Measuring Active Drag within the Different Phases of Front Crawl Swimming

20105

Formosa, D. P.[1,2] Mason, B.R.[1] & Burkett, B. J.[2]

[1] *Australian Institute of Sport, Australia*
[2] *University of the Sunshine Coast, Australia*

The aim of this study was to quantify the passive and active drag forces in front crawl swimming at the swimmer's maximum swimming velocity and to present this data as a force-time profile. This method enabled the minimum and maximum force with respect to the phase within the stroke to be identified. Elite freestylers (n=18) completed three maximum swim velocity time trials to determine their maximum velocity. This was followed by three passive drag trials and three active drag trials using a towing device mounted upon a force platform. The computed active drag and the propulsive force profiles were represented as a force-time graph, allowing identification of intra-cyclic force fluctuations. The force-time profiles were synchronised to video footage which provided unique quantitative stroke mechanic feedback to the elite coaches and athletes.

KEYWORDS: biomechanics, swimming, front crawl, active drag, technique

INTRODUCTION

An elite swimmer's success during the free swimming phase is primarily dependent upon their ability to minimise active drag, whilst optimising propulsive force. Active drag is defined as the water resistance associated with the swimming motion (Kolmogorov et al, 1997). Before 1974 passive drag, defined as the amount of water resistance that a human body experiences in an unchanging body position, was considered the best method of predicting active drag (Chatard et al, 1990). In the late 1980's, a research team in the Netherlands developed the first system to measure active drag, known as the MAD system. The MAD system required the participant to swim at a constant velocity, whilst pressing upon fixed pads with the hands. The swimmer's legs were elevated and restricted with pull buoy. This system was limited to front crawl only. Kolmogorov & Duplischeva (1992) developed the Velocity Perturbation Method (VPM) which measured active drag irrespective of swimming stroke. Using the VPM method participants were instructed to swim maximally during two conditions; without and with a hydrodynamic body. The hydrodynamic body was of a known resistance, therefore allowing active drag to be determined by the velocity differences between the two conditions. The common assumption made in calculating active drag was that at a constant velocity the propulsive force was equal to the opposing active drag (Kolmogorov & Duplishcheva, 1992; Toussaint et al, 2004). Regardless of the method adopted, active drag was calculated as a mean value, therefore ignoring the fluctuations in the propulsive force during the stroke phases. The swimming stroke is typically segmented into distinct phases consisting of the entry and catch, pull, push and recovery (Chollet et al., 2000). The primary aim of this study was to quantify the passive and active drag values as a force-time profile by using a motorised towing device. The secondary aim of this study was to examine the force-time profile to determine in which segment of the stroke phase a swimmer produced minimum and maximum force, and therefore providing unique biomechanical feedback to elite coaches and athletes.

METHODS

Following human ethics approval by the University of the Sunshine Coast and the Australian Institute of Sport, eighteen Australian national front crawl swimmers (10 male aged 21 ± 2.2 years, 8 female aged 20 ± 3.0 years) were tested to determine the participant's passive and active drag profile.

Firstly, the swimmers completed a typical 20 min individual race preparation warm up, followed by three individual maximum swimming velocity trials. The maximum velocity trials were measured over a 10 m interval using two 50 Hz cameras (Samsung model: SCC-C4301P). The cameras were time coded. Using a custom computer program, the mean velocity was calculated for each trial. The trial with the highest mean velocity was selected for the passive and active drag trials. The passive and active drag testing was conducted using a motorised towing device, which enabled a constant towing velocity to be accurately set. The towing device was positioned directly upon a calibrated Kistler™ force platform (Kistler Instruments in Winterthur Switzerland Dimensions: 900 x 600 m Type Z12697). The towing device and the force plate enabled the force required to tow the swimmer through the water to be measured. The validity and reliability of the system was determined prior to data collection. During the three passive drag trials the swimmers were towed at their maximum swimming velocity. The swimmers were instructed to hold the end of the tow line around the middle finger of their dominant hand, with the non-dominant hand interlocking to minimise any additional movement. The criteria for a successful passive trial was that the swimmer maintained a streamline position just below the water surface, with no arm strokes nor kicking nor breathing, and there was visible water flow passing over the head, back and feet. Three active drag trials were completed at a velocity five percent greater than the swimmer's maximum swimming velocity. The active drag trials consisted of the participants actively swimming whilst using their typical stroke characteristics with an Eyeline ® tow belt attached to the lumbar region and the dynamometer. Through pilot testing the five percent increase in towing velocity was considered to not have any major effect on the swimmer's stroke pattern while still allowing continuous force measurement.

