

## THE APPLICATION OF FOURIER ANALYSIS TO DEMONSTRATE THE IMPACT OF THE FLUTTER KICK ON LONGITUDINAL ROTATION IN FRONT CRAWL

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The contribution of the flutter kick to front crawl performance from its influence on longitudinal body rotation has not been thoroughly investigated. Fourier analysis was used to examine the impact of the kick on segmental and whole body angular momentum about the body's longitudinal axis in fourteen elite front crawl specialists swimming at sprint and 400m pace. The third harmonic frequency, representing the effects of the six-beat flutter kick, was greater at sprint than 400m pace in lower limb, upper limb, and whole body angular momentum. The presence of the third harmonic in upper limb and whole body angular momentum indicates that the flutter kick has an influence on longitudinal body rotation. The role of the flutter kick in front crawl performance may be linked to actions of the torso muscles to help control longitudinal body rotation.

**KEYWORDS:** Swimming, body roll, Fourier series, angular momentum.

**INTRODUCTION:** The flutter kick has the potential to improve the effectiveness of the front crawl stroke by influencing longitudinal rotation to enhance the propulsion from the arm stroke (Watkins & Gordon, 1983); however, empirical investigations of the impact of the flutter kick on longitudinal rotation in front crawl swimming are lacking. Analyses of segmental angular momentum have been used in other sports to explain the role of limb movements for performance; for example in running, the angular momentum of the upper limbs is out of phase with that of the lower body to balance the axial rotations of the lower limbs (Hinrichs, 1990). Due to the differences in frequencies between the two-beat rhythm of body roll and the six-beat rhythm of the flutter kick in front crawl, the timing of longitudinal rotation from the flutter kick is not perfectly in phase or out of phase with body roll. A different approach is therefore needed to analyse the effects of the flutter kick on longitudinal body rotation in front crawl. The repetitive nature of front crawl permits the use of Fourier analysis to represent longitudinal body rotation as a Fourier series of harmonic frequencies. The two-beat rhythm of body roll, for instance, can be represented by the first harmonic frequency while the six-beat rhythm of the flutter kick can be represented by the third harmonic frequency (Sanders & Psycharakis, 2009). In this way, Fourier analysis can be used to investigate the transmission of longitudinal rotation from the flutter kick to the rest of the body by examining the amplitude of the third harmonic in longitudinal angular momentum. Since flutter kick intensity is greater in faster swimming paces than at slower swimming paces (de Jesus et al., 2016), a comparison of the harmonic frequencies in the angular momentum signal at different swimming speeds would provide further information about the influence of the flutter kick on longitudinal body rotation. Fourier analysis was therefore used in this study to examine the frequency components of angular momentum data obtained from elite swimmers swimming at two different front crawl speeds to explore the impact of the flutter kick on longitudinal rotation.

**METHODS:** Digitised three-dimensional coordinate data of sixteen body segments of fourteen elite male Scottish front crawl specialists (age:  $17.50 \pm 1.91$  years; height:  $181.89 \pm 5.47$  cm; mass:  $72.45 \pm 6.86$  kg) previously collected for studies of McCabe, Psycharakis, and Sanders (2011) and McCabe and Sanders (2012) were analysed. Participants were either sprint (50m) or middle distance (400m) swimmers who had specialised in front crawl for a minimum of two years, were not currently injured or recovering from injury, and held a short course personal best time of less than 24.60s for 50m or less than 4min10s for 400m. The data comprised one stroke cycle (SC), defined as the moment of hand entry into the water to the subsequent entry of the same hand, from four 25m sprint trials. From a 400m

effort, one SC from the first 25m length of each 50m lap was selected for laps 2, 3, 4 and 5, totalling four observations at 400m pace. These were selected to align with previous findings that laps 1, 7 and 8 were consistently different for laps 2-6 (McCabe & Sanders, 2012). Lap 6 was excluded to further minimise the effect of fatigue on swimming technique.

Body segment parameters required for calculation of segment and whole body centres of mass and angular momentum were those obtained by McCabe (2008) using the “eZone” program (Deffeyes & Sanders, 2005) based on the elliptical zone method established by Jensen (1978). The body segment parameter data and manually digitised position data from each trial were then entered into a bespoke MATLAB (Mathworks, Inc.) analysis program written by the fourth author to calculate segmental and whole body centre of mass at each point in the SC. An additional 30 frames at each end of the SC were extrapolated by reflection to prevent data loss during filtering. Fourier transform with a 6 Hz cut-off was used to smooth the data. SC length was standardized to 201 points using Fourier transform and inverse transform so that each datum represented a half percentile of the SC (i.e. 0-100%).

