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## Power production of the lower limbs in flutter-kick swimming

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### Abstract

This study aimed to compare the power produced by the flutter-kick action at different swimming velocities. Eighteen high-level male swimmers completed a maximal 15-m flutter-kicking sprint and underwent two tests (one passive and one with maximal flutter-kicking) in which they were towed at six velocities ranging from 1.0 to 2.0 m/s. Power values were computed for each velocity, and selected kinematic indices were evaluated at 1.2 and 2.0 m/s. The highest power ( $54 \pm 8$  W) was observed at the velocity at which the drag equaled the propulsive force ( $1.27 \pm 0.08$  m/s), which was similar to that recorded in the flutter-kicking sprint ( $1.26 \pm 0.09$  m/s). Thereafter, power decreased significantly with increasing velocity, up to  $17 \pm 10$  W (at 2.0 m/s). The angle between the horizontal and the line connecting the highest and lowest points of the malleolus trajectory was significantly wider at 1.2 m/s than at 2.0 m/s ( $75 \pm 4^\circ$  vs.  $63 \pm 6^\circ$ ). This could explain the change of power with velocity because all the other kinematic indices considered were similar at the two velocities. These results suggest that the propulsive role of the flutter-kick increases as the swimming velocity decreases.

**Keywords:** *Front crawl, passive drag, propulsion, towing*

### Introduction

In the front crawl swimming stroke, the upper and lower limbs move in a coordinated manner to produce a propulsive action. The action of the lower limbs is performed with outstretched limbs and externally rotated and plantarflexed feet, through an alternating top to bottom movement referred to as 'flutter-kicking'. Contrary to the upper limbs, the propulsive function of which is generally recognized, the specific role of the lower limbs and the importance of their action for swimming performance are still under discussion.

Early studies in this area questioned the contribution of the lower limbs to propulsion in front crawl swimming (Counsilman, 1968; Onusseit, 1972). Subsequent studies comparing lower limbs only, upper limbs only, and normal front crawl swimming, individuated an indirect contribution of the lower limbs to propulsion. According to Watkins and Gordon (1983), the lower limbs do not have a direct propulsive action, but stabilize the trunk's

position, allowing for approximately a 9% increase in swimming velocity. By measuring quantitative changes in the kinematic parameters of the wrist's underwater trajectories, Deschodt et al. (1999) assigned a 10% gain in swimming velocity due to the contribution of the lower limbs. Tethered swimming trials have been used to assess the force generated by the movements of the lower limbs in the water. Yeater et al. (1981) reported an average force of 119 N in flutter-kick swimming. However, the mechanical characteristics of the motion in that study are different from those of dynamic swimming, and therefore the observed force values could, to a large extent, be different from those of normal front crawl swimming.

A commonly used approach to assess the propulsive force of a swimmer involves the measurement of the water drag force that the swimmer has to balance to move forward, and the mechanical power produced by the swimmer. By using various methods, previous authors have established that at high velocities the power produced by the action of the lower limbs is 10–20% of the power produced in the total swimming stroke (Hollander et al., 1988; Vorontsov & Rumyantsev, 2000). However, these studies only considered the power relative to a single given velocity. To our knowledge, the approach of evaluating how the force and power produced by a swimmer are affected by the swimming velocity, which has previously been used in the literature when studying normal front crawl swimming (e.g. Toussaint et al., 1990; Toussaint et al., 1991), has never been applied when analyzing the propulsive action of the lower limbs. Furthermore, some authors (Cureton, 1930; Alley, 1952; Mookerjee et al., 1995; Yamamoto, 1996; Maglischo, 2003; McCullough et al., 2010) have hypothesized that individual differences in flutter-kicking technique may affect the propulsive action of the lower limbs. Given that technique can be influenced by swimming velocity, evaluating the propulsive force and power produced in flutter-kicking as a function of velocity represents an important and promising way to further investigate the contribution of the lower limbs to propulsion.

