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Research article

A KINEMATIC STUDY OF FINSWIMMING AT SURFACE

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ABSTRACT
Finswimming is a sport of speed practiced on the surface or underwater, in which performance is based on whole-body oscillations. The present study investigated the undulatory motion performed by finswimmers at the surface. This study aiming to analyze the influence of the interaction of gender, practice level, and race distance on selected kinematic parameters. Six elite and six novices finswimmers equipped with joints markers (wrist, elbow, shoulder, hip, knee, and ankle) were recorded in the sagittal plane. The position of these anatomical marks was digitized at 50 Hz. An automated motion analysis software yielded velocity, vertical amplitude, frequency, and angular position. Results showed that stroke frequency decreased whereas the mean amplitude of all joints increased with increasing race distance ($p < 0.01$). Mean joint amplitude for the upper limbs (wrist, elbow and shoulder) was smaller for experts than for novices. Whereas that of the ankle was larger, so that the oscillation amplitude increased from shoulder to ankle. Elite male finswimmers were pitching more acutely than female. Moreover, elite male finswimmers showed a smaller knee bending than novices and than elite females ($p < 0.01$). This indicated that elite male finswimmers attempt to reduce drag forces thanks to a weak knee bending and a low upper limbs pitch. To sum up, gender, expertise, and race distance affect the performance and its kinematics in terms frontal drag. Expertise in finswimming requires taking advantage of the mechanical constraints pertaining to hydrodynamic constraints in order to optimize performance.

KEY WORDS: Swimming, undulations, technique, movement

INTRODUCTION

Finswimming is a speed competition sport practiced at the surface or underwater with different monofins of variable rigidity. Alike the motion of dolphins (Videler, 1981), propulsion bears on the vertical displacement of the whole body. The use of the upper body is forbidden for propulsion purposes. The vertical displacement of the body during the stroke cycle has been described as wave-like (Ungerechts, 1982). Since such motion could be characterized by specific amplitudes of oscillations. Such oscillations were also specified by a particular frequency and phase relationship (Sanders et al., 1995).

Our knowledge on finswimming bears mostly on underwater finswimming. It was shown that the wave-like motion traveled along the body in the caudal direction and that finswimmers adapted their undulations in frequency and amplitude, starting the propulsive motion at the hip level (Baly et al., 2002). Nevertheless, because of the air-water interface, finswimmers' motion is quite different in amplitude and frequency at the surface than underwater.

Concerning finswimming at the surface, Zamparo et al. (2002) performed a kinematic study that quantified the efficiency of human swimming in using fins. Another study revealed the effect of the monofin shape on the propulsive forces by analyzing the change in the swimmer's velocity over one cycle of the monofin's motion (Tamura et al., 2002).

Finally, a finswimmer is at one and the same time a propelling and a propelled body. Given the speed reached ($3.89\ m \cdot s^{-1}$), body pitch and knee bending must be weak in order to limit the frontal surface area, as defined by Vogel (1994), a main factor of hydrodynamic resistance. The gliding and the propulsion must be finely tuned in order to optimize performance. A previous study at the surface showed that the race distance and practice level increase the stroke frequency and the ankle vertical amplitude (Gautier et al., 2004). However the gender influence on kinematic parameters was not taken into consideration.

In the present study, we hypothesized that the gender affects finswimming performance in association with the practice level and the race distance. Thus, we aimed to quantify finswimming at the surface in terms of kinematic parameters such as the swimming speed, the movement excursion, and the degree of knee bending according to gender, race distance and practice level. Their analysis may provide information useful to coaches and technicians in order to reduce drag of the finswimmer.

METHODS

The experiment was carried out in a 50 m pool. Six elite finswimmers members of French National Team (3 males, 3 females) and six novices (3 males, 3 females) who started competition six months ago participated on a voluntary basis. For the elite group, average age was 20 ± 4 years, body mass 69.1 ± 8.1 kg, and stature 1.74 ± 0.8 m. For the novices, average age was 25 ± 3 years, body mass 64.6 ± 5.2 kg, and stature 1.69 ± 0.4 m. Finswimmers were instructed to perform 3 random trials of 25 m per race distance (100 m and 800 m). Using a snorkel, finswimmers performed trials with their standard monofins.

