Original Research

Relationship between Stroking Parameters and Leg Movement Quantity in 100 Metre Front Crawl

ANDREW D. SORTWELL

School of Exercise, Biomedical and Health Sciences, Edith Cowen University, Perth, Australia.
asortwel@our.ecu.edu.au

ABSTRACT

Int J Exerc Sci 4(1) : 22-29, 2011. The objective of this study was to examine the relationship between stroking technique parameters and leg kick quantity in 100 m front crawl swim. Ten New South Wales Sydney Metropolitan swimmers were examined (14.1 ± 1.09 years). The investigation was performed during 100 meter swimming (average speed 1.35 ± .04 [m.s-1]) commencing from water at 50 m outdoor pool. Stroke length (SL), Stroke rate (SR), Swim velocity (SV), Leg Kick Quantity (LKQ) were measured. Arm stroking parameters and LKQ were analysed during segments of the 100m distance. The relationship between SR and LKQ was negative. The correlation between stroke length and leg kick quantity was statistically significant r = .96, and p = .05. Leg Kick quantity influenced stroke length.
This study shows that swimming front crawl with a significant leg kick quantity (LKQ) such as a six beat kick, induces a longer stroke length (SL) and therefore improved arm stroke efficiency.

KEY WORDS: swimming, stroke parameters, Stroke length, Leg kick Quantity

INTRODUCTION

In the sport of swimming, one hundred metre freestylers have used the front crawl technique since the London Olympics in 1908. Front crawl is the most common stroke swum in the freestyle event. The front crawl swimming technique is the fastest swimming technique used by swimmers in freestyle events, biathlons and triathlons. Leading specialists in front crawl at shorter distances are Eamon Sullivan and Lisbeth Trickett, at middle distance are Michael Phelps and Pellegrini Federica, at long distances Mellouli Oussama and Ryan Cochrane who both compete additionally at middle distance races.

Recent studies into front crawl stroke performance have analysed factors that influence front crawl performance at varying distances. Stroke length and kicking tend to show a strong relationship. In freestyle races, elite swimmers perform front crawl with optimal stroke length and a six beat kick in competition (Pyne 2006). In short distance events, elite male swimmers show a higher stroke length and use a six beat kick throughout the whole race (Seifert, Boulesteix, Carter, Chollet 2005) (Persyn, Daly, Van Tilborgh, Verhetsel 1983). In spite of this no study has specifically determined the relationship between the stroking parameters of leg kick quantity, stroke rate and stroke length. Considering the above observations it seemed necessary to examine the relationship between stroke rate, stroke length, swim velocity and also leg kicking quantity. Multifaceted examination of highly competitive swimmers enables strength and conditioners to determine the most important factors limiting performance, and also factors that may enhance

performance and improvement in technique skill learning.

Stroke Parameters

The front crawl stroke swum at a specific swim velocity requires application of an effective swimming technique. Swim velocity is determined by stroke length, stroke rate, and to a lesser degree kicking, and significantly physiological determinants. In front crawl, the mathematical equation to calculate speed (in m.s-1) is stroke rate (in Hertz) multiplied by stroke length (in meters), as seen in this formula V = (SR×SL) (Craig et al., 1979).

A swimmer's ability to reach high speeds is determined by the ability to cover a long distance per stroke, while stroking at maximum frequency. A high stroke length value is strongly linked with better swimming economy (Costill, Kovaleski, Porter, Kirwan, Fielding, King 1985), and in previous studies stroke length has been the best discriminative factor of swim velocity (Ludovic, Chollet, Chatard 2007). Ability to cover a long distance per stroke demonstrates a greater propulsive efficiency (Toussaint, Beek 1992) of the swimmer to reduce drag (Sanders 2002).

Elite swimmers have long stroke lengths which highlights their level of skill and superior expertise (Chollet et al 1997) (Wakayoshi et.al.1993). They also tend to modify the stroke parameters (SR and SL) as their fatigue increases (Dekerle, Nesi, Lefevre, Depret, Sidney, Hout- Marchand 2005). If the coach has to determine the best combination between the swimmer's stroke length and stroke rate to swim at the highest velocity (Sidney et.al 2005), they must improve stroke length initially to reach such a level of skill to begin with (Chollet, Pelayo, Delaplace, Tourny, Sidney 1997).