An effective method to evaluate the force and power produced in flutter-kicking involves the measurement of passive drag. When using this method, multiple trials are performed at given constant velocities, in which the swimmer is towed with an electromechanical motor to assess the passive drag. In a towing swimming test, Bonifazi et al. (2005) observed a lower passive drag value if the swimmers performed a flutter-kick action, compared to a state of lower limb inactivity. Therefore, to estimate the contribution of flutter-kicking to countering water drag, it is logical to subtract the passive drag value obtained in a maximal leg-kicking trial from that obtained in a passive trial at the same velocity. The power produced by the action of the lower limbs at each velocity can be obtained as the product of the passive drag difference and the velocity.

Using this approach, the aim of this study was to compare the power produced by the flutter-kick action at different swimming velocities. To better understand the mechanisms linking the flutter-kick action to propulsion, the behavior of some relevant biomechanical descriptors of the flutter-kick at selected velocities was also analyzed.

## Methods

### *Participants*

Eighteen high-level competitive male swimmers were involved in this study. Their mean ( $\pm$ SD) age, height and weight were  $21.3 \pm 3.6$  years,  $1.82 \pm 6.3$  m and  $75.8 \pm 10.4$  kg, respectively. All the athletes had participated in short-distance freestyle swimming competitions (50–200 m). At the time the study was carried out, their weekly training duration was  $15 \pm 3$  h per week. The swimmers were informed about the procedures and

signed a written consent to participate. Written consent was also provided by the parents of U-18 participants. The study was approved by the local review board.

### *Procedures*

In a 25-m swimming pool, the swimmers completed three different tests in random order, each one on a different day. All the experimental sessions were carried out within 1 week. The three tests included a dynamic maximal flutter-kicking sprint, a towed swimming test performed passively and a towed swimming test performed with flutter-kicking at the maximum frequency.

### *Flutter-kicking sprint*

A 15-m maximal flutter-kicking sprint was performed with the arms in the best glide position. The time to cover the 15-m distance, with the athlete already at maximum velocity, was assessed by determining the time taken for the subjects' head to pass between two points 15 m apart. Two aligned underwater cameras (TS-6021PSC, Sony Hyper Had, Tokyo, Japan) were placed at the end points of the testing zone. The cameras were synchronized using a specially developed software application (see Ceseracciu et al., 2011, for further details on the synchronization system). Velocity was then calculated as distance (15 m) divided by the measured time.

### *Towing tests*

The athletes were towed for 25 m with an electromechanical motor (Ben-Hur, ApLab, Rome, Italy). The system dragged the swimmer via a cable at set constant velocities (Figure 1). Simultaneously, the passive drag (expressed in Newtons) was assessed and recorded using specially developed software (Sport DAQ, ApLab, Rome, Italy). Six trials were performed at towing velocities of 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 m/s, separated by 3-min pauses.

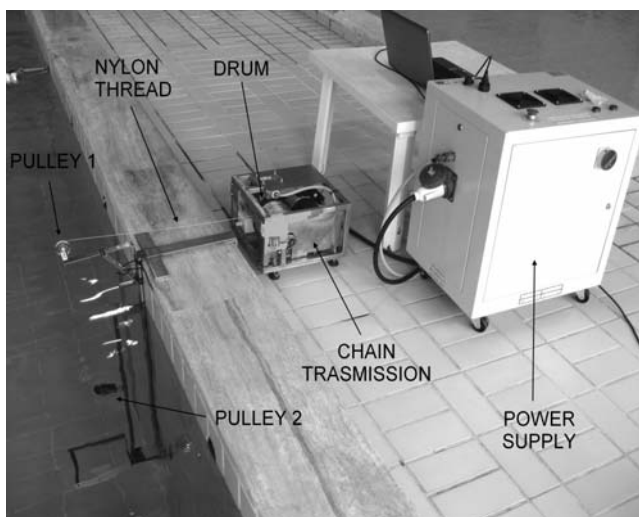


Figure 1. The electromechanical motor used to assess passive drag in the towed swimming tests.

