A SIMPLE MATHEMATICAL MODELING FOR KINEMATIC, DYNAMIC STUDIES OF SWIM TURN PERFORMANCES

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A simple mathematical modeling for kinematic and dynamic studies of swim turn performances has been suggested. Side camera was used to obtain timing, hip displacement, velocity and acceleration characteristics of push-off and glide phases in order to justify the proposed modeling. Five elite swimmers were analyzed for a pilot study. It was concluded that this modeling was reliable and useful for feedback to swimmers and coaches on fast and effective turn performances. Water resistance and average leg muscle forces, velocities and accelerations in both push-off and glide phases have been estimated and compared with the results obtained by the other researchers.

KEY WORDS: modeling, kinematic, dynamic, turn, swim performances.

INTRODUCTION: Few papers in the literature have dealt with the force applied by swimmers at push-off and its relation with the velocity gained after push-off, (Toshiaki et al., 2001, Blanksby et al., 1996, Lyttle et al., 1999, Nicol and Kruger, 1979, Walker, 1995). The force ranged from 600 to 1750 N. The human anatomy, physiology and skill of the swimmer is as important during the turn as in the free swimming stage of a race. The degree of segmental flexion during the pivoting and placement of the feet on the wall determines how effectively a swimmer can generate force for streamlined propulsion off the wall and the degree of resistance created which offsets the propulsive motions. The purpose of this study was to develop a mathematical model to estimate push-off force, velocity, acceleration and the water resistance coefficient, regardless the error introduced by hip and knee flexion associated with the kicking action. However, this error is mostly in the vertical direction, thus, estimating the horizontal velocity of a fixed point of the body and the push-off force may be regarded as reasonable for the purpose of providing a mathematical model.

METHOD: The model requires push-off time, glide time, push-off distance, and glide distance records. These records could be obtained from digitized video of the swimmer from an underwater view. A marker representing a fixed point on the body, such as the hip joint, can be used to represent whole body motion. Video data of swimmers may be collected in various ways provided that the camera is viewing from below the water surface. We collected the data for the development of the model described here using fixed camera. A JVC handicam sampling at 50 Hz was at 3m from the plane of motion of swimmers. A scale line has been used which comprised black markers positioned at 1m intervals on a taut cable directly under the midline of the swimmer and aligned in the direction of travel of the swimmer. The subjects wore a white body suit to maximize contrast of a black marker fixed in line with the hip point. The subject's hip markers were digitized and analyzed by APAS Analysis System.

MATHEMATICAL MODEL: Two separate phases; push-off and gliding, have been considered in our analysis. The water resistance has been considered as proportional to swimmer's speed (-CV), Sanders and Byatt-Smith, 2001, Shahbazi and Sanders, 2002.

1-PUSH-OFF PHASE

The motion equation can be written as following;

$$F-C1V=MdV/dt \qquad (1)$$

F is the average muscle force and C1 is water resistance coefficient. Integrating (1) yields;

$$V=(F/C1)(1-EXP(-C1\ t/M)) \qquad (2)$$

(2) shows that the swimmer velocity increases exponentially at push-off. On the other hand, as $C1\ t/M<1$, we can also get;

$$-(C1/M)\ t=-C1V/F \qquad (3)$$

At t=T, (T is the time after which swimmer gains the maximum speed), V=Vmax therefore from (3) we can get;

$$Vmax=FT/M \quad (4)$$

On the other hand, at Vmax, the acceleration is zero then from (1) we can get;

$$F=C1\ Vmax \quad (5)$$

Solving (4) and (5) for C1, yields;

$$C1=M/T \quad (6)$$

(6) shows that the water resistance coefficient is inversely proportional to push-off time. Inserting (6) into (2), we get for velocity;

$$V=(FT/M)(1\text{-}EXP\text{-}(t/T)) \quad (7)$$

The derivation of (7) yields the acceleration;

$$a= (FT^2/M)(EXP\text{-}(t/T)) \quad (8)$$

The average force can be extracted from (4);

$$F= (M\ Vmax)/T \quad (9)$$

2-GLIDING PHASE

In gliding phase, there is no muscle force, therefore (1) becomes;

$$C2\ V=MdV/dt \quad (10)$$

Integrating yields for velocity;

$$V= Vmax\ EXP\text{-}(C2\ t/M) \quad (11)$$

Vmax is the maximum speed gained by swimmer at the end of push-off. Replacing V by dX/dt in (11) and integrating yields for gliding distance;

$$X=(Vmax\ M / C2)(1\text{-}\ EXP\text{-}(C2\ t/M)) \quad (12)$$

When t increases, the exponential term vanishes and we can readily extract C2;

$$C2 =(M\ Vmax) / X \quad (13)$$

The water resistance coefficient in gliding phase is inversely depending upon the gliding distance.