Data capture was collected for a total of seven seconds, one second prior to and six seconds after the synchronisation trigger was depressed. The sensitivity of the amplifier was set at 5000 pC for both conditions. Data was processed using a 12 bit A to D card, sampled at 500 Hz, and a 5 Hz Butterworth low pass digital filter was applied to the force data collected (Formosa et al, 2009). Each trial was video-recorded at 50 Hz using three genlocked cameras; a side-on underwater, side-on above and head-on camera. The side-on underwater and side-on above water cameras were synchronised with an Edirol video mixer (EDI-V8).
The following formulas were used to determine active drag:

$$F_1 = 0.5C \cdot \rho \cdot A \cdot V_1^2 \qquad (1)$$

$$F_2 = 0.5C \cdot \rho \cdot A \cdot V_2^2 - F_b \qquad (2)$$

Where C a constant, ρ is a water density, A is the frontal surface area of the swimmer & F_b is the force needed to pull the swimmer at the increased velocity, which was measured by the force platform. F_1 = force applied by the swimmer during free swimming (unaided) and is assumed to be equal to the total drag force during free swimming. F_2 = the force applied by the swimmer during free swimming in the assisted condition.
Here it was assumed an equal power output in both the free swimming and the active drag swimming conditions existed:

$$P_1 = P_2 \qquad (3)$$

If $P_1 = P_2$ and therefore $F_1 \cdot V_1 = F_2 \cdot V_2$ (4)

substitution of F_1 and F_2 gives:

$$0.5C \cdot \rho \cdot A \cdot V_1^3 = 0.5C \cdot \rho \cdot A \cdot V_2^3 - F_b \cdot V_2 \qquad (5)$$

Rearranging the formula to find C:

$$C = \frac{F_b \cdot V_2}{0.5\rho \cdot A \cdot (V_2^3 - V_1^3)} \qquad (6)$$

substitution of C gives the following formula for active drag:

$$F_1 = \frac{F_b \cdot V_2 \cdot V_1^2}{V_2^3 - V_1^3} \qquad (7)$$

V_1 = the swimmer's free swim maximum velocity and V_2 = 5% greater than the swimmer's free swim maximum velocity (Kolmogorov & Duplishcheva, 1992) (Note: equation was modified for assisted, rather than resisted). To identify the force distribution within the stroke cycle, phases were considered as entry and catch, pull, push and recovery (Chollet et al, 2000).

RESULTS

The coefficient of variation between the towing device velocity and the side-on cameras was 0.6 % (90% Confidence Intervals (CI) 0.5 to 0.7). The Pearson product moment coefficient between the towing device pulling velocity and the calculated side-on camera velocity was r =1.0. Within a testing day the typical error of measurement from the force platform set up was 4.0 N (90% CI 3.4 to 4.8) or 5.2% (4.4 to 6.3) for passive drag; and 2.5 N (2.1 to 3.0) or 4.9% (4.1 to 5.9) for the active drag. Testing sessions within and between days of testing, reported intraclass correlation coefficients (ICCs) of between 0.97 (0.93 to 0.99) and 0.99 (0.96 to 1.00) for passive and active drag respectively.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s^{-1}, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s^{-1}. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s^{-1}, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s^{-1}.

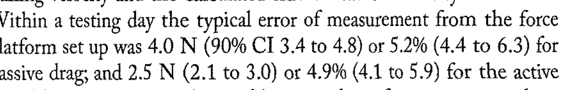

Figure 1: Male participant nine propulsive force profile at 1.84 m·s^{-1}.
1. L entry R push 2, R recovery, L pull 3, L push R entry 4. L recovery, R pull (Chollet et al., 2000).

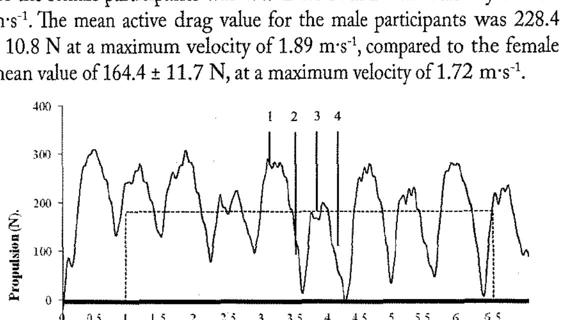

Figure 2: Male participant ten propulsive force profile at 1.81 m·s^{-1}.
1. R entry L push 2. L recovery, R pull 3. R push L entry 4. R recovery, L pull (Chollet et al., 2000).