This protocol was performed under one of two different conditions: (a) with the swimmer in a prone position, the head between the arms, and the lower limbs passively lifted using a pull buoy; and (b) with the swimmer in a position similar to the previous one but with maximal voluntary flutter-kicking. In the passive test, a  $21 \times 12.5 \times 8$  cm foam figure-eight-shaped pull buoy (Finis, Livermore, CA, USA) was used to lift the lower limbs. Preliminary assessments showed that the hydrodynamic position of the feet while using the pull buoy was more similar to that in flutter-kicking swimming than the best glide position (i.e. without a pull buoy) because the underwater torque effect was avoided (Charbonnier et al., 1975). To evaluate the extent to which the additional drag acting on the pull buoy affected the passive drag, the subjects also performed a passive towing test using the best glide position (without the pull buoy), following the same protocol as the other towing tests. The mean individual differences (passive drag in the trial without the pull buoy minus passive drag in the trial with the pull buoy) were small but significantly different from zero at all the velocities tested, ranging from 2.19 N (at 1.0 m/s) to 4.38 N (at 1.2 m/s). Lower passive drag values were observed in the test performed with the pull buoy, indicating that the drag acting on the pull buoy was not particularly relevant, at least when compared with the additional drag caused by the lower limbs not being lifted, which occurred in the test carried out without the pull buoy. For each swimmer, the trend of passive drag assessed in the passive test with lifted lower limbs as a function of velocity was best modeled ( $r^2 > 0.95$ ) using a quadratic fit of the data (Figure 2). The passive drag values during the flutter-kicking towing test were not detectable at the velocities lower than that achieved in the flutter-kicking sprint because the propulsive force provided by maximal leg-kicking overcame the resistance of the water. Passive drag values were instead recorded at the velocities higher than that achieved in the flutter-kicking sprint, showing a linear trend with respect to velocity. The velocity at which the water drag and the propulsive force generated by the flutter-kick action were equal was obtained by extrapolation from the linear passive drag versus towing velocity relationship, corresponding to a passive drag value of 0 (Figure 2).

For each swimmer, the propulsive force generated by the flutter-kick action ( $F_{FK}$ ), expressed in Newtons, was computed at each velocity (except for those lower than the velocity achieved in the flutter-kicking sprint, at which no passive drag was observed) as

$$F_{FK} = D_{LIFT} - D_{FK}, \quad (1)$$

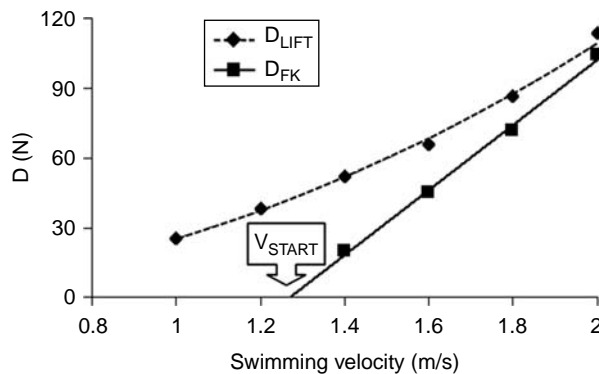


Figure 2. Trend of passive drag ( $D$ ) in the towing test with lifted lower limbs ( $D_{LIFT}$ , quadratic polynomial fit) and passive drag in the flutter-kicking towing test ( $D_{FK}$ , linear fit) in a representative swimmer. Note:  $V_{START}$  = velocity at which the water drag equaled the propulsive force generated by the flutter kick action.

where  $D_{\text{LIFT}}$  and  $D_{\text{FK}}$  are the passive drag values recorded in the passive test with lifted lower limbs and in the flutter-kicking test, respectively. Finally, the power produced by the flutter-kick action ( $P_{\text{FK}}$ ), expressed in Watts was computed at each of the velocities for which a  $F_{\text{FK}}$  value was available as

$$P_{\text{FK}} = F_{\text{FK}} \cdot V_{\text{T}}, \quad (2)$$

where  $V_{\text{T}}$  is the towing velocity, expressed in m/s.