Passive disk markers were applied on selected joints to facilitate their tracking and video analysis: wrist, elbow, shoulder, hip, knee, and ankle were visible to the camera throughout the stroke cycle. Video images were collected from two digital cameras (SONY VX-2000E, 50Hz). One digital camera was immerged and securely fixed in a watertight box at 0.15 m below the water surface and recorded in sagittal plane. A calibration was carried out separately for each trial, at the middle tank and 5.34 m away from the camera. The width of the optical field of view in the plane of motion was 6 m. The other digital camera (SONY VX-2000E, 50Hz) was placed in the axe of the first to record motion above the water in order to control whether the whole body was kept underwater, except for the snorkel, vertex, and heel.

The markers were semi automatically tracked (3D Vision, Kihopsys). The analysis period comprised one complete stroke cycle starting from the video frame corresponding to the first whole body appearance. Body marks were seized to determine a 5-segment human model: forearm, arm, trunk, thighs, and shank. The knee bending angle was determined using the relative angle between the distal extension joint center of the thigh and the shank. As for all biomechanical data, random error from the digitizing process was reduced using a recursive fourth-order Butterworth digital filter with a frequency cut off at 4 Hz.

The analysis consisted of a repeated measures ANOVA with gender (male vs. female) and expertise level (novice vs. expert) as between-subject factors, and distance (100 m vs. 800 m) as within-subject factor (N = 12). The dependant variables were the velocity, the amplitude and the frequency of oscillation, and the knee angle. All effects were declared significant at a threshold of $p < 0.05$.

RESULTS

The average speed for 800 m was lower than for 100 m for the experts (2.09 $m \cdot s^{-1}$ ± 0.17 $m \cdot s^{-1}$ and 2.66 $m \cdot s^{-1}$ ± 0.26 $m \cdot s^{-1}$, respectively). Novices were slower than experts (1.69 $m \cdot s^{-1}$ ± 0.11 $m \cdot s^{-1}$ and 2.07 $m \cdot s^{-1}$ ± 0.18 $m \cdot s^{-1}$ respectively). Irrespective of the distance, males were faster than females (2.58 $m \cdot s^{-1}$ ± 0.40 $m \cdot s^{-1}$ vs. 2.15 $m \cdot s^{-1}$ ± 0.31 $m \cdot s^{-1}$).

Table 1 shows that the average frequency of stroke cycle decreased with increasing distance for both experts and novices ($p < 0.01$). On 800 m, novices were slower than elite finswimmers, although their frequency was higher. Such frequency was higher for males (1.61 Hz) than female (1.22 Hz) on 100 m as well as on 800 m males (0.81 Hz vs. 0.61 Hz, respectively).

Figure 1 indicates that the amplitude of body oscillation increased as a function of race distance ($p < 0.01$) for all expertise levels. The upper limbs amplitude of oscillation (i.e., wrist, elbow, and shoulder) was smaller for experts than for novices. Concerning the lower limbs (hip, knee, and ankle),

Table 1. Frequency (Hz) of stroke cycle of the most oscillant joints as a function of practice level and race distance in elite (EXP) and novice (NOV) finswimmers. Data are means (±SD).

Frequency (Hz)	EXP 100m	NOV 100m	EXP 800m	NOV 800m
Hip	1.89 (.30)	1.54 (.26)	0.97 (.16)	1.01 (.16)
Knee	1.88 (.29)	1.53 (.28)	0.97 (.16)	0.98 (.17)
Ankle	1.88 (.29)	1.53 (.28)	0.96 (.16)	1.01 (.16)
Average	1.88 (.01)	1.54 (.01) **	0.97 (.00)	1.00 (.02)