However, other stroke mechanics are also connected with level of proficiency, such as inter-arm coordination (Chollet 2000). Studies on competitive swimmers have mainly centered on the impact of varied swimming techniques used in competition on swim velocity, and the function of energy systems. All front crawl biomechanics parameters influence hydrodynamic development of swimming technique, and they should all be focused in training (Touissaint 2005) (Kolmogorov 1997).

Leg Kick Quantity

The three common types of kick used in the front crawl are the two beat, four beat and six beat (Persyn et.al 1983). In competitive sprint and middle distance events in swimming, the most common kicking pattern used throughout the race is the six beat kick (Toussaint et.al 1992). In lower level ability swimmers the kicking pattern is predominantly two to four beat kick. The influence of the legs on the propulsion in front crawl varies from 4% (Hollander et.al 1988) to 10% (Deschodt, Arsac, Rouard 1999) when performing the six beat kick pattern. Therefore it would be assumed that the propulsion from the two beat or the four beat kick would be even lower. However, a recent study by Nakashima (2007) into the six beat kick while performing the front crawl technique was analysed by the swimming human simulation model SWUM. In this study it was found that in the standard six beat front crawl, that the six beat kick contributed approximately 20 – 30 % of all thrust in front crawl and 20% propulsive efficiency in the simulation.

The kick plays an important role assisting both balance, stabilisation to the trunk and propulsion to the front crawl stroke. The kick does improve the effectiveness of the upper body and overall efficiency in

the crawl stroke by elevating the lower limbs. This keeps the body stable and improves buoyancy and roll motion fluctuation (Takagi and Sanders 2002) (Toussaint, Van Den Berg, Beek. 2002). Therefore, a swimmer with good posture control and balance in the water is characterised with a six beat kick (Hollander et.al 1988) (Costill 1992). The six beat kick which enables the swimmer to maintain balance and stability and rhythm, contributes to propulsion (Richards 2006).

An inconsistent or poorly coordinated kick can increase the risk of shorter stroke length and depth, as well as risk of shoulder injury (Richards 2006). In front crawl good posture control enables the swimmer to pull further and correctly, enabling longer stroke length. Poor balance in the water will lead to the swimmer moving the arms less efficiently in an attempt to gain stability (Toussaint et.al 2002).

METHODS

Subjects

Ten male, well trained swimmers 13 to 15 years were examined. They all qualified for the 2009 Sydney Metropolitan Championships. The swimmers and their parents signed a written informed consent form to participate in the study, which included video analysis.

Table 1. Population Characteristics (n=10)

Age (Years)	Height (cm)	Weight (kg)	BMI (kg·m-2)	Arm Span (cm)
14.1 ± 1.09	170 ± 9.0	60.4 ± 9.9	20.9 ± 2.2	175 ± 11.5

Field Tests

The field tests were performed at Canterbury Municipality Olympic Pool. The tests were conducted during the 100 m swimming. The swimmers began in the water from a push start. Assessment of the parameters was performed at the end of the 100m segment of the distance (between 55 and 75m). Time of the swim and segment were measured using a Metador TW01-898 sports timer with an error of 0.16% (Pyne 2009). There were three trials with each subject and then the average for each subject was used for analysis.

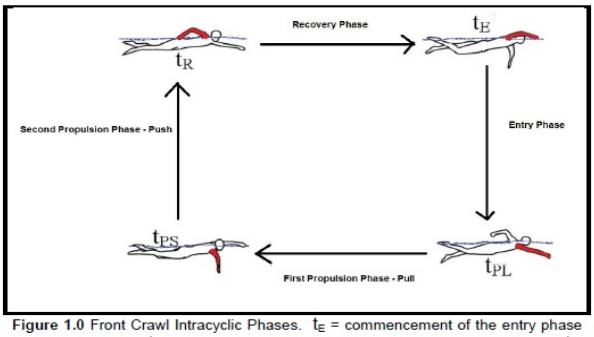

Figure 1.0 Front Crawl Intracyclic Phases. t_E = commencement of the entry phase (non propulsive), t_{PL} = commencement of the first propulsion phase, t_{ps} commencement of the second propulsion phase t_R = commencement of the recovery phase (non propulsive).