### *Biomechanical analysis*

By means of apposite markers on the right side of the swimmers' body, anatomical landmarks were highlighted on the great trochanter, the lateral malleolus of the fibula, and the fifth metatarsus. In the towing test with flutter-kicking, the action of lower limbs was filmed at a rate of 50 Hz with an underwater camera (Sony Hyper Had). To maximize the visibility of the limb, the camera was placed perpendicular to the swimmer's direction on a sagittal view, 12.5 m far away from the start, 0.3 m under the water surface, and 3 m from the swimmer's trajectory. The data collection area was calibrated with a method previously used in the literature (Clothier et al., 2004). A two-dimensional sagittal plane analysis of the left leg action was performed using the SIMI Twin Pro motion analysis system (SIMI Reality Motion Systems, Unterschleissheim, Germany).

The following biomechanical indices were obtained from the motion analysis:

- Kick frequency: the inverse of the time to complete a flutter-kick cycle.
- Kick depth: the distance between the highest (i.e. that at the start of the downbeat) and the lowest point (i.e. that at the end of the downbeat) of the malleolar marker trajectory.
- Body roll angle: assessed using the proportion between the individual intertrochanteric distance and the mean vertical oscillation of the right trochanter. To do this, it was assumed that the vertical movement of the left trochanter (not visible from the camera viewpoint) was symmetrical to that of the right trochanter. This assumption was reasonable because the subject performed no upper limb or breathing movements during the test.
- Foot trajectory angle: the angle between the horizontal and the line connecting the highest and the lowest point of the malleolar marker trajectory (Figure 3a,b).
- Pitch angle: the angle between the horizontal and the line connecting the malleolus and the fifth metatarsus, assessed at the start of the downbeat and at the end of the downbeat (Figure 3c).
- Angle of attack: the angle between the malleolus-fifth metatarsus axis and the path of the foot displacement, assessed at the start of the downbeat and at the end of the downbeat (Figure 3c).

The video tracking was performed on three consecutive flutter-kick cycles, and one value per cycle was obtained for each of the considered indices. The average value of the three available data sets was used for the further analyses.

### *Statistical analysis*

All the data are reported as the  $M \pm SD$ . A one-way repeated measure ANOVA with post-hoc Bonferroni correction was used to compare the power values obtained at the different considered velocities. Paired Student's  $t$  tests were used to compare the mean value of



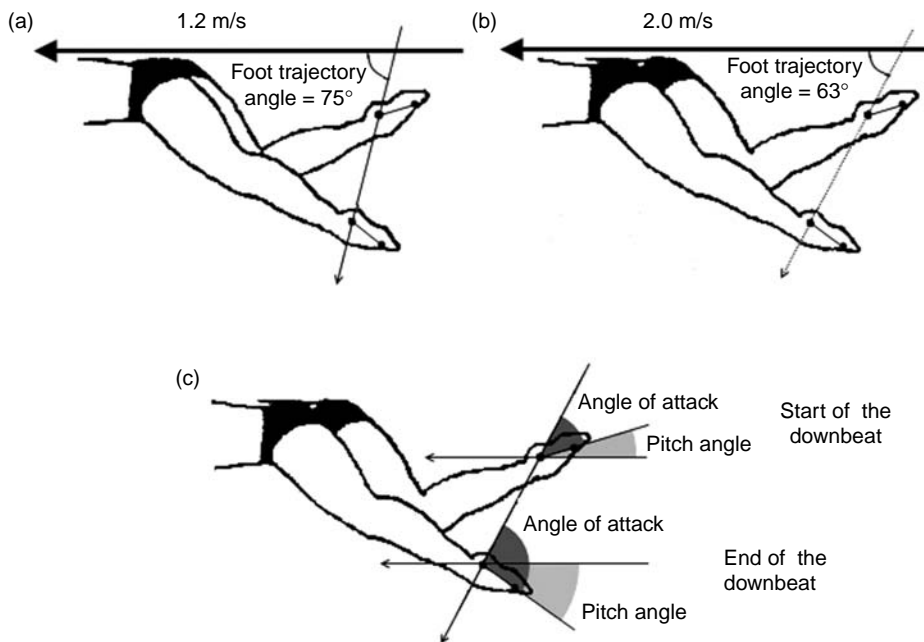


Figure 3. Determination of the foot trajectory angle (a and b), the pitch angle and the angle of attack (c). The values of the foot trajectory angle at 1.2 and 2.0 m/s are referred to a representative swimmer.