Derivation of (11) yields the acceleration in gliding phase, which is caused by drag force;

$$a = -\ (V^2Max / M)(EXP\text{-}(Vmax\ t / X)) \quad (14)$$

The water resistance force can finally be given from (15);

$$R=V^2maxEXP\text{-}(Vmax\ t / M) \quad (15)$$

RESULTS AND DISCUSSION: The results indicate that mathematical model predict the coefficients of water resistance in both push-off and glide phases and also provide additional supporting evidence of the model's applicability to estimate the push-off force, velocity, and acceleration in both phases. Further, these characteristics were compared with those obtained by video filming and 2-D APAS Analysis System.

The primary purpose of this study was to confirm the accuracy of the mathematical model. Such a result may be easy to achieve with a 2-D Analysis System. In this experiment the calculated velocities and accelerations in two phases were compared with the results of 2-D System and also push-off force and water resistance coefficients have also been estimated. The comparison of data indicates if there were no systematic errors in 2-D System (because of the commercial cameras used), then probably both results would match better.

The necessity to accomplish turns in four strokes with 3-D System using CG instead of hip point is an imposed change of task specification characteristics to finalize the reliability of the model. Utilizing a more reliable Analysis System with no systematic errors and thereby using non-commercial cameras appears to be a robust biomechanic model.

The context of the performance environment in this study was unique compared to similar studies. Other studies examining push-off force, velocities and accelerations in both push-off and glide phases (Toshiaki et al., 2001, Blanksby et al., 1996, Lyttle et al., 1999). The force ranged from 600 to 1750) have utilized force platform fixed on the wall of the pool and more sophisticated cameras for turn performances. If subjects perceive, then they will be doing the turns for a period of time, they may tend to use a more economical and effective movement pattern, which is what the mathematical model is proposed to estimate.

In Figure 1a, the actual and theoretical velocities seem to have the same behavior unless that they are not matched completely. This is probably because of the fact that we have got a systematic error on our actual measurements, because of the commercial cameras were used with APAS System. In addition we have also applied a reasonable approximation on water resistance. The same fact can be seen on Figure 1b, regarding the push-off acceleration. In glide phase, the actual and the theoretical velocities are very similar and close together, Figure 1c, but the accelerations are not matched. The other reason may come from the fact that we have chosen a point on the hip, which has introduced the extra ondulations in our measurements.

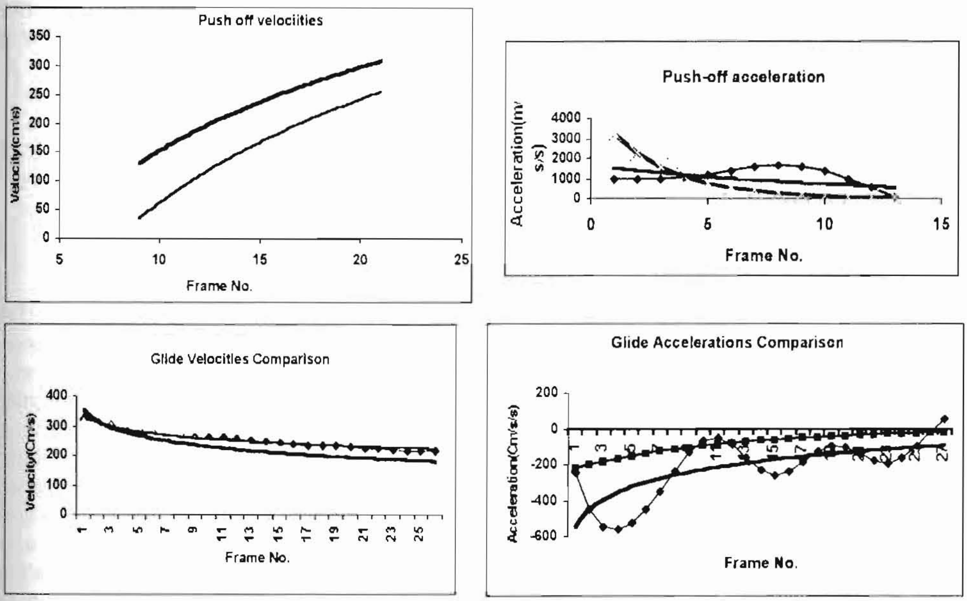

Figure 1 (a, b, c, d): In Figures a and b (top), the velocities and the accelerations at push-off are presented. In Figures c and d (bottom), the velocities and the accelerations in glide phase are presented and compared.

CONCLUSIONS: Relying on the assumption that approximating the water resistance as proportional to swimmer's velocity and proposing a mathematical model for turns, this study offers additional advantage of formulizing the variation of swimmer velocities and accelerations in two separate phases; push-off and gliding. These findings also highlight the dependence of average push-off force on the whole velocity. The actual and theoretical findings did not match completely because of the systematic error and the approximation applied in water resistance force. The necessity of using high quality cameras in place of commercial ones in actual measurements for justifying the theoretical model seems to be obvious.

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