MEASURING PROPULSIVE FORCE WITHIN THE DIFFERENT PHASES OF BACKSTROKE SWIMMING

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The purpose of this study was to identify the propulsive force profile associated within the different phases of backstroke to provide individual feedback to elite swimmers and coaches. Elite backstrokers (n=4) performed three maximal velocity time trials to determine the swimmers maximum velocity. This was followed by three passive drag trials and three active drag trials using a flux vector drive dynamometer mounted on a force platform to tow them at set velocities (derived from the swimmer's maximum swim pace) while measuring the force to do so. The computed active drag and the propulsive propelling force profile were represented as a dynamic parameter, allowing identification of intra cyclic force fluctuations with respect to time. The force profiles were synchronised to video footage which provided unique quantitative and individual stroke kinematic feedback to the elite swimmers and coaches.

KEY WORDS: biomechanics, swimming, backstroke, propulsion, technique

INTRODUCTION: The propulsive and resistive forces in free swimming are continuously changing, within each stroke. To objectively measure these forces is a complex task. One of the first methods used to measure these forces was the Measuring Active Drag, (MAD) system. The swimmer's hands pull directly on a series of fixed pads 1.35 m apart, at a depth of 0.8 m, while the legs are restricted with a pull buoy (Toussaint, 2002). Another method developed was the Velocity Perturbation Method (VPM) where the swimmer performed a maximal effort swim with and without the added resistance of a towed hydrodynamic body (Kolmogorov & Duplishcheva, 1992). The difference in the two velocities was used to compute the active drag force. In both methods the common assumption was that at a constant velocity, the propulsive force was equal to the opposing, active drag (Hollander et al, 1987; Kolmogorov & Duplishcheva, 1992; Xin-Feng et al, 2007). These methods presented the net force as a single or mean value representing drag force, across each individual stroke cycle, or a number of stroke cycles, thereby neglecting the intra-stroke force fluctuations. Providing a single mean value which represents active drag to elite swimmers and coaches does not highlight specific aspects within the stroke that can guide intervention to enhance performance. To address these limitations, this research investigated the propulsive force profile generated whilst freely swimming backstroke, at maximal velocity. The aim of this study was to identify the propulsive force profile within the different phases of backstroke, and to synchronise this information with above and underwater video to provide unique and valuable feedback to elite athletes and coaches.

METHODS: Four Australian National swimmers (male age; 21 ± 3.6; female age; 18) were tested using a flux vector drive dynamometer positioned directly on a calibrated Kistler™ force platform (Kistler Instruments in Winterthur Switzerland Dimensions: 900 x 600 m Type Z12697). The validity and reliability of the system was determined prior to data collection (Fulton et al, 2008). The dynamometer enabled towing velocity to be accurately set and the force plate allowed the net force to tow the swimmer through the water to be measured. The swimmers completed a typical 20 min individual race preparation warm up, followed by three individual maximal swimming velocity trials. The highest average velocity achieved over a set 10 m interval defined the passive and active testing velocity. The swimmers were towed at their top swim velocity during the passive drag test. For the three passive drag trials 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 tows were performed at a velocity five percent greater than the swimmer's maximal swimming velocity. The active trials consisted of the swimmers actively swimming and using their typical stroke characteristics with an Eyeline ® tow belt attached to the lumbar region and the dynamometer. 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. (Alcock & Mason, 2007). Each trial was filmed at 50 Hz using three genlocked cameras; a side-on underwater, side-on above and head-on camera.
The following formulas were used to determine active drag:

$$F_1 = 0.5C \,.\, \rho \,.\, A \,.\, V_1^2 \quad \text{(equation one)}$$

$$F_2 = 0.5C \,.\, \rho \,.\, A.\, V_2^2 - F_b$$

Where C is dimensionless coefficient of drag, ρ is the density of water, A is the frontal cross sectional area of the swimmer, F_b is the force needed to pull the swimmer. F_1= the force applied by the swimmer during free swimming (unaided) and F_2 = the force applied by the swimmer during the assisted condition.
If we assume an equal power output in both the free swimming and assisted conditions:

$$P_1 = P_2 \text{ and therefore } F_1 \,.\, V_1 = F_2 \,.\, V_2$$

then substitution of F_1 and F_2 gives:

$$0.5C \,.\, \rho \,.\, A \,.\, V_1^3 = 0.5C \,.\, \rho \,.\, A \,.\, V_2^3 - F_b \,.\, V_2$$

Rearranging the formula to find C:

$$C = \frac{F_b \,.\, V_2}{0.5\rho \,.\, A \,.\, (V_2^3 - V_1^3)}$$

then substitution of C into equation one gives the following formula for the active drag:

$$F_1 = \frac{F_b \,.\, V_2 \,.\, V_1^2}{V_2^3 - V_1^3} \qquad \text{(Alcock \& Mason, 2007)}$$

RESULTS:

Table 1: Mean passive and active forces (mean ±SD) at maximal velocity (participants 1-3 male, 4 female)

		Mean Passive Force (N)	Mean Propulsive Force (N)
Participant	**Maximal Velocity ($m.s^{-1}$)**	**Force (N) (mean ± N)**	**Force (N) (mean ± N)**
1	1.79	63.72 ± 0.73	235.89 ± 25.48
2	1.75	69.15 ± 1.59	184.84 ± 2.98
3	1.78	74.92 ± 1.60	199.92 ± 15.89
4	1.63	46.19 ± 1.99	128.17 ± 11.11

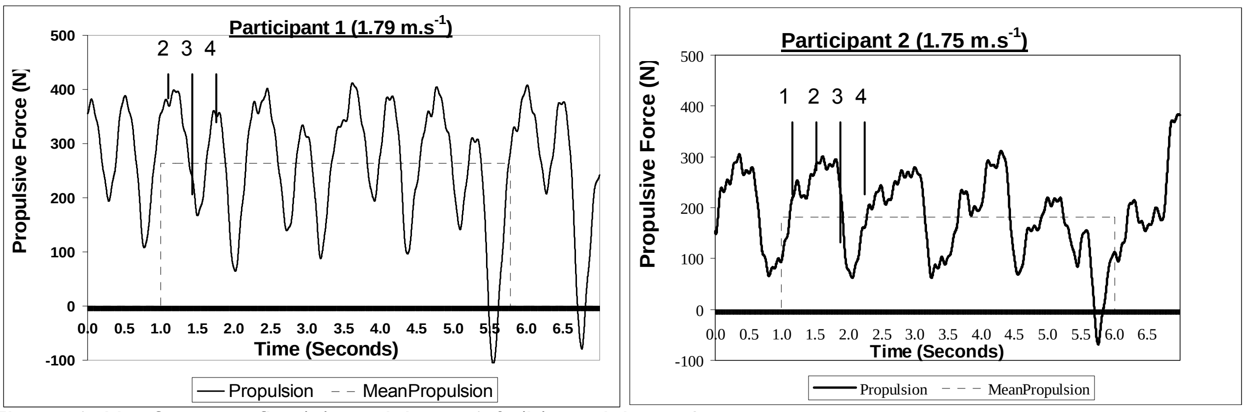
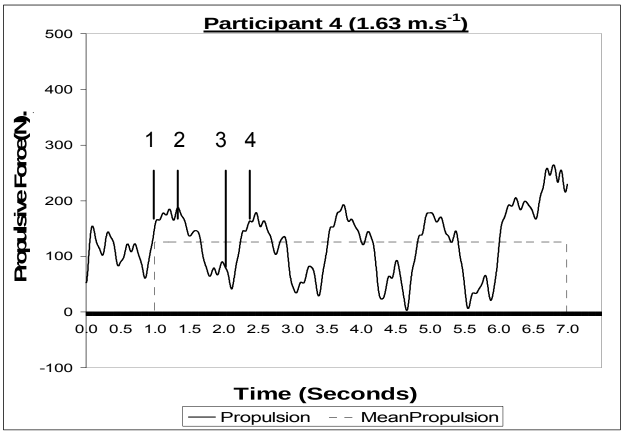


Figure 1: Net force profile (a) participant 1 & (b) participant 2



1. Right hand entry and left hand 2nd downsweep
2. Right hand 1st phase
3. Left and entry and right hand 2nd downsweep
4. Left hand 1st phase

First downsweep: begins immediately when the swimmer stops pushing back against the water.
Second downsweep: begins during the transition from the previous sweep and continues until the arm is completely extended and below the body (Maglischo, 1993).

Figure 2: Net force profile

DISCUSSION: The aim of this research was to quantify the propulsive forces within the different phases of backstroke swimming, to provide unique feedback to the swimmer and coach. As shown in figures 1 and 2 the individual swimmer's intra-cyclic propulsive force profiles are presented. These graphs demonstrate the importance of expressing propulsive force as a dynamic parameter, as opposed to single mean value representing the parameter. Each swimmer presented by their own unique profile of generated forces within their stroke, which highlighted the individual's profile. The synchronised head-on and side-on video footage (figure 3) allowed the swimmer and coach to identify specific strengths and weaknesses. This unique information provided objective and quantitative feedback highlighting technical errors within the stroke, as opposed to making judgements based on speculation or opinion. The mean active drag values in this study did not concur with the values established by Kolmogorov et al (1992) using the VPM method. The participants in the current study achieved a higher maximal velocity. Kolmogorov et al (1992) suggested that a female swimming at 1.43 $m.s^{-1}$ produced an average force of 49.78 N, while males, at 1.72 $m.s^{-1}$, produced an average force of 119.92 N. Had the participants in Kolmogorov et al (1992) study achieved faster maximal velocities the force may have been similar to the values obtained in this study due primarily to the fact that force is a function of velocity squared.

Participant one presented a symmetrical stroke pattern compared to participants two, three and four. Based on participant one analysis it was evident that minimal force occurred at the beginning of the left arm down sweep and during the extension kick (Figure 3a). Maximal force occurred during the second downsweep phase. Participant two produced two propulsive force peaks on the right side. The first peak during the right side stroke was during the first downsweep phase and the second occurred during the second downsweep phase. The multiple peaks was supported by Schleihauf et al (1988) research which illustrated three large resultant force phases occurred when examining the propulsive forces associated with the arm stroke during backstroke swimming. A limitation of Schleihauf et al (1988) research was the data only represented the forces associated with the hand not the whole body. In contrast, participant four presented with maximal force during the first down sweep of the right arm phase. However, during this same phase on the left arm minimal force was produced (figure 2). Similarly, participant two presented a weakness on the left side of the body which may have been due to muscular weakness or technique error (figure 1b). Weaknesses in musculature or technique can be highlighted in the force profile and identified from the video analysis prompting changes to technique based on quantitative feedback.

It was evident by examining the force profiles of four swimmers in that each individual produced distinctive propulsive force profiles, therefore strengthening the importance of providing propulsive force as a dynamic parameter synchronised to video footage. This allowed swimmers and coaches to correct technique based upon individual feedback. This effective biomechanics servicing tool provides unique quantitative, stroke kinematics feedback to elite swimmers and coaches. The kinematic data was displayed in an easy to interpret format, providing analysis to each swimmer independent of their biomechanics knowledge. Future research could be directed to identify the actual intra cyclic velocity of breaststroke and how it is related to the propulsive force profile.

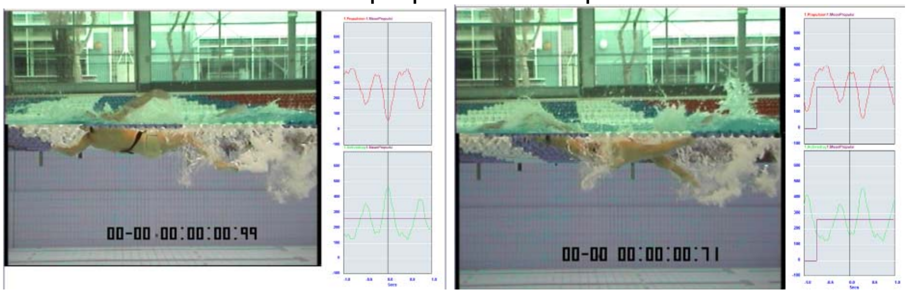


Figure 3: Participant One (a) minimal propulsion (b) maximal propulsion

CONCLUSION: Understanding and identifying the dynamic forces generated within backstroke swimming provides further guidance to optimising swimming performance. Previous researchers have tended to neglect investigating propulsive force during backstroke swimming due to limitations in the various methods of data collection. The present study has illustrated the importance of representing the propulsive force as a dynamic parameter synchronised to video footage, thereby highlighting the intra-stroke force variability within and between individuals. This provided a beneficial feedback tool to coaches and swimmers allowing specific technique changes based upon objective and quantitative analysis.

REFERENCES:

Alcock, A., & Mason, B. (2007). Biomechanical analysis of active drag in swimming. In *c2007, p.212-215.* Brazil.

Hollander, A. P., de Groot, G., & van Ingen Schenau, G. J. (1987). Active drag in female swimmers. In *In, Jonsson, B. (ed.), Biomechanics X-B, Champaign, Ill., Human Kinetics Publishers, c1987, p. 717-720.* United States.

Fulton, S. K., Pyne, D. P., & Burkett,B (2008). Influence of kicking velocity and amplitude on net force and kick rate in elite swimmers. *Journal of Applied Biomechanics (In review)*

Kolmogorov, S. V., & Duplishcheva, O. A. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *Journal of Biomechanics, 25*(3), 311-318.

Maglischo, E. (2003). Swimming Fastest. USA: Human Kinetics

Schleihauf, R.E., Higgins, J.R., Hinrichs, R., Luedtke, D., Malglischo, C., Maglischo, E.W., Thayer, A.,(1988) Propulsive techniques: Front crawl stroke, butterfly, backstroke, and breaststroke In, Ungerechts, B.E. et al. (eds.), Swimming science V, Champaign, Ill., Human Kinetics Publishers, p. 53-59.

Toussaint, H. M. (2002). Biomechanics of front crawl swimming: propulsion and drag. (Abstract). In *In 12th Commonwealth International Sport conference, 19-23 July 2002, Manchester, United Kingdom: abstract book, London, Association of Commonwealth Universities, 2002, p.310.* United Kingdom.

Xin-Feng, W., Lian-Ze, W., Wei-Xing, Y., De-Jian, L., & Xiong, S. (2007). A new device for estimating active drag in swimming at maximal velocity. *Journal of Sports Sciences, 25*(4).

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