velocity at which the water drag equaled the propulsive force with that of the velocity achieved in the flutter-kicking sprint, and the mean values of the assessed biomechanical indices at the two considered velocities. In all the analyses, the statistical significance was set at  $\alpha = 0.05$ .

## Results

The velocity achieved in the flutter-kicking sprint was  $1.26 \pm 0.09$  m/s, with a minimum and a maximum of 1.15 and 1.46 m/s, respectively. No significant difference was found between this velocity and the velocity at which the water drag equaled the propulsive force ( $1.27 \pm 0.08$  m/s, minimum: 1.16, maximum: 1.46 m/s), with the highest individual difference between the two velocities being 0.10 m/s. The propulsive force at the velocity at which it equaled the water drag was  $42 \pm 4$  N, and the power associated with this was  $54 \pm 7$  W. It is worth noting that, according to Equation 1, the propulsive force at the velocity at which it equaled the water drag corresponded to the passive drag recorded in the towing test with lifted lower limbs, and therefore the passive drag in the flutter-kicking towing test was equal to zero at that velocity.

Table I displays the mean values of the passive drag forces obtained in the towing tests and the propulsive force at the different velocities considered, and at the individually determined velocity at which the water drag equaled the propulsive force itself. With increasing velocity, the passive drag recorded in the flutter-kicking test increased at a higher rate compared to that recorded in the test executed with lifted lower limbs, resulting in a decrease in the propulsive force. A visual inspection of the passive drag vs. velocity relationships obtained in the lifted lower limbs and flutter-kicking towing tests, respectively, in a representative athlete (Figure 2) provides an example of this behavior.



Table I. Summary of the passive drags and propulsive forces ( $M \pm SD$ ).

Velocity (m/s)	$D_{LIFT}$ (N)	$D_{FK}$ (N)	$F_{FK}$ (N)
1.0	$25 \pm 4$		
1.2	$38 \pm 6$		
1.27	$42 \pm 4$		$42 \pm 4$
1.4	$52 \pm 7$	$20 \pm 7$	$32 \pm 8$
1.6	$66 \pm 9$	$45 \pm 10$	$21 \pm 6$
1.8	$86 \pm 13$	$72 \pm 12$	$15 \pm 7$
2.0	$113 \pm 15$	$104 \pm 16$	$9 \pm 5$

Notes:  $D_{LIFT}$  = passive drag in the towing test with lifted lower limbs,  $D_{FK}$  = passive drag in the flutter-kicking towing test,  $F_{FK}$  = propulsive force generated by the flutter-kick action.

The trend of the passive drag in the lifted lower limbs test fitted a second order polynomial curve, while that in the flutter-kicking towing test showed a linear relationship. At high velocities, the two curves tended to converge, and thus the propulsive force tended to zero. In all the subjects, the maximum power value was that associated with the velocity at which the water drag equaled the propulsive force ( $54 \pm 8$  W). Thereafter, there was a decreasing trend of power with increasing velocity (Figure 4), linked to the decrease of the propulsive force. At a given velocity, the power was significantly lower than at all lesser velocities. The only exception to this significant relationship was between power values at 1.6 vs. 1.8 m/s ( $32 \pm 10$  vs.  $27 \pm 12$  W), and 1.8 vs. 2.0 m/s ( $27 \pm 12$  vs.  $17 \pm 10$  W).

