B6-4 ID124

HAND PROPULSION TECHNIQUE OF SKILLED SPRINT SWIMMERS

Shigetada Kudo[1], Takahiro Miwa[2], Yoshihisa Sakurai[2]

[1]Republic Polytechnic, Singapore
[2]Japan Institute of Sports Science, Japan

This study investigated the technique of skilled sprint front-crawl swimmers in terms of the exertion of hand propulsive forces quantified by the dynamic pressure approach. Four skilled sprint front-crawl swimmers, who can swim a 100 m in less than 49 seconds, swam at a 25 m swimming pool where a motion capture system for above and under water was set up. Pressure sensors were attached on the hand to estimate hydrodynamic forces acting on the hand. The mean propulsions in the downsweep, insweep, and upsweep were 26 ± 4 N, 57 ± 12 N, and 46 ± 9 N, respectively. The four swimmers used propulsive lift of 36 ± 6 N in the downsweep, propulsive drag of 40 ± 7 N in the insweep, and propulsive drag and lift of 25 ± 9 N and 21 ± 10 N in the upsweep while swimming at their race pace.

KEY WORDS: propulsive drag and lift, downsweep, insweep, upsweep

INTRODUCTION: Hand propulsion of skilled sprint front-crawl swimmers was quantified by the quasi-static approach (Cappaert et al., 1995) who reported that hand propulsion in the upsweep was 1.6 times greater than the propulsion in the insweep. The result may imply to a swimmer and coach that a sprint swimmer should focus to exert the greatest hand propulsion in the upsweep. However, the quasi-static approach does not consider the effect of hand acceleration on quantifying hydrodynamic forces exerted by the hand (Shleihauf et al., 1983) and the acceleration induces additional hydrodynamic forces on the hand (Rouboa et al, 2006). It is possible that a swimmer accelerates the hand more in the insweep than the upsweep (Ohgi et al. 2000). Therefore, the hand propulsion exerted by the swimmers needs to be re-evaluated by a method which can consider the effect of hand acceleration on estimating hydrodynamic forces acting on the hand. The dynamic pressure approach was developed to determine hydrodynamic forces acting on the hand during swimming (Kudo et al. 2008). This approach can take account of hand acceleration during swimming while estimating hydrodynamic force acting on the hand. The dynamic pressure approach can also quantify propulsive drag and lift forces acting on the hand. Thus, the present study aims to re-evaluate the technique of skilled sprint front-crawl swimmers for exerting hand propulsive forces estimated by the dynamic pressure approach.

METHODS: Four skilled swimmers, who can swim a 100 m in less than 49 seconds, participated in this study after they signed informed consent. The mean height and weight of the swimmers were 1.83 ± 0.04 m and 773 ± 68 N, respectively.
The motion capture system (Qualisys, Sweden) was set up at a 25 m swimming pool. Reflective markers were attached on the right hand, the third finger tip, trapezium and pisiform, to determine hand motion and two reflective markers were attached on the right and left ASIS to determine a swimming speed. Twelve pressure sensors with a portable data logger (MMT, Japan) were attached on the swimmer's hand to quantify the magnitude of hydrodynamic forces exerted by the swimmers (Kudo et al. 2008). The portable data logger, synchronized with the motion capture system, was attached on the back of the swimmer. A right-handed Cartesian coordinate system was "embedded" at the bottom of the pool; the x-axis defined the direction of swimming, the y-axis defined the side-to-side direction, and the z-axis defined the vertical direction. The four swimmers were asked to swim the front crawl stroke at their race pace in the 25 m swimming pool from a push-off. All data were recorded from 12.5 m to 20 m of the swimming pool at 100 Hz.
The marker position and pressure data were smoothed using a low-pass Butterworth filter with a cut-off frequency of 11 ± 5 Hz. The resultant hydrodynamic forces acting on the hand

for one stroke were determined by the method of Kudo and Lee (2010). Combining the resultant hydrodynamic forces on the hand and the hand movement based on the marker positions, propulsion and propulsive drag and lift forces exerted by the swimmers were computed. The swimming speed for one stroke was calculated by using the x-coordinates of the midpoint between the two ASIS markers. The one stroke used for the quantification of the hand propulsion was decomposed into three phases; downsweep, insweep and upsweep. For the present study, the downsweep was from the frame that the position of finger tip became deeper than the midpoint of the two ASISs to the frame before the hand started moving backwards (catch), and the insweep was from the frame for the catch to the frame before the hand started moving outwards, and the upsweep was the frame that the hand started moving outwards to the exit of the hand out of the water. The mean of the hand resultant force, hand propulsion and hand propulsive drag and lift among the four swimmers was computed for the three stroke phases. Also the mean magnitude of hand velocity (|V|), hand velocity in the x-component (|Vx|) and in the yz-component (|Vyz| and acceleration (|A|) among the four swimmers was computed for the three stroke phases. The angle of pitch (AP) and the sweep-back angle (SB) for each swimmer were computed for the three phases (Shleihauf et al., 1983).