Angular momentum of the lower limbs (LL – sum of local and transfer terms of the left and right foot, shank, and thigh), upper limbs (UL – sum of local and transfer terms of the left and right hand, forearm, and upper arm), and whole body (WB) were calculated about the longitudinal axis of the body’s centre of mass for each  $i$ th percentile of the SC:

$$H_{si} = \sum HL_{si} + \sum HT_{si}$$

where  $HL_s$  is the local term,  $HT_s$  is the transfer term, and  $H_s$  is the angular momentum of each group of  $s$  segments.

$HL_s$  and  $HT_s$  were calculated using the Newtonian equation (i.e.  $H = I\omega$ ) as the product of moment of inertia and angular velocity of each segment about its own centre of mass ( $HL_s$ ) and about the longitudinal axis of the body’s centre of mass ( $HT_s$ ), respectively.

A Fourier analysis was used to decompose the angular momentum signals into the first three harmonic frequencies (see Kreyszig (2006)). In front crawl swimming, the first harmonic (H1) is associated with the two-beat rhythm of body roll and the third harmonic (H3) is associated with the six-beat rhythm of the flutter kick (Sanders & Psycharakis, 2009). The amplitude ( $C$ ) of each  $n$ th Fourier harmonic frequency was determined as:

$$Cn = (An^2 + Bn^2)^{0.5}$$

where,  $An$  and  $Bn$  are the sine and cosine coefficients.

The proportions of average power (i.e. the mean squared value) comprising the first and third harmonic, respectively, were determined as a percentage of angular momentum signals as:

$$2Cn^2$$

Separate paired  $t$ -tests were used to compare the amplitudes of H1 and H3, independently, in LL, UL, and WB between sprint and 400m pace ( $\alpha = 0.05$ ).

**RESULTS:** Time series data of angular momentum and the corresponding H1 and H3 frequency components are shown in Figure 1 for a typical SC at sprint pace and 400m pace. Average power of H1 and H3 in each angular momentum variable is presented in Table 1. H3 dominated LL, comprising almost 90% of the signal at sprint pace and over 70% at 400m pace. Though H1 comprised the majority of UL (approximately 75%), H3 accounted for approximately 17% of UL at both paces. H3 was over 40% of WB at sprint pace and more than 25% at 400m pace. Figure 2 shows the amplitudes of H1 and H3 at sprint and 400m pace. H1 in LL was greater at 400m pace ( $p < 0.05$ ), while H1 in UL was greater at sprint pace ( $p < 0.01$ ). There was no difference in H1 amplitude in WB. H3 was greater at sprint pace for all angular momentum variables ( $p < 0.05$ ).

**DISCUSSION:** This study demonstrated the use of Fourier analysis to illustrate the impact of the flutter kick on longitudinal body rotation. At both sprint and 400m pace, the flutter kick had a notable influence on upper limb and whole body angular momentum. The differences in H3 of LL between paces observed in this study (Figure 2) aligns with findings that the six-beat flutter kick is associated with faster swimming (Chollet, Chalties, & Chatard, 2000). It could be expected that the size of the difference in H3 of UL between paces would be similar

to the difference in H3 of LL; however, there was a much smaller disparity between the paces of H3 in UL than LL, indicating that the torso muscles have a role in controlling longitudinal rotation from the flutter kick. A “filtering” of the six-beat rhythm by the torso muscles may diminish the amount of rotation transferred from the lower limbs to the upper limbs. Furthermore, this “filtering” effect seems to be more prevalent at sprint pace, suggesting a greater demand on the torso muscles in faster swimming. Identification of torso muscle activation profiles in front crawl is required to test this hypothesis.