Table II shows the values of the biomechanical descriptors of the flutter-kick action. Compared to the 1.2 m/s trial, the 2.0 m/s trial showed a slightly higher kick frequency and body roll angle, and a slightly lower kick depth. However, the differences were not statistically significant ( $p > 0.05$ ). Similarly, the pitch angle did not differ between the two velocities when assessed at either the start or the end of the downbeat. Instead, both the foot trajectory angle and the angle of attack were significantly wider ( $p < 0.001$ ) at the lowest velocity.

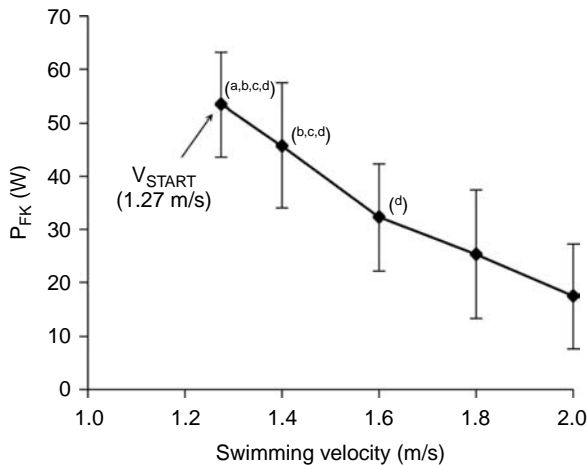


Figure 4. Trend of the power produced by the flutter-kick action ( $P_{FK}$ ) as a function of swimming velocity. <sup>a</sup>Significantly higher than at 1.4 m/s ( $p < 0.05$ ); <sup>b</sup>significantly higher than at 1.6 ( $p < 0.05$ ); <sup>c</sup>significantly higher than at 1.8 m/s ( $p < 0.05$ ); <sup>d</sup>significantly higher than at 2.0 m/s ( $p < 0.05$ ).

Table II. Summary of the biomechanical indices ( $M \pm SD$ ).

	Velocity	
	1.2 m/s	2.0 m/s
Leg-kick frequency (Hz)	$2.4 \pm 0.2$	$2.5 \pm 0.2$
Kick depth (m)	$0.30 \pm 0.07$	$0.26 \pm 0.05$
Foot trajectory angle ( $^{\circ}$ )	$75 \pm 4$	$63 \pm 6^*$
Body roll angle ( $^{\circ}$ )	$34 \pm 6$	$35 \pm 8$
Pitch angle at the start of the downbeat ( $^{\circ}$ )	$27 \pm 15$	$24 \pm 12$
Pitch angle at the end of the downbeat ( $^{\circ}$ )	$-39 \pm 6$	$-40 \pm 4$
Angle of attack at the start of the downbeat ( $^{\circ}$ )	$48 \pm 16$	$39 \pm 15^*$
Angle of attack at the end of the downbeat ( $^{\circ}$ )	$114 \pm 8$	$103 \pm 9^*$

\* Significantly different from the 1.2 m/s condition ( $p < 0.05$ ).

## Discussion and implications

The main purpose of this study was to compare the power produced by the flutter-kick action at different swimming velocities. To this aim, we used a towing testing procedure in which the passive drag was evaluated while the swimmer was towed with an electromechanical motor. To our knowledge, no author has evaluated the biomechanics of flutter-kicking in a towing test, but the values of kick depth and body roll angle observed here (Table II) are similar to those reported in the literature for full front crawl swimming at comparable velocities (Allen, 1948; McCabe et al., 2010). Furthermore, the flutter-kick frequencies we measured in the maximal flutter-kicking trials at 1.2 m/s ( $2.4 \pm 0.2$  Hz) and at 2.0 m/s ( $2.5 \pm 0.2$  Hz) almost correspond to the frequency used by a swimmer flutter-kicking at six beats per stroke cycle, at a stroke frequency of 0.83 Hz, i.e. 50 stroke cycles per minute. The major finding of this study is that the power produced by the flutter-kick action is not constant across velocities but decreases when the velocity increases. In fact, the highest power values were observed at the velocity where the water drag equaled the propulsive force (1.27 m/s on average), namely the velocity in which the force generated by the flutter-kick action balanced the water drag. Then, the power tended to decrease almost linearly with increasing velocity, with a 67% difference between the power at the velocity in which the water drag equaled the propulsive force and at 2.0 m/s. We infer that the power decrease indicates a progressively reduced contribution of the flutter-kick action to propulsion with increasing velocity.