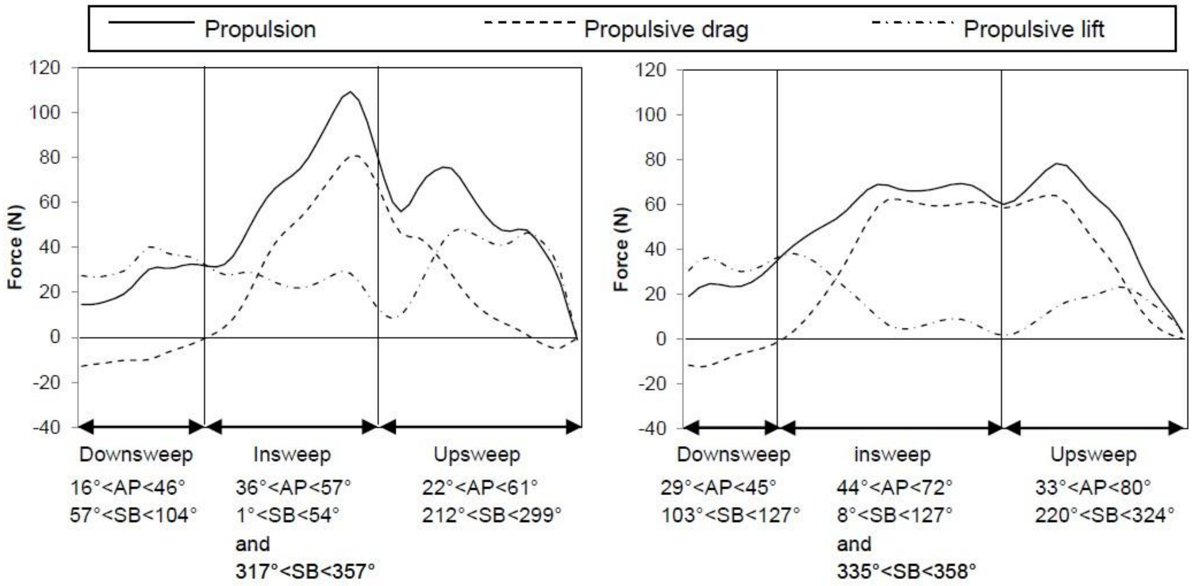
RESULTS: The mean swimming speed of the four swimmers was 1.86 ± 0.04 m/s. Table 1 shows the means and standard deviations of hydrodynamic forces at the hand exerted by the four swimmers. Mean resultant force of 70 ± 14 N was the greatest in the upsweep among the three phases and mean propulsion of 57 ± 12 N was the greatest in the insweep among the three phases. Mean propulsive drag of 40 ± 7 N was the greatest in the insweep among the three phases while mean propulsive lift of 36 ± 6 N was the greatest in the downsweep among the three phases. Mean magnitude of the hand velocity ranged from 0.98 to 2.96 m/s while the mean magnitude of the hand acceleration ranged from 16.41 to 28.10 m/s^2 (Table 2). Figure 1 shows the curves of propulsion for two of the swimmers with the range of AP and SB; one exerted the maximum propulsion in the insweep phase and the other exerted the maximum propulsion in the upsweep.

Table 1 Mean resultant force, propulsion, propulsive drag and lift forces exerted by the hand

	Resultant force (N)	Propulsion (N)	Propulsive drag (N)	Propulsive lift (N)
Whole stroke	46 ± 10	35 ± 8	11 ± 2	24 ± 6
Downsweep	35 ± 5	26 ± 4	-10 ± 3	36 ± 6
Insweep	62 ± 13	57 ± 12	40 ± 7	17 ± 6
Upsweep	70 ± 14	46 ± 9	25 ± 9	21 ± 10

Table 2 Mean magnitude of hand velocity (|V|) and acceleration (|A|)

	Mean |V| (m/s)	Mean |Vx| (m/s)	Mean |Vyz| (m/s)	Mean |A| (m/s^2)
Whole stroke	2.46 ± 0.14	1.51 ± 0.15	1.64 ± 0.37	20.14 ± 2.66
Downsweep	2.28 ± 0.12	0.98 ± 0.26	1.95 ± 0.19	16.41 ± 3.02
Insweep	2.29 ± 0.04	1.53 ± 0.16	1.50 ± 0.19	28.10 ± 2.47
Upsweep	2.96 ± 0.22	1.23 ± 0.27	2.47 ± 0.39	27.64 ± 1.05