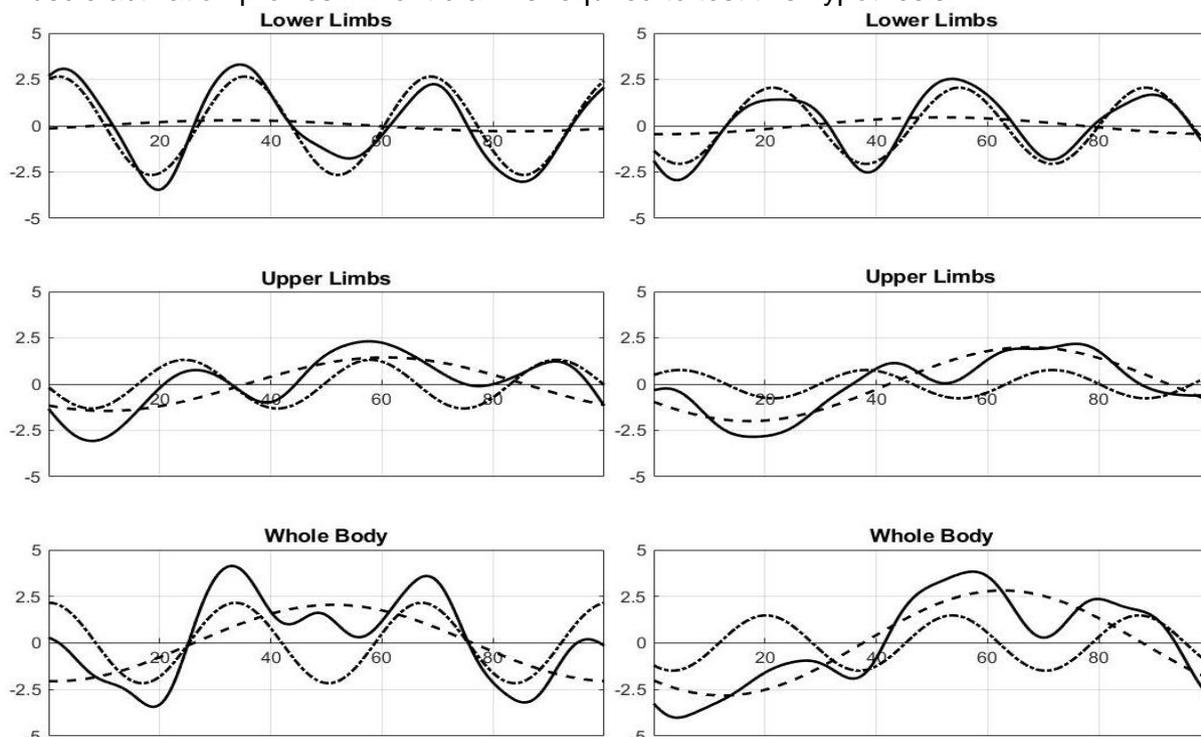


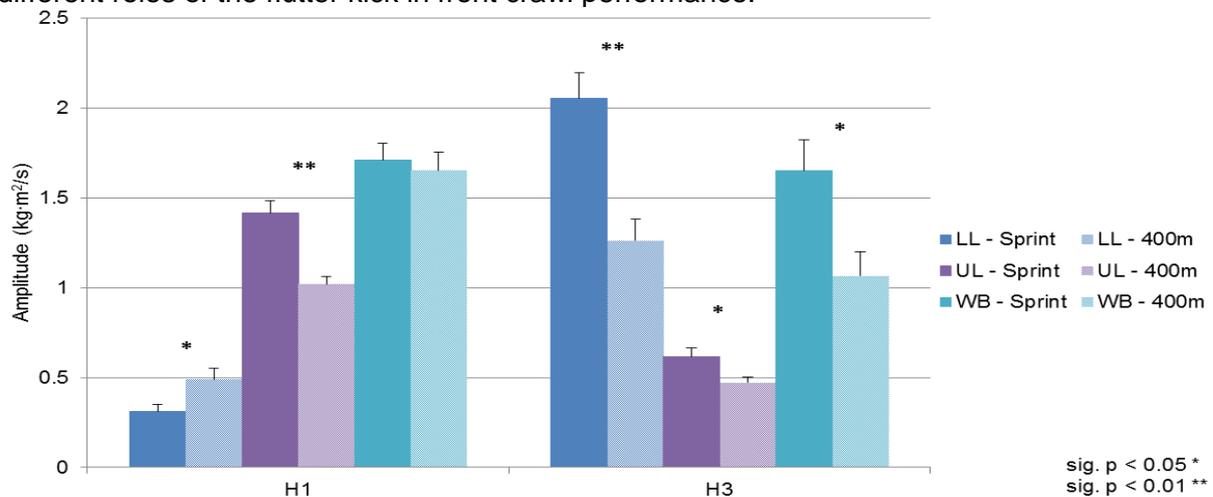
Figure 1. Time series of angular momentum ( $\text{kg}\cdot\text{m}^2/\text{s}$ ) for one stroke cycle at sprint (left) and 400m pace (right). Solid lines show angular momentum, dashed lines are the first harmonic frequency (H1), and dash-and-dot lines are the third harmonic frequency (H3) for each signal.

Table 1. Mean (*SD*) of amplitude (%power) of the first (H1) and third (H3) harmonic frequency in lower limb (LL), upper limb (UL), and whole body (WB) angular momentum.