To interpret the observed loss of power and to eventually link it to modifications in the biomechanics of the lower limbs movements occurring with velocity changes, it is appropriate to analyse the behavior of the relevant kinematic descriptors of flutter-kicking. According to previous investigators (Hull, 1990; Engesvik, 1992; Maglischo, 2003; McCullough et al., 2010), there is a positive relationship between ankle flexibility and the propulsive efficacy of the action of the lower limbs. In fact, an athlete with elevated ankle flexibility should be able to achieve a high degree of plantar flexion during the flutter-kick action, which requires that the foot be suitably angled to push water backwards to perform an optimal propulsive action.

Although we did not measure flexibility in our subjects, we observed no significant differences between the two considered velocities (1.2 and 2.0 m/s) with regard to the mean value of the pitch angle, i.e. the angle between the foot's axis and the horizontal, when assessed at either the start or the end of the downbeat (Table II). This may be because a

maximal flutter-kick action was required by the swimmers at both the velocities. We can therefore state that the different values of power produced by the flutter-kick action at the two velocities were not attributable to a different degree of foot orientation, as indicated by the similar pitch angle values. Moreover, these data demonstrate that the 2.0 m/s velocity was not high enough to cause significant passive changes in the foot orientation.

Even more than the pitch angle, which refers to the orientation of the foot's axis with respect to the horizontal in a fixed instant, the path covered by the whole foot throughout the kicking action is an important parameter to be considered when assessing a dynamic action such as the flutter-kick. The movement of the lower limbs in flutter-kick swimming is similar to that in undulatory underwater swimming (Arellano et al., 2002), although with an alternated rather than simultaneous action of the lower limbs. Furthermore, the undulatory underwater swimming of humans is comparable to the analogous movement of cetaceans (Von Loebbecke et al., 2009). By analyzing the lift-based propulsion typical of cetaceans, Fish (1993) individuated a lift force vector perpendicular to the path of the propulsive appendage. When considering the flutter-kick action of a swimmer, an analogous force vector can be identified perpendicular to the path of the foot throughout the leg-kick ( $\mathbf{F}_r$ , Figure 5). This vector results from the sum of the horizontal thrust force component ( $\mathbf{F}_t$ ), which contributes to the advance, and the vertical force component ( $\mathbf{F}_v$ ), which prevents the sinking of the legs (Figure 5).

In flutter-kick swimming, the foot is translated along the direction of the movement over a distance proportional to the swimming velocity. This modifies the path of the foot as observed in a reference frame attached to the subject, i.e. the foot trajectory angle decreases with increasing velocity (Figure 3a,b). In our swimmers, a mean  $12^\circ$  difference in the foot trajectory angle was observed between the 1.2 and the 2.0 m/s velocities (Table II). Hypothesizing that, due to the similar pitch angles at the different velocities, similar values of the modulus of the force vector perpendicular to the foot's path occurred in given points during the flutter-kick action, the higher inclination of the foot's path at the higher velocity would involve an overall decrease of the modulus of the horizontal thrust force component. This could explain the observed loss of power produced by the flutter-kick action with increasing velocity.