DISCUSSION: This study quantified hand propulsion exerted by skilled sprint front-crawl swimmers with the dynamic pressure approach. Mean propulsion exerted by the hand in the insweep was greater than for the upsweep, however, three swimmers exerted similar peak propulsion for the insweep and the upsweep (approximately 10 N differences). These results are different from those estimated by the quasi-static approach (Cappaert et al., 1995) which reported that propulsion in the upsweep was 1.6 times greater than in the insweep. The different propulsion between this study and the previous study may be due to different skill levels and technique of swimmers. However we believe the difference in results is most likely due to the inclusion of hand acceleration which induces an additional hydrodynamic forces acting on the hand (Rouboa et al, 2006). The quasi-static approach does not take account of the effect of acceleration on the estimated hydrodynamic forces acting on the hand. In the current study, the mean magnitude of acceleration in the insweep was slightly greater than for the upsweep. Active drag estimated by MAD-system for swimmers whose profiles were similar to those in the present study was about 93 N at 1.86 m/s of swimming speed (Toussaint et al., 2004). At the constant swimming speed, the swimmers in the present study would exert about 61% of propulsion by the hand during the insweep while the rest might be exerted by the other limbs such as the forearm and legs.

The four swimmers used the same strategy to exert propulsion by the hand. In the downsweep, they used only lift force to propel by the hand because drag force exerted on the hand was due to resistance on the hand moving forward. A better swimmer should be able to exert greater hand propulsion in the downsweep by exerting more propulsive lift and by minimizing propulsive drag. In the insweep, swimmers used drag force by the hand mainly to propel. The result of hand propulsive drag was consistent with the observed hand velocity changes in the x-axis ($|V_x|$) as the maximum among the three phases. Propulsive drag exerted by the hand should increase as the hand velocity increases in the negative x-direction because propulsive drag is generated by the hand movement in the x-direction. In the upsweep, swimmers used drag and lift forces by the hand to propel and the result of propulsive drag and lift was consistent with the observed hand velocities in the x-axis and yz-axes ($|V_{yz}|$). The propulsive drag exerted by the hand decreased from the insweep partly because $|V_x|$ decreased and the propulsive lift exerted by the hand increased from insweep because the hand velocity perpendicular to the x-direction ($|V_{yz}|$) increased. Propulsive lift exerted by the hand was induced by the hand movement perpendicular to the x-direction.

There were two patterns shown by the swimmers to exert propulsive drag. Two swimmers showed convex curves with the apex of the peak value in the insweep (the left example in Figure 1), while the other two showed convex curve with a prolonged plateau of force close to the peak value (the right example in Figure 1). From the insweep to the upsweep the swimmers who showed the convex curve used smaller AP than the swimmers who showed the prolonged plateau of nearly peak hand propulsive drag (maximum AP: 69° vs 83°). There was one pattern to exert propulsive lift, with decreasing propulsive lift from the downsweep to the insweep and then increasing propulsive lift from the insweep to the upsweep.

CONCLUSION: For the sprint front-crawl swimmers studied, the peak propulsion was exerted in the insweep, or, nearly peak propulsion was exerted in the insweep and maintained until the middle phase of upsweep. Thus, the insweep phase is as important as the upsweep phase in terms of exerting hand propulsion. Further study of sprint front-crawl swimmers should be conducted to determine whether these findings are swimmer specific or can be generalised to all sprint swimmers. Sprint front-crawl swimmers should trial training to exert hand propulsion through propulsive lift in the downsweep and propulsive drag in the insweep with large hand accelerations, and by using propulsive drag and lift in the downsweep.

REFERENCES:

Cappaert, J. M., Pease, D. L., & Troup, J. P. (1995). Three-dimensional analysis of the men's 100-m freestyle during the 1992 Olympic games. *Journal of Applied Biomechanics*, 11, 103-112.

Kudo, S. & Lee, M. K. (2010). Prediction of propulsive force exerted by the hand in swimming. In P. L. Kjendlie, R. K. Stallman, and J. Cabri (Eds.), *Biomechanics and Medicine in Swimming XI* (pp112-114). Oslo: Norwegian School of Sport Science.

Kudo, S., Yanai, T., Wilson, B., Takagi, H., & Vennell, R. (2008). Prediction of fluid forces acting on a hand model in unsteady flow conditions. *Journal of Biomechanics*, 41, 1131-1136.

Ohigi, Y., Yasumura, M., Ichikawa, H., Miyaji, C. (2000). Analysis of stroke technique using acceleration sensor IC in freestyle swimming. In A. J. Subic, S. J. Haake (Eds.), *The Engineering of Sport* (pp503-511). London: Blackwell Science Ltd.

Rouboa, A., Silva, A., Leal, L., Rocha, L., & Alves, F. (2006). The effect of swimmer’s hand/forearm acceleration on propulsive forces generation using computational fluid dynamics. *Journal of Biomechanics, 39,* 1239-1248.

Schleihauf, R., Gray, L., & DeRose, J. (1983). Three-dimensional analysis of hand propulsion in the sprint front crawl stroke. In P. A. Hollander, Huijing, P. A., and de Groot, G. (Eds.), *Biomechanics and Medicine in Swimming* (pp173-184). Champaign, IL.: Human Kinetics.

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