OPTIMISING KINETICS IN THE FREESTYLE FLIP TURN PUSH-OFF

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INTRODUCTION: At the elite swimming level, the opportunity for performance improvements is relatively restricted. However, one possible area is to enhance turning efficiency throughout the push-off, glide and stroke resumption phases. However, little is known about the mechanics of an effective turn technique. The advent of vertically mounted forceplates has led to various studies investigating wall push-off kinetics, although the results of these studies were mainly descriptive in nature (Nicol & Kruger, 1979; Takahashi et al., 1982; Blanksby et al., 1996; Lyttle & Mason, 1997). In addition, measurement of the hydrodynamic parameters during wall push-off has not been studied. Analysis of the hydrodynamic drag during this phase is essential for a complete examination of this phase of the turn.

This study sought to provide an exploratory analysis of how the various kinetic and hydrodynamic variables during wall push-off are related to the wall exit velocity.

METHODOLOGY: Thirty experienced male swimmers with body types of within one standard deviation of the mean for selected anthropometric parameters reported for elite male adult swimmers (Mazza et al., 1994) were recruited for the study. Subjects performed freestyle flip turns with selected kinetic, hydrodynamic and kinematic variables of the wall push-off being recorded. Rather than the total wall contact time, this study examined only the time spent pushing off (active portion of wall contact), as the hydrodynamic drag is primarily a consideration only during this phase. This push-off time represented the period from the first forward displacement of the hips after wall contact until the feet left the wall.

Kinetics were recorded via a 2D vertically mounted forceplate which recorded peak push-off force, total push-off impulse and push-off time. The acceleration of each swimmer's centre of gravity (CG) during the push-off and the wall exit velocity of the swimmer's CG were calculated from underwater videography using a 60 fields/s SVHS camera. The underwater video and the forceplate were synchronised by a trigger, which initiated forceplate data collection and triggered a light emitting diode situated in the underwater camera view.

Calculations of the drag profile were then achieved by multiplying the CG acceleration (a_{CG}) by the mass of the swimmer (m), and subtracting the average propulsive force measured on the forceplate, for each 0.017 s interval ($F_{drag} = \sum_{i=0}^{i \to n} (m*a_{CG} - F_{prop.})$). Figure 1 outlines a sample profile of the measured variables during push-off. The use of a 2D forceplate limited drag profile calculations to the horizontal direction (direction of push-off). The drag measures used in the analysis represented the resistive force to the swimmer's motion (friction drag, form drag and wave drag) as well as the force used to accelerate the water surrounding the swimmer (added mass).

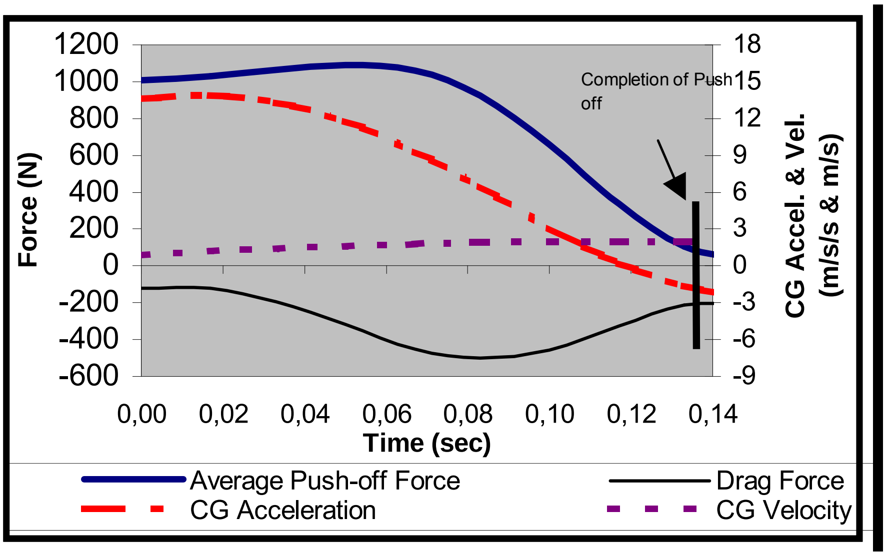

Figure 1. Sample profile of a freestyle turn push-off outlining the CG velocity and acceleration, and drag and average push-off forces.

A stepwise regression was used to determine the optimal combination of kinetic and hydrodynamic variables that could produce a higher push-off velocity. The CG velocity of the swimmer immediately after leaving the wall was used as the criterion variable. The wall push-off time, peak propulsive force, total propulsive impulse, peak drag force and total drag impulse were selected as the independent variables. Total wall contact time (WCT) was also recorded from the turning board to determine the proportion of the overall wall contact time spent pushing off.

RESULTS AND DISCUSSION: The means and standard deviations of the kinetic, kinematic and hydrodynamic variables are presented in Table 1. A reliability analysis was also performed on the acceleration data of one of the trials. The trial was digitised eight times and resulted in an alpha coefficient of 0.9946 and a standardised item alpha coefficient of 0.9953. Thus, high digitiser consistency was indicated.

Table 1. Means (M) and standard deviations (SD) for the measured variables (n=30)

Variable	**M ± