this study.

The MAD system required the swimmer to directly push off from fixed pads, which were connected to a single load cell (Figure 1) (Toussaint et al., 2004). The push-off pads were attached to a 23 m rod, which was fixed at the end of the pool (0.8 m below water surface), and had a standard distance of 1.35 m between each pad. The rod was instrumented with a force transducer allowing measurement of push-off force from each pad. The subjects were instructed to swim at set speeds, over 23 m. The swimmer’s legs were elevated and constrained with a
pull buoy. At a set swimming speed, the mean propelling force is equal to the mean active drag (Van der Vaart et al., 1987). The force signal was sampled at a frequency of 100 Hz and filtered with a low-pass digital filter with a cut-off frequency of 25 Hz. The data were collected using an Apple Power Book and processed with Matlab (version 7.4). To establish the relationship between active drag and swimming speed, each subject completed ten trials at different set speeds (Figure 2). To interpolate the active drag over all speeds, a least squares curve fit was applied to the function $D = Av^n$ (Toussaint et al., 1988), where $D =$ total active drag, $v =$ swimming speed, and $A$ and $n$ were parameters of the power function (Toussaint et al., 2004). For each subject, $A$ and $n$ were obtained via a least square fit with a Levenberg-Marquardt algorithm using Matlab (Toussaint et al., 1988, 2004). The fitted functions established were used to calculate the active drag at the subject’s mean maximum speed and used to compare values determined with the ATM.

The swimmer’s active drag was computed using an assisted motorized towing device (Motor Power Company) developed in the Netherlands. The subjects were tested in two conditions: unaided and aided. To determine the maximal speed, each swimmer completed three 10 m maximum speed (unaided) trials. The mean speed from the maximum trials defined the towing speed during the aided condition. The aided condition required the subject to swim maximally for 20 m, while the pulling apparatus towed the subjects 10% faster than the swimmer’s determined towing speed. The aided condition was repeated three times. The 10% faster towing speed allowed continuous tension on the tow line, without changing the swim technique (Williams et al., 2006). Force was measured using a strain gauge, which was positioned 1 m from the belt that attached around the swimmer’s lumbar region (Figure 3). The force signal was sampled at a frequency of 100 Hz and filtered with a low-pass Butterworth filter with a cut-off frequency of 15 Hz (Figure 4) (Toussaint et al., 2004). The ATM mean active drag calculation was compared with the active drag obtained with the MAD system. The ATM mean active drag was calculated using the following equation:

$$F_i = \frac{F_b \cdot V_2 \cdot V_1^2}{V_2^3 - V_1^3},$$

where $F_i =$ the calculated mean force generated by the swimmer during free swimming (unaided), $F_b =$ the force measured via the strain gauge during the aided trials, $V_1 =$ the swimmer’s free swim mean maximum speed, and $V_2 =$ 10% faster speed than the swimmer’s free swim maximum speed. The major assumption to calculating active drag using the ATM was that equal power output was achieved in the unaided and aided condition (Kolmogorov & Duplishcheva, 1992; Xin-Feng et al., 2007).

The reliability measure was reported as the typical error of the measurement and expressed in raw and standardized (coefficient of variation) units with 95% confidence intervals. Intraclass correlation coefficients (ICC) were calculated to interpret the reliability of the repeated measures.

### Results

The reliability of the MAD system was established in previous research (Toussaint et al., 1988) and the reliability for the ATM had a typical error of 18.1 N (CI 13.8–26.4), or expressed as a percentage, 9.7% (CI 8.1–12.2). The intraclass correlations were excellent, 0.91 (CI 0.67–0.98). The MAD system mean active drag was 82.3 N (74.0–90.6 N), at a mean speed of 1.68 m·s⁻¹ (1.40–1.87 m·s⁻¹), compared with 148.3 N (127.5–169.1 N) from the ATM, at the same mean speed of 1.68 m·s⁻¹ (1.40–1.87 m·s⁻¹). Using a paired $t$ test ($n = 9$), there was a significant difference ($p = .002$) between the two active drag measures, the mean difference was 65.9 N (48.7–83.2 N).

![Figure 1 — Schematic drawing of the MAD system.](image-url)
Figure 2 — Active drag data derived from the MAD system over a range of speeds.
Discussion

The MAD system calculation of active drag was significantly different ($p = .002$) from the ATM, when comparing the same swimmer at maximum speed. The MAD system mean active drag was 55% less than that measured with the ATM. These differences were attributed to different methodology, swimming technique, and subsequent assumptions made. Similarly, Toussaint et al. (2004) examined the relationship between the MAD system and the VPM. The MAD system active drag (66.9 N) was significantly different compared with the VPM (53.2 N) results. The researchers conducted a sensitivity analysis to determine whether the equal power assumption was violated. The results concluded that the differences in values were due to a violation in the equal power output assumption (Toussaint et al., 2004). The differences in the current study’s mean active drag may also be explained by violation of the equal power output assumption in the ATM unaided and aided conditions. The difference in VPM and ATM values may be a result of subtle, but critical, variations in the swimmer’s speed, which in turn influenced the power assumption within each protocol. By towing the swimmer at 10% faster than their maximum speed, the ATM can more closely produce a constant swimming speed. In comparison within the VPM, the swimmer generated natural intracyclic fluctuations as they towed the hydrodynamic body. The VPM derived active drag from the change in speed with and without towing a hydrodynamic body. During the front crawl action, intracyclic fluctuations occur within the stroke phases; therefore, the fluctuations were amplified when the subject towed the hydrodynamic body. The skill level, testing method (assisted vs. assisted), and swimming speed may be other attributes contributing to different results. A comparative difference between the two systems was the ATM represented active drag as a force-time graph (Figure 4). The presentation of a force-time graph, rather than just a mean active drag, allowed identification of the intracyclic fluctuations within the swimmers’ stroke cycles. Furthermore, this new methodology of a force-time graph synchronized with underwater video enabled the swimmer’s stroke mechanics to be evaluated.

The MAD system quantified mean active drag during front crawl throughout a range of speeds, including mean maximum speed (Figure 2). This range of speeds provided insight into the drag-speed relationship and the profile obtained was similar to previous research results. In comparison, the ATM was limited to assessing active drag at only the subject’s maximum swimming speed and was unable to produce a drag-speed curve for each subject.

The two systems required two different swimming techniques. The towing method allowed subjects to replicate front crawl with arm and leg actions. This measurement of whole-body swimming closely represented the swimming technique during competition. However, when towed the swimmer was traveling slightly faster than their maximum swimming speed and the tow-line attachment may possibly have caused some differences in the swimming style, although this was not observed or reported by the swimmers. Researchers have investigated the effect of assisted and resisted training on swimming kinematics and concluded that assisted training had minimal effect on the swimmer’s technique (Girold et al., 2006; Maglischo et al., 1985; Williams et al., 2006). The MAD protocol was restricted to only arm action, and due to the apparatus setup, the force measured at the hand did not include the complete underwater propulsive stroke, as the swimmer’s hand only made contact with the pad approximately 0.8 m underwater (Hollander et al., 1986). The MAD system measured directly the force required to pull the subject through the water; however, it was questionable how closely this action represented the swimming technique in the free swimming condition. Other methods (ATM and VPM) used similar stroke mechanics to the free swimming condition; however, these systems were dependent upon the equal power assumptions to obtain a calculation for active drag. In summary, the MAD system’s mean active drag, compared with the ATM system (at the same mean maximum speed) differed by 55% in magnitude,
and the values obtained were significantly different between the two methods. The MAD system computed active drag at various speeds, whereas the ATM system allowed a self-selected arm stroke (plus kick), as well as the force-time output at the subject’s maximum speed.

Acknowledgments

The researchers would like to thank InnoSport and the Eindhoven Training Centre for their support, as well as the swimmers for their participation.

References


