INVERSE DYNAMIC MODELLING OF SWIMMERS IMPULSE DURING A GRAB START

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results of Sanders's report (3), emphasizing horizontal motion, rather than vertical motion. In other words, Sub. A generated the upward propulsive force through the lift force generated the foot sculling motion. In contrast, Sub. B performed the eggbeater kick emphasizing the vertical motion, and generating the propulsive force mainly using the drag force. Almost half of the subjects in this study performed the eggbeater motion similar to Sub. B. This study did not clarify which motion was better for large propulsive force generations during eggbeater kick; however, it was suggested that there were two variants for the eggbeater kick—one emphasized the horizontal motion for the lift force and the other the vertical motion for the drag force.

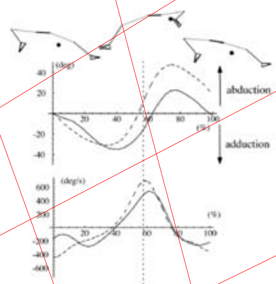

Figure 5. The left foot angle of abduction and adduction (upper) and the angular velocity (lower) of Sub. A (broken line) and Sub. B (solid line).

CONCLUSIONS

In this study, the magnitude of the rotational angle of the hip in the eggbeater kick was clarified performed by elite synchronized swimmers. The hip almost rotated internally during the eggbeater kick. In this study, the maximum internal angle ranged from 20.0° to 50.0°. It was considered that this internal rotation movement of the hip was reflected in the foot abduction and adduction movement that is expected to be very important for the generation of propulsive force to elevate the body. From the results of the analysis of the subjects who attains higher positions with regard the eggbeater kick, it was suggested that there are two variants of eggbeater kicks - one emphasizing the horizontal motion and the other emphasizing the vertical motion.

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INVERSE DYNAMIC MODELLING OF SWIMMERS IMPULSE DURING A GRAB START.

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Under race conditions, the start directly influences an athlete's performance. Taking into account the difficulties coming from the specific parameters relative to the start, comparing the swimmer's movement with the kinematic data stays the best approach to understand the motion. The model of the present work was developed through this approach allowing us to predict the swimmer's performance (trajectory, velocity) and the joint moment of each articulation during the impulse phase of the grab start. This model defines kinematical and dynamical data with the following mean dispersions: 9 % for horizontal and total speed at the instant of take off, 1 % for the swimmer's internal joint power. By means of this model, it becomes possible to analyze and understand the joint moment of each articulation and the segmental coordination for each swimmer performing a grab start.

Key Words: swimming, grab start, model, performance, joint moment, energy cost.

INTRODUCTION

Regardless of the discipline, whether 100 m Freestyle, 200 m 4 strokes (medley), or other, the study of the swimmers' performances involves the identification of three technical phases: start, turns and strokes phases. An analysis of the temporal distribution of the races showed that the start phase accounts for 15 % and 7.7 % of total time, respectively for 50 m and 100 m freestyle events (1). In short distance races (50m and 100m) the start represents a particularly important factor. For instance, at the Athens Olympic Games (2004), the time separating the eight finalists in the men's 50m freestyle finals was 0.44 s, which represents 2% of the winner's total race time (21.93 s). This difference in performance among the finalists may result from the time lost during the start phase.

Several studies carried out since the 1970's have shown that the start depends primarily on the quality of the swimmer's impulse on the starting platform and also on the water glide (7). However, the studies carried out to date are often contradictory when it comes to defining the most efficient movement required to optimize the athlete's performance impulse. This may lie partly in the fact that there are no objective tools currently available to provide a precise and quantitative evaluation of the movements in situ. Although recent studies have been undertaken, using both dynamic and kinematic approaches, they do not yield additional information concerning the relationship between the swimmers' movements and their actual performance (7). Few studies have addressed the modelling (dynamic and/or kinematic) of the parameters that determine the performance according to the swimmers' movements during start phases (4). Thus, the modelling method used for the study of movements in others sports (skiing, etc.) seems the most effective approach as far as understanding movements and predicting performance is concerned (5). A model based on inverse dynamic was developed in order to predict the impulse parameters during grab starts. The study presented here aimed the evaluation of the precision of this model by comparing the predicted speed and power values with experimental data collected in situ.

METHODS

Four national level swimmers were instructed to perform a grab start. Subjects' average height and mass were respectively 183.5 cm (± 3.41) and 75.77 kg (± 3.89). Swimmers were equipped with passive markers fixed on each articulation. For each start, a high speed camera (125 frames.s^{-1}) was placed at the edge of the swimming pool, at a perpendicular angle to the athlete's trajectory. The camera recorded the swimmers' profile movements. At the same time, ground reaction forces were recorded using a force platform fixed on the starting platform in order to simulate real competition starts (figure 1). The sampling frequency was 1000 Hz. Speed of the swimmer's centre of mass was obtained by integration of its acceleration. For each start, the kinematical (camera) and dynamical (platform) data were synchronised (0.008 s accuracy).