Video Analysis

Swimmers movements were recorded with Underwater Housing Case and Canon's HV20 Camcorder at a frequency of fifty shots per second. Video recordings were taken from poolside view .6m below surface of the water. Four arm cycles and leg kick quantity was analysed.

Arm Coordination and Kick

For determination of the cycles and stroke rate, the stroke cycles were divided into phases for analysis of the movement of the strokes. The recognition of the intra-cyclic phases was carried out in accordance to the Chollet (2000) method.

The cycle began with initial hand entry into the water till the beginning of the pulling movement and finished at the non-propulsion phase, the hand's exit from the water to its next entry.

The following formula was used to examine front crawl technique during the 20m swim:

- Swimming speed = 20m/ Change in Time

- Stroke rate = 1/ average duration of the two cycles
- Stroke length = Velocity / Stroke Rate

Leg kick quantity was determined from counting the number of kicks from the same video footage as the arm's movements. Leg kick quantity, was classified as six beat kick (six complete alternating emersion and or immersion kicks in one arm cycle), or four (four complete alternating emersion and or immersion kicks in one arm cycle), or two (two complete alternating emersion and or immersion kicks in one arm cycle).

Statistical Analysis

To determine the relationship between stroke length, stroke rate, velocity and Leg kick quantity partial correlations were calculated. To evaluate the relation between stroke length, stroke rate, swim velocity and leg kick quantity, Pearson correlation coefficients were calculated to evaluate the relationship. All statistical analysis was conducted with Statistica 8 Statistical Software.

Table 1.1 100m front crawl swimming technique parameters

Athlete	Stroke Parameters			
	SV [m.s-1]	SL (metres)	SR (per sec)	LKQ(number)
1	1.42	1.846	0.769	2
2	1.33	1.862	1.4	4
3	1.33	1.92	0.72	6
4	1.35	1.87	0.72	4
5	1.36	1.93	0.7	6
6	1.37	1.89	0.724	4
7	1.39	1.93	0.72	6
8	1.32	1.848	0.714	2
9	1.32	1.874	0.704	4
10	1.31	1.84	0.711	2

RESULTS

Raw Data

Swimmers technical parameters data, such as swim velocity, stroke rate, and stroke length and leg kick quantity for each young athlete is shown in Table 1.1. The stroke parameters vary widely and reflect the stroke technique competence of the swimmers. As seen, athlete one has the best swim velocity, but also the poorest stroke economy. Descriptive statistics of the front crawl swimming technique parameters are shown in Table 1.2. As expected the mean leg kick quantity is a four beat kick, which reflects the age group and achievement level of the athletes, involved in this study.

Table 1.2 Descriptive Statistics of 100m front crawl swimming technique parameters.

Variable	Descriptive Statistics (Spreadsheet1)				
	Valid N	Mean	Minimum	Maximum	Std.Dev.
SV	10	1.350000	1.310000	1.420000	0.035277
SL	10	1.881000	1.840000	1.930000	0.034849
SR	10	0.788200	0.700000	1.400000	0.215787
LKQ	10	4.000000	2.000000	6.000000	1.632993

Analysis of Raw Data

As can be seen in Table 1.3 the relationship between stroke length and leg kick quantity was statistically significant ($r = .96$, $p < .05$) and had an impact on stroke length. The leg kick quantity was negatively correlated with the arm's stroke rate ($r = -.0.03$, $p < .05$), there was very little to no correlation between these factors. Linear correlation between stroke length, swim velocity, stroke rate, and leg kick quantity of each arm movement cycle were also determined as shown in Table 1.3

Table 1.3 Correlations of Front Crawl Technique Variables

Variable	SV	SL	SR	LKQ
SV	1.00	0.24	-0.14	0.12
SL	0.24	1.00	-0.22	0.96
SR	-0.14	-0.22	1.00	-0.03
LKQ	0.12	0.96	-0.03	1.00

Marked correlations are significant at $p < .0500$

The relation between stroke length and leg kick quantity was statistically significant $r=.96$, at $p < .05$, and leg kick quantity influenced stroke length. As can be seen in Graph1.0, the relationship between stroke length and leg kick quantity from this study was very strong. The correlation between other technical parameters showed no statistical significance.