** significant difference ($p < 0.01$).

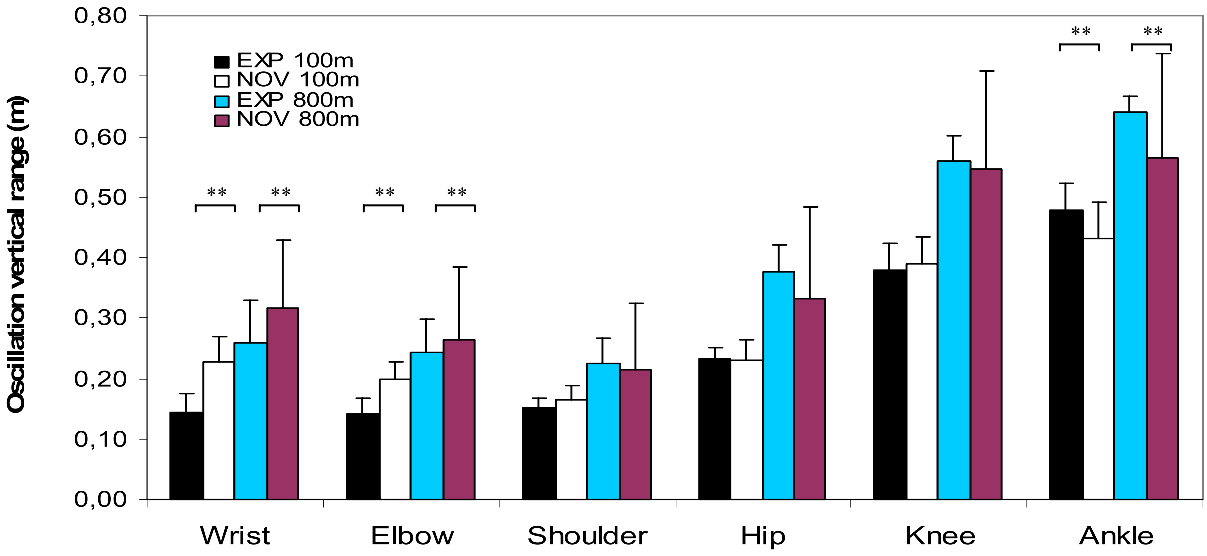

Figure 1. Range of vertical oscillation for elite (EXP) and novice (NOV) finswimmers in a 100 m and 800 m race. ** significant difference (p<0.05).

only the amplitude at the ankle level was larger for experts than for novices. There was non difference between male and female in vertical ankle amplitude (0.56 m vs. 0.51 m, respectively). However, wrist amplitude was significantly lower in female (0.22 m) than in male (0.26 m).

Knee bending was a factor of performance as a function of the expertise ($p < 0.01$) associated with the important vertical amplitude of the ankle. Bending for experts was smaller than for novices (119.25 ± 3.31 deg. and 104.60 ± 4.96 deg. respectively on 100m). On the 800 m, novices' knee bending was higher than the elite's one (94.85 ± 7.30 deg. vs. 108.87 ± 6.61 deg.). However, such main effects on knee bending were comprised within a 4-way gender x race distance x practice interaction. This result will be discussed in the following part.

DISCUSSION

The present study investigated the undulation motion performed by finswimmers at the surface, aiming to uncover the influence of gender, practice level, and race distance on selected kinematic parameters.

The undulation frequency and the swimming speed decreased with the increasing race distance from 100 m to 800 m for both expertise levels. This suggests an adaptive decrement in the energy expenditure for long races. Moreover, although novices were slower than experts on 800 m, they showed a higher frequency. Novices seem thus to rush their action, privileging muscular strength and quick motion in a attempt to swim faster. This point to a lack of efficiency in the novices' stroke technique.

While stroke frequency decreased with increasing race distance, mean joint amplitude increased, irrespective of the expertise level. This also suggests that both novices and experts can adapt their energy output. Regarding motion amplitude, the experts' upper limbs appeared to act as a stabilizing device. Expert finswimmers limit potential energy due to upper limbs oscillation in order to increase kinetic energy. In contrast, novices' larger upper limbs amplitude and lower speed indicate that potential energy is not transformed in to kinetic energy as efficiently. Such an inefficacy is reinforced by the fact that their shoulder operated as a pivot point, so that the body behaved as a pendulum rather than as an element along which a wave was transmitted, and by the fact that their frontal area was wider due to their larger upper limbs amplitude. In addition, the novices' shoulder was nearer to the snorkel, as they were privileging breathing and were not as used to submerge their head as elite finswimmers. They did not take advantage of buoyancy to balance their upper limbs. Note that underwater, the undulatory motion starts from the hip down to the ankle (Baly et al., 2002), whereas at the surface this motion basically starts from the shoulder for novices.