DISCUSSION

The aim of this study was to quantify active drag during freestyle swimming, whilst providing a valuable biomechanical feedback tool for elite coaches and athletes. The mean passive drag values measured were comparable to those previously reported, such as the force values of 53.3 ± 7.2 N at 1.76 m·s^{-1} for female participants (Maglischo et al, 1988). Similarly, Kolmogorov & Duplishcheva (1992) observed male and female passive values ranging from 69.7 – 103.0 N and 44.2 - 56.9 N, respectively at velocities 1.73 - 1.91 m·s^{-1}and 1.52 - 1.67 m·s^{-1}, respectively.

The active drag obtained in this study does not concur with the literature. Toussaint *et al.* (2004) compared active drag values collected with both the MAD and VPM systems. Active drag measured at a velocity of 1.64 m·s $^{-1}$ was 66.9 N (MAD) and 53.2 N (VPM). Similar findings were reported by Toussaint *et al.* (1988) when comparing active drag of females and males. Using the function D=Aυ^n to obtain a range of values from the MAD system, the researchers were able to make a comparison with the mean results from the present study. The values measured using the MAD system were 70.2 N at a maximum velocity of 1.72 m·s^{-1} (females), whilst for males, the maximum velocity was 1.89 m.s^{-1} with an active drag of 111.4 N. This variation between the results may be due to the different methods used to assess active drag. The MAD system was limited to arm propulsion only, whilst the VPM system measured the whole body whilst in a resisted state.

Representing active drag in a force-time graph synchronised to video footage allowed researchers and coaches to identify the propulsive force fluctuations within the stroke phases. As illustrated in figures 1 and 2 each individual presented a unique force profile, therefore strengthening the importance of representing propulsive force as a force–time graph, rather than a mean value. The project provided coaches and athletes with a quantitative biomechanical analysis associated with video footage. This allowed identification of the weaker phases of the stroke cycle. This project provided quantifiable information to identify modification aspects required to optimise the swimmer's technique based upon scientific feedback. An example of a practical application was: following the data analysis and feedback to the coach and athlete, an intervention strategy was derived to modify the weaknesses in the stroke mechanics. Future testing quantified that after intervention, participant ten reduced the active drag by a mean of 27.8 N, whilst swimming at the same velocity. Participant nine increased the swimming velocity, however maintaining a similar mean active drag value.

There are a limited number of researchers that have explored the propulsive force production throughout different stroke phases of front crawl, however most researchers have examined this through digitising. There was significant variation between minimum and maximum propulsive force range for left and right stroke phases between and within participants. By examining the force-time graph synchronised to video footage this allowed researchers to identify during which exact phase, minimum and maximum force production occurred. It was evident that mean minimum propulsive force was generated during the first pull phase of the stroke cycle. The towing device used to calculate active drag, measured the whole body propulsive action. This considered the effect the recover arm had on the total body propulsive force. This did not indicate the pull phase was not generating propulsive force, however the arm producing the pulling motion was counteracting the equal and opposing forces of the recovering arm. The force-time graph indicated that the maximum propulsive force production occurred during the final push phases of the stroke cycle. Previous researchers have adopted an indirect method to determine the forces associated with the hands/arms (Maglischo et al, 1988; Schleihauf, 1979). These researchers digitised the hand/arm motion to determine the lift and drag components. The researchers reported maximum propulsive force during the final push phase. In the present study, examining the force-time graph synchronised to video footage, it was evident that maximum propulsive force was unable to be produced until the recovering arm was in the water following the catch.

CONCLUSION

The present study demonstrated the importance of representing active drag as instantaneous force, rather than a mean value. This provided unique and valuable insight into the intra-cyclic force fluctuations within a stroke cycle. The graphical demonstration allowed comparison for future intervention studies. The values measured from the towing device were comparable to previous research during the passive drag condition. However the active drag values were much greater than previously investigated. Through examining the force-time graph synchronised to video footage, it was evident that minimum force was produced during the pull phase and maximum force during the push phase. The towing device used to calculate active drag, measured the whole body propulsive action, therefore taking into consideration the effect the recover arm had on the total body propulsive force.

REFERENCES

Chatard, J. C., Collomp, C., Maglischo, E. & Maglischo C. (1990). Swimming Skill and Stroking Characteristics of Front Crawl Swimmers. *International Journal of Sports Medicine, 11*, 156-161.

Chollet, D., Chalies, S. & Chatard, J. C. (2000). A New Index of Coordination for the Crawl: Description and Usefulness. *International Journal of Sports Medicine, 21*(1), 54-59.

Formosa, D. P., Mason B. R. & Burkett, B. (2009). Measuring propulsive force within the different phases of backstroke swimming. In A. J. Harrison, R. Anderson & I. Kenny (Eds.), *Proceedings of the XXVII International Symposium on Biomechanics in Sports* (pp. 98-101), Ireland.