DISCUSSION

In this study, the front crawl parameters of stroke length and leg kick quantity had a strong relationship. The results of the analysis of these front crawl parameters demonstrate that the relationship between stroke length and leg kick quantity is statistically significant. The findings from this study are similar to the data obtained by other authors (Deschodt et.al 1999) (Boulesteix et.al 2005) demonstrating the six beat kick and maximal stroke length by elite swimmers in front crawl. The significant correlation between stroke length and leg kick quantity confirms that in front crawl the leg kick contributes to the overall efficiency of the forward motion by increasing stroke length (Grimston & Hay 1986) (Deschodt, Arsac, Rouard 1999).

Front crawl with optimal stroke length is more efficient and hence travel a greater distance with each pull. Characteristics which allow greater distance with each pull is the six beat kick and body roll. In stroke length dominated front crawl, the swimmer tends to have has greater amount of body roll. This larger amount of body roll enhances the ability to reach in further in front for the entry phase of the stroke (Sanders, Ross and Psycharakis, Stelios 2008) (see Fig 1.0 $\mathbf{t_E}$ entry phase). The greater reach in the entry phase increases the distance per stroke or stroke length.

A swimmer, whilst performing the front crawl, who is both balanced and stable in the water, is able to rotate and roll (Watkins and Gordon 1988). Six beat kick allows the swimmer to be stable while rotating and rolling throughout all phases of the arm cycle (Chollet 2000). Rotation and rolling is important for stroke length since it allows greater use of larger muscle groups and further reach (Sanders & Psycharakis 2008). A large amount of roll is beneficial for front crawl performance when the swimmer keeps a fluent rhythm without dead spots or pauses in the six beat kick (Sanders et.al 2008). A constant six beat kick assists with maintaining stroking rhythm and hence stroke length (Chollet 2000). When the swimmer rotates while maintaining six beat kick for stability, they are able to reach further in the non propulsion phase (Seifert et.al 2007). This increases the distance per stroke and consequently stroke length. So six beat kick indirectly enhances stroke length via maintaining stability and balancing allowing for greater rotation and roll for further reach in front crawl.

In conclusion, it is clear that stroke length is influenced by leg kick quantity. The preferable leg kick quantity for the enhancement of stroke length is the six beat kick. The six beat kick positively influences stroke length in three ways; (1) greater distance covered per stroke, (2) greater body roll and therefore greater reach with each stroke, (3) stabilization of the of the lower body and high body position which assists streamlining and reaching in front. Thus, monitoring leg kick quantity and stroke length during front crawl drills and working sets is recommended for swimmers.

Practical Implications

The front crawl stroke is constantly being refined and hence affects swim velocity and overall efficiency. Development of good swimmers requires improvement of the biomechanics and physiological

efficiency of the body to perform. The importance of kick and stroke length in competitive front crawl is an accepted principle. For optimal performance in the front crawl events, long efficient arm strokes and continuous six beat kick is needed to impart constant propulsive force. For maintenance of efficient stroke length and effective six beat kick, the muscles of upper limbs and legs need to be conditioned for continuous and fast muscle contractions. Highly skilled, elite swimmers consistently hold ideal stroke length throughout the duration of the whole race (Yanai 2003). The importance of conditioning is highlighted in a study (Dekerle et.al 2005) that noted a decrease in stroke length by 6.5% in front crawl swimmers during 30 minute exercise with maximal speed.

The training programme needs to emphasis and reinforce six beat kick and distance per stroke or stroke length. When performing drills, emphasis needs to be on the six beat kick and maintaining ideal stroke length consistently and the use of stroke rate to determine swimming speed. An effective drill to practice distance per stroke is; six kicks on the side, then three arm strokes with six beat kick per stroke, and then six facing the other side. With this drill, the swimmer also learns to kick while they roll to breath, thus maximising reach and stability.

The coach needs to continually assess and evaluate the progress of the swimmer. This can be used to highlight to the swimmer the importance of continuous six beat kick and stroke length throughout training as well as when racing. Monitoring swimmers progress will assist the swimmer to build confidence in developing stroke length dominated front crawl with a six beat kick which may feel slower initially.