Regarding gender, females were slower than males, and their stroke frequency was lower. Females' upper limbs oscillation was larger, while that of the lower limbs was smaller. In spite of such a large lower limbs oscillation and an important knee bending, males were faster than females. They appear to take most advantage of the maximal acceleration generated at the moment of down-kick than female (Tamura et al., 2002).

The experts' vertical amplitude at the ankle was larger than for novices irrespective of the race distance. Likewise, thanks to the stabilizing role of the upper limbs and the resulting streamlining, the energy gained and stored was used to increase the ankle vertical amplitude. Therefore the speed reached by male finswimmers might be due to the potential energy generated by the wrist amplitude, which is transformed in kinetic energy and transmitted caudally, in the line of the suggestion made by Sanders et al. (1995). That amplitude increased from hip to ankle in elite finswimmers, particularly on 800 m, suggests a whip-like action (Ungerechts, 1982). Both the reduction of frequency and the rising of ankle amplitude induced a relief in the foot pain resulting from the friction and the rigidity of the monofin. Nevertheless, standard monofin with specific length and rigidity allowed to reach an amplitude and a frequency most adept to the race. As suggested by Videler and Kamermans (1985) for dolphins, elite finswimmers seem to beneficiate from a large propellant area and to accelerate during downstroke, which they optimized by setting both a gliding and a propellant phase. Interlimb dissociation allowed elite finswimmers to reach and to preserve their high speed and to achieve the best performance.

Expert male finswimmers exhibited a smaller knee bending than females of the same expertise and than male novices, inducing a limitation in frontal drag. Indeed, at the surface, the body has better be always profiled.

In comparison to underwater results reported by Baly et al. (2002), the experts' upper limbs were used as a stabilizing device at the surface too. For novices however, an efficient oscillation starts at the shoulder level at the surface, whereas it starts at the hip level underwater. Stroke frequency at surface is higher than underwater for the same race distance, whereas the ankle amplitude is bigger. For both surface and underwater swimming, hip and knee amplitude of oscillation is almost similar. Interestingly, our out-water camera did not record any marker. This suggests that even in surface swimming, finswimmers tended to operate in a quasi-underwater situation, probably because underwater swimming is faster than doing so at the surface. The ankle amplitude was larger underwater than at the surface, despite the lower hip angular excursion. Such results may be understood by the larger mass of water efficiently used underwater.

CONCLUSIONS

Finswimmers cannot get away from body streamlining in order to reach high level of performance through the adaptation of stroke frequency and motion amplitude to the constraints of a race at the surface. Elite male finswimmers achieve such a feat thanks to a weaker knee bending and a low upper limbs pitching, reducing concomitantly their frontal area and drag. Moreover, they optimally transform potential energy into kinetic energy during stroke cycles and transfer it caudally, tantamount contributing to a propulsive whip-like action. Expertise may be conceived as taking advantage of the mechanical constraints pertaining to hydrodynamics in order to optimize performance. This empirical study represents a first if incomplete step towards a more thorough modeling of finswimming.

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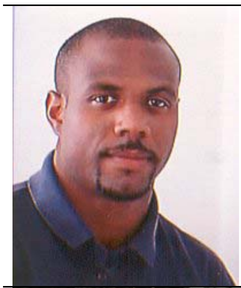

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KEY POINTS

- Finswimmers are at one and the same time a propelling and a propelled body. This study investigates the undulatory motion performed by finswimmers at the surface.
- Elite male finswimmers were pitching more acutely than female swimmers and showed a smaller knee bending than both novices and elite female swimmers.
- Finswimmers tended to perform a dolphin-like motion, which is used underwater situation and optimizes hydrodynamics.

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