Kolmogorov, S. V. & Duplishcheva, O. A. (1992). Active Drag, Useful Mechanical Power Output and Hydrodynamic Force Coefficient in Different Swimming Strokes at Maximum Velocity. *Journal of Biomechanics, 25*(3), 311-318.

Kolmogorov, S. V., Rumyantseva, O. A., Gordon, B. J. & Cappaert, J. M. (1997). Hydrodynamic Characteristics of Competitive Swimmers of Different Genders and Performance Levels. *Journal of Applied Biomechanics, 13*(1), 88-97.

Maglischo, C. W., Maglischo, E. W., Higgins, J., Hinrichs, R., Luedtke, D., Schleihauf, R. E., et al. (1988). A Biomechanical Analysis of the 1984 U.S. Olympic Freestyle Distance Swimmers. In B. E Ungerechts, K Wilke & K Reischle (Eds.), *In Proceedings of the International Symposium of Biomechanics and Medicine in Swimming* (pp. 351-360). Bielefeld, Germany: Human Kinetics Books, Champaign.

Schleihauf, R. E. (1979). Swimming propulsion: a hydrodynamic analysis. *Swimming III*, 8, 70-110.

Toussaint, H. M., de Groot, G., Savelberg, H. H., Vervoorn, K., Hollander, A. P. & van Ingen Schenau, G. J. (1988). Active drag related to velocity in male and female swimmers. *Journal of Biomechanics, 21*(5), 435-438.

Toussaint, H. M., Roos, P. E. & Kolmogorov, S. (2004). The determination of drag in front crawl swimming. *Journal of Biomechanics, 37*(11), 1655-1663.

ACKNOWLEDGMENTS

The researchers would like to thank the Australian Institute of Sport, Aquatics Testing, Training and research, Australian and National swimming team for their contribution to the research.

The Mechanical Power Output in Water Polo Game: a Case Report

2o 320

Gatta, G.[1], Fantozzi, S.[2], Cortesi, M.[1], Patti, F.[1], Bonifazi, M.[3]

[1]Faculty of Exercise and Sport Science, University of Bologna, Italy
[2]Computer Sciences and Systems, Bologna, Italy
[3]*Faculty of Medicine, University of Siena, Italy*
[3]*Italian Swimming Federation, Roma, Italy*

In water polo some authors have assessed the physical requirements of the game by analysing physiological indices or considering the distances covered at various swimming speeds in the match. In this work, the passive drag was measured in "best glide" (Swim) and "head-up" (Wp) position in a water polo player. The active drag was estimated indirectly from the passive drag. The mechanical power required to play a match is calculated on the data of a match model obtained from a video analysis in a series of international water polo matches. The average mechanical power of a water polo match in the Swim model was 150489 J/2400 s= 62.70 W, while in WP model it was 481375 J/2400 s= 200.57 W. The mechanical power required in water polo players could be more than three-fold higher than that required for freestyle swimming at the same velocities.

KEYWORDS: water polo, mechanical power, drag, acceleration, trudgeon

INTRODUCTION

A precise definition of the performance model in sports games is far from being simple. In water polo some authors have assessed the physical requirements of the match by analysing physiological indices as heart rate or considering the distances covered at various swimming speeds in a series of matches (Pinnington et al. 1987, Hohmann & Frase 1992, Rudic et al. 1999, Platanou & Geladas 2006). Coaches still develop training programs considering swimming speeds but this does not take into account that, during the match, the water polo player does not move as a swimmer in the best hydrodynamic position, but: 1) swims with the head raised and often in contact with opponents, therefore not totally in a hydrodynamic position that is subjected to a higher drag; 2) starts statically in maximum acceleration, without any push from a fixed support. For this reason we believe that motion patterns of swimming used so far underestimate the real amount of mechanical power developed by the player during the match.

The purpose of this work was to compare, in a water polo player, the mechanical power required to play a match as computed with two different methods: the method used so far in swimming, and a new model based on the specific analysis of the technique of water polo.

METHODS

To obtain the power required to swim at different speeds, the resistive force of the water must be computed, defined by the value of the drag. The estimation of active drag is still quite complex and the methods used do not find an agreement among scientists, while the measurement of passive drag is easier, and more reliable. In a water polo player (27 years, 1.77 m, 79 kg), two indices of passive drag (pd) were measured with the method of towing at different speeds. The first index was obtained in the position of "best glide" (Swim), i.e. a lying down position with head between the arms, while the second index was obtained in a "head-up" position, similar to the previous one, but with head above water, common in water polo playing (Wp).

For the test we used a tow electromechanical motor (Ben-Hur, ApLab, Roma) dragging the swimmer through a cable at a programmed speed, while assessing the resistance of the fluid (see figure 1).