Regular focus on the six beat kick concept should also concentrate on developing a fast kick. A fast six beat kick is necessary for corresponding increase in stroke rate while maintaining stroke length and consequently increased swimming speed. Speed drills help develop the fast six beat kick while maintaining good technique. Speed drills involve drills being performed at maximal effort while maintaining good technique and a six beat kick.

For young swimmers with poor stroke length and kick, the focus needs to be on reducing stroke rate, and increasing stroke length and kick to improve swimmers energy efficiency and also level of performance (Wakayoshi, D`Acquisto, Cappaert, Troup 1995). Coaches of young swimmers need to combine drills with slow stroke frequency and the six beat kick, so the swimmer will develop; greater stroke length, improved swimming efficiency, and greater capability to improve swim velocity. If the swimmer has reduced stroke length, then there is reduced scope for shortening the stroke and a greater reliance on stroke rate to swim faster. The ability to maximise swimming effectiveness and velocity potential is related to the stroking parameter stroke length as demonstrated by Craig & Pendergast (1979).

Summary

In summary, leg kick quantity influences stroke length and swimming velocity directly and indirectly. Future studies are needed to examine;

- The overall contribution of leg kick quantity to front crawl swim velocity and performance
- Increasing arm strength in swimmers would be beneficial so they apply more force in the stroke over a longer period of time, creating a good impulse rather than having a high stroke rate.

REFERENCES

1. Berger, M. A., Hollander, A. P., & De Groot, G. (1999) Determining propulsive force in front crawl swimming: A comparison of two methods. *Journal of Sports Sciences, 17* (2) 97–105.

2. Chollet D, Pelayo P, Delaplace C, Tourny C, Sidney M(1997) Stroking characteristic variations in the 100-M freestyle for male swimmers of differing skill**.** *Percept Mot Skills*, 85(1): 167-177.

3. Costill DL, Kovaleski J, Porter D, Kirwan J, Fielding R, King, D.L (1985). Energy expenditure during front crawl swimming: Predicting success in middle-distance events. *Int J Sports Med*, 6(5) 266-270

4. Costill DL, Maglischo EW, Richardson AB: (1992) **Swimming.** London, Blackwell Scientific

5. Chollet D., Chalies S., Chatard J.C. (2000) A new index of coordination for the crawl: description and usefulness. *Int J Sports Med*, 21(1) 54–59.

6. Chollet, D., Pelayo, P., Delaplace, C., Tourny, C.Sidney, M (1997) Stroking characteristic variations in the 100-M freestyle for male swimmers of differing skill. *Perceptual and Motor Skills, 885*(1) 167-177

7. Dekerle J., Nesi X., Lefevre T., Depretz S., Sidney M., Hout- Marchand F. (2005) Stroking parameters in front crawl swimming and maximal lactate steady state speed. *Int J Sports Med*. 26(1) 53–58.

8. Deschodt, V. J. Arsac, L.M. Rouard, A.H. (1999) Relative contribution of arms and legs in humans to propulsion in 25 m sprint front crawl swimming. *Eur. J. Appl. Physiol.* 80(1)192–199,

9. Craig A.B., Skehan P.L., Pawelczyk J.A., Boomer W.L. (1985) Velocity, stroke rate, and distance per stroke during elite swimming competition. *Med Sci Sports Exerc*, 17(1) 625– 634.

10. Craig A.B., Pendergast D.R. (1979) Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. *Med Sci Sports*, 11(3) 278–283.

11. Grimston S.K., Hay J.G.(1986) Relationships among anthropometric and stroking characteristics of college swimmers. *Med Sci Sports Exerc*, 18(1) 60–68.

12. Huot-Marchand F, Nesi X, Sidney M, Alberty M, Pelayo P(2005) Stroking parameters and improvement on a 200-m front crawl event in top level swimmers. *J. Sports Biomech*, 4(1): 89-99

13. Keskinen K.L., Tilli L.J., Komi P.V. (1993) Stroking characteristics of front crawl swimming during exercise. *J Appl Biomech*, 9(1), 219–226.

14. Kolmogorov, S. V., Duplischeva, O. A. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *Journal of Biomechanics, 25*(1) 311–318.

15. Kolmogorov, V., Rumyantseva, O. A., Gordon, B. J., & Cappaert, J. M. (1997). Hydrodynamic characteristics of competitive swimmers of diVerent genders and performance levels. *Journal of Applied Biomechanics, 13*(1) 88–97.