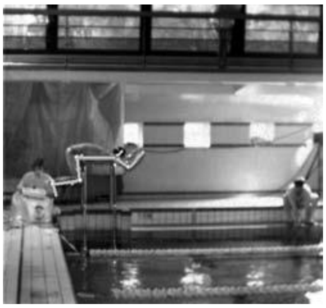

Figure 1. Image of recording a swimmer's impulse on the force platform by the high speed camera. In gray lines, segment's modelling using passive markers.

While the athletes were on the platform, a two-dimensional cinematography analysis was carried out during the impulse phase, in order to determine the angle between the subjects' segments (right side) and the horizontal axis. These data have been fitted using a polynomial method (6, 8). Morphological properties of the subjects are defined using their height, mass and the anthropometric tables of Dempster et al. (3). The sum of segment energies was obtained using the equations of sum of segment energies as defined in Winter (8).

During the impulse phase, subjects were represented using an open tree structure composed of eight straight segments connected with frictionless joints. Input data for the model consisted of the fitting angles calculated at each joint, and the subjects' morphological properties. For each joint, the dynamic torque, force and power were determined using the inverse dynamic equations (8, 5). Based on an analysis of the swimmers' forces and joint moments exerted during the impulse, the model predicts the total power of the subject during the impulse phase, as well as the speed, angle and position of the subjects' centre of mass at the instant of takeoff.

RESULTS

The model presented in this study was able to predict parameters that have also been collected from the force platform, with the following mean dispersions: underestimation of 9% (0.4 ± 1.1 m.s^{-1}) for horizontal and total speed, overestimation of 0.3 m.s^{-1} (± 0.15) for the vertical speed and overestimation of 4 degrees (± 3) for the angle between the vector tangent to the trajectory of subjects' centre of mass at takeoff and the horizontal axis (figure 2). The model was able to predict the swimmer's internal joint power observable using the video image and the time derivative of the sum of segment energies (8), with the mean dispersions of 1% (figure 3).

Subject	$V_{XGtakeoff}$		$V_{Zgtakeoff}$		$V_{Gtakeoff}$		$\alpha_{takeoff}$	
	a)	b)	a)	b)	a)	b)	a)	b)
1	3.56	4.09	0.38	-0.09	3.58	4.09	6.20	-1.35
2	3.92	4.25	-0.16	-0.35	3.92	4.26	-2.34	-4.82
3	3.75	4.14	-0.54	-0.66	3.79	4.20	-8.16	-9.16
4	4.10	4.44	-0.13	-0.44	4.10	4.47	-1.92	-5.73
mean	3.83	4.23	-0.11	-0.38	3.84	4.25	-1.55	-5.26
Sd	0.23	0.15	0.37	0.23	0.21	0.15	5.90	3.21

Figure 2. Swimmer's performance parameters: a) using the model; b) using force platform.
With: $V_{XGtakeoff}$: horizontal speed of the swimmer's centre of mass at take off (m.s^{-1}), $V_{ZGtakeoff}$: vertical speed of the swimmer's centre of mass at take off (m.s^{-1}), $V_{Gtakeoff}$: total speed of the swimmer's centre of mass at take off (m.s^{-1}), $\alpha_{takeoff}$: angle between the vector tangent to the trajectory of subject's centre of mass at takeoff and the horizontal axis (degree).

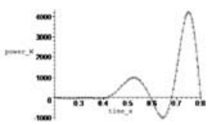

Figure 3. Swimmer's power: a) using the model (point); b) using the energies approach (line) of Winter (8).

DISCUSSION

This model makes it possible to consider joint moments resulting from the muscle activation during the movement (figure 4). These joint moments reflect the muscular activities of the subject (8). The main interest of this model lies in the possibility of analysing the individualised coordination of each segment of the swimmer.

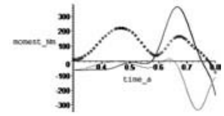

Figure 4. Joint moment of the hip (point), the knee (black line) and the ankle (gray line) during the impulse of a grab start.

The model still remains limited by the lack of the precision of the kinematics data and the lack of knowledge related to the morphological properties of the subject. The specificity of the measurement "in situ" imposes the use of passive skin fixed markers. The shifting of these markers during the subject's movement can differ from the anatomical centre of giration of each articulation and create a major source of error in the inverse dynamic estimations (2). This phenomenon is amplified by variations between the morphological properties of the segments resulting from the studies of Dempters et al. (3), and those specific to each swimmer. Using the same kinematical (video) and anthropometric data as input parameters, the estimations of the power developed by the swimmer resulting from the model and that resulting from the energy calculations (8) present a weak mean dispersion. This dispersion between the results of these two methods confirms the hypothesis that small errors in kinematic measurements will lead in mistakes in results obtained by the model.

CONCLUSION

The impulse model developed for a grab start is able to predict the swimmers' performance parameters using easy to install tools (only one camera). In the short term, this model should be able to provide more precise informations regarding the role played by joints in achieving the most effective grab start and to determine the swimmers' joint moments during the impulse phase. Future developments will increase the accuracy of the model and will contribute to the modelling and optimization of the most efficient movement strategies.

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