In studies on the propulsion of cetaceans, when the forces are evaluated in a 'hydrodynamic model', the angle between the tangent to the direction of the tail displacement and the axis of

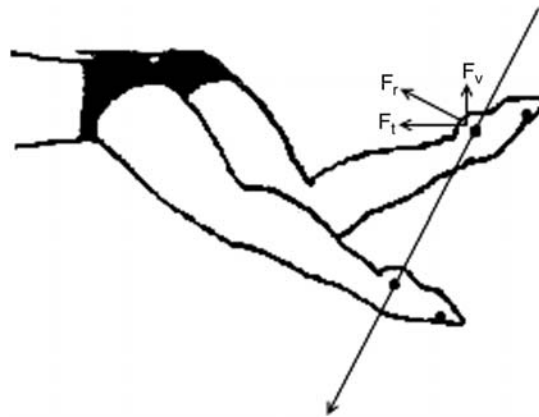


Figure 5. Representation of the action of the thrust and vertical force during the flutter-kick action.  $\mathbf{F}_r$ : resultant force;  $\mathbf{F}_t$ : thrust force;  $\mathbf{F}_v$ : vertical force.

the back of the tail has also been considered (Chopra & Kambe, 1977). This angle, defined as the 'angle of attack', can be similarly individuated for a swimmers' foot (Figure 3c). The angle of attack also affects the magnitude of the propulsive force vector, and when computing the horizontal thrust force component produced by the undulatory action of the tail, the propulsive efficiency is corrected by considering the value of the angle of attack (Chopra & Kambe, 1977).

Analyzing the movements in cetaceans, Triantafyllou has shown that the propulsive efficiency is optimal when the angle of attack is between  $15^\circ$  and  $25^\circ$  (Triantafyllou & Triantafyllou, 1995). To maximize the thrust, cetaceans regulate the angle of attack throughout the stroke, carrying out a specific action of control on the caudal peduncle, allowed by the elevated mobility of their skeletal structure (Long et al., 1997). Moreover, in dolphins, the thrust-generating action involves the instantaneous swimming velocity being decreased during the upstroke and increased during the down stroke (Videler & Kamermans, 1985).

To our knowledge, this study is the first to assess the angle of attack in human flutter-kicking. The values of the angles of attack observed here, namely  $48 \pm 16^\circ$  (at 1.2 m/s) and  $39 \pm 15^\circ$  (at 2 m/s) at the start of the downbeat, and  $114 \pm 8^\circ$  (at 1.2 m/s) and  $103 \pm 9^\circ$  (at 2 m/s) at the end of the downbeat, were certainly higher than those considered to be optimal for an effective propulsive action ( $15\text{--}25^\circ$ ), especially in the case of the end of the downbeat. Therefore, in contrast to cetaceans, humans are not capable of adjusting the angle of attack throughout the leg kick to optimize propulsion because of the limited flexibility of the ankle joint. It is important to note that the decrease in the mean values of the angles of attack, significant between the 1.2 and 2.0 m/s velocities (both at the start and end of the downbeat) is actually referable to variations in the foot trajectory angle, with the pitch angle remaining constant at the same time (Table II). In fact, the angle of attack can be computed by subtracting the value of the pitch angle from that of the foot trajectory angle. It can therefore be argued that the angle of attack has limited importance in determining the efficacy of the propulsive action of flutter-kicking in humans.

A limitation of this study is that the present results cannot be directly generalized to front crawl swimming as a whole. In fact, despite the fact that the mean values of body roll angle, kick depth, and kick frequency observed here are similar to those reported in the literature for front crawl swimming, only one cycle of body roll per stroke cycle occurs in front crawl swimming, whereas one cycle of body roll per kick cycle occurs in flutter-kicking. This difference may affect the kinematics of lower limb movements, and the influence of given amplitude of body roll, therefore, may not be the same in the two cases. It will be a matter for future studies to determine if, and to what extent, the power production of the flutter-kick action is different in front crawl compared with flutter-kick swimming.

## Conclusions

This study aimed to compare the power produced by the flutter-kick action at different swimming velocities. The results show that the propulsive action of the lower limbs decreases with increasing velocity. We postulate such a phenomenon to be linked to changes in the patterns of the thrust force generated by the swimmer, caused by variations in the angle between the horizontal and the foot's trajectory during the flutter-kick action. From an applied perspective, the present results would suggest that the propulsive role of the flutter-kick increases as the swimming velocity decreases. Similarly, this would seem to indicate that the kick becomes more important, in terms of propulsive capacity, as race distance increases.

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