		H1		H3	
		Sprint	400m	Sprint	400m
LL	Mean	2.9%	14.6%	89.1%	71.1%
	<i>SD</i>	2.4%	13.0%	5.7%	17.9%
UL	Mean	75.6%	74.6%	17.1%	16.9%
	<i>SD</i>	9.2%	7.6%	8.7%	6.6%
WB	Mean	48.7%	64.9%	41.5%	27.1%
	<i>SD</i>	12.2%	13.2%	14.8%	13.7%

Though the upper body does not rotate about the longitudinal axis with a six-beat rhythm in experienced swimmers, there was a clear impact of the flutter kick on UL in this study. The presence of the third harmonic in UL could have been a byproduct of the “stabilising” role of the flutter kick (see Watkins and Gordon (1983)). The rotation produced by the flutter kick, though its purpose may have been to control torso rotation, was also transferred to the upper limbs. Similar to the benefits of the arm swing in running, the flutter kick could produce a countering effect to control longitudinal torso rotation in front crawl. In this way, the flutter kick could improve the effectiveness of the stroke by helping swimmers direct propulsion from the arms towards the intended swimming direction. In contrast, swimmers may also use the movements of the lower limbs to *facilitate* longitudinal rotation. Yanai (2003) proposed that

fluid forces from the flutter kick contribute to longitudinal rotation, allowing swimmers to generate more forward propulsion from the arm stroke rather than “wasting” fluid forces from the arms to drive body roll. Further investigation is needed into the timing and sequencing of lower limb movements and longitudinal body rotation to improve understanding of the different roles of the flutter kick in front crawl performance.



**Figure 2. Mean H1 and H3 amplitude in angular momentum at sprint and 400m pace. Error bars represent standard error.**

**CONCLUSION:** Fourier analysis is a powerful tool that can be used to determine the impact of segmental motion on body rotation. The findings suggest an important role of the torso muscles in controlling longitudinal rotation from the flutter kick in front crawl. Furthermore, the impact of the flutter kick on longitudinal body rotation presented here indicates that lower limb movements could help control body roll. The findings from this study provide a foundation for discussions with coaches and athletes to maximise performance.

## REFERENCES

- Chollet, D., Chaliès, 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.
- de Jesus, K., Sanders, R. H., de Jesus, K., Ribeiro, J., Figueiredo, P., Vilas-Boas, J. P., & Fernandes, R. J. (2016). The effect of intensity on 3-dimensional kinematics and coordination in front-crawl swimming. *International journal of sports physiology and performance*, 11(6), 768-775.
- Deffeyes, J., & Sanders, R. (2005). *Elliptical zone body segment modelling software: Digitising, modelling and body segment parameter calculation*. Paper presented at the XXIII International Symposium on Biomechanics in Sports, Beijing, China.
- Hinrichs, R. N. (1990). Upper extremity function in distance running. In P. R. Cavanagh (Ed.), *Biomechanics of distance running* (pp. 107-133). Champaign, IL: Human Kinetics.
- Jensen, R. K. (1978). Estimation of the biomechanical properties of three body types using a photogrammetric method. *Journal of biomechanics*, 11, 349-358.
- Kreyszig, E. (2006). *Advanced Engineering Mathematics* (9 ed.). Hoboken, NJ: John Wiley & Sons, Inc.
- McCabe, C. B. (2008). *Effects of 50m and 400m race paces on three-dimensional kinematics and linear kinetics of sprint and distance front crawl swimmers*. (Doctor of Philosophy), The University of Edinburgh.
- McCabe, C. B., Psycharakis, S., & Sanders, R. H. (2011). Kinematic differences between front crawl sprint and distance swimmers at sprint pace. *Journal of Sports Sciences*, 29(2), 115-123.
- McCabe, C. B., & Sanders, R. H. (2012). Kinematic differences between front crawl sprint and distance swimmers at a distance pace. *Journal of Sports Sciences*, 30(6), 601-608.
- Sanders, R. H., & Psycharakis, S. G. (2009). Rolling rhythms in front crawl swimming with six-beat kick. *Journal of biomechanics*, 42(3), 273-279.
- Watkins, J., & Gordon, A. T. (1983). *The effects of leg action on performance in the sprint front crawl stroke*. Paper presented at the Biomechanics and Medicine in Swimming IV, Champaign, IL.
- Yanai, T. (2003). Stroke frequency in front crawl: its mechanical link to the fluid forces required in non-propulsive directions. *Journal of biomechanics*, 36(1), 53-62.