16. Nakashima. M (2007) "Mechanical Study of Standard Six Beat Front Crawl Swimming by Using Swimming Human Simulation Model", *Journal of Fluid Science and Technology*, 2(1), 290-301

17. Persyn, U., D. Daly, H. Vervaecke, Van Tilborgh, (1983) Profiles of competitors using different patterns in front crawl events. In: **Swimming Science IV**, A. P. Hollander, P. A. Huijing, and G. de Groot (Eds.). Champaign, IL: Human Kinetics Publishers, pp. 323–328.

18. Pyne, D. (2009) Accuracy of Manual and Electronic Timing. *Journal of the Australian Swimming Coaches and Teachers Association*. 25(3) 33-34

19. Richards, R. (2006) The mechanics of modern freestyle. *Journal of the Australian Swimming Coaches and Teachers Association.* volume 22(3), 54-58.

20. Seifert, L., Boulesteix, L., Carter, M., Chollet, D. (2005) The spatial-temporal and coordinative structures in elite 100-m front crawl swimmers. *Inter J Sports Med* 26 (40), 286–293.

21.Sanders,Ross and Psycharakis,Stelios (2008) *Roll ing rhythms in front crawl swimming with six-beat kick. Journal of Biomechanics*, 42 (3). 273-279.

22. Sanders R (2002). New analysis procedures for giving feedback to swimming coaching and swimmers. *XXth International Symposium on Biomechanics in Sports – Swimming*, 1-14.

23. Seifert L, Boulesteix L, Carter M, Chollet D (2005) The spatial–temporal and coordinative structures in elite male 100-m front crawl swimmers. *Int J Sports Med*. a;26(4):286–93.

24. Seifert, L., D. Chollet, and J. C. Chatard (2007) Kinematic Changes during a 100-m Front Crawl: Effects of Performance Level and Gender. *Med. Sci. Sports Exerc* 39 (10) 1784–1793,

25. Strzała M., Tyka A., Żychowska M., Woźnicki P (2005) Components of physical work capacity, somatic variables and technique in relation to 100 and 400m time trials in young swimmers. *J Hum Kinetics 14* 105–116.

26. Takagi, H. (2002) *How fast can human swim?* Iwanami Shoten, 90-91

27. Takagi,H. (1999) Hydrodynamic Study of Active Drag in Swimming, *JSME International Journal, Series B, 42(2), 171-177*

28. Takagi, H. Sanders, R. (2002) Propulsion by the hand during competitive swimming. Ujihashi, S. and Haake, S. J. (Eds). *The engineering of Sport,* Blackwell Publishing, Oxford : 631-637

29. Toussaint, H.M. Beek, P.J. (1992) Biomechanics of competitive front crawl swimming. *Sports Med.*, 13(1) 8-24.

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

31. Toussaint, H. M., & Truijens, M. (2005) Biomechanical aspects of peak performance in human swimming. *Animal Biology, 55*(1) 17–40.

32. Toussaint, H. M., Van Den Berg, C. Beek, W.J. (2002) Pumped-up propulsion during front crawl swimming. *Med. Sci. Sports Exerc.*, 34(5) 314-319

33. Wakayoshi K, D'Acquisto LJ, Cappaert JM, and Troup JP. (1995) Relationship between oxygen uptake, stroke rate and swimming velocity in competitive swimming. *Inter J of sports med* 16(1):19-23,

34. Wakayoshi K., Yoshida T., Udo M., Kasai T., Moritani T., Mutoh Y.(1992) A simple method for determining critical speed as swimming fatigue threshold in competitive swimming. *Int J Sports Med*,13(5) 367–371.

35. Wakayoshi K, Y. T., Ikuta Y, Miyashita M. (1993). Adaptations to six months of aerobic swim training, changes in velocity, stroke rate, stroke length and blood lactate. *Int J Sports Med, 14*(4), 368-372

36. Watkins J., Gordon AT (1988) The effect of legs on performance in the sprint front crawl stroke. In: BE Ungerechts, K. Reischle (eds.) Swimming Science V. P310-315.

37. Yanai T. (2003) Stroke frequency in front crawl: its mechanical link to the fluid forces required in non-propulsive directions. *J Biomech.* 36(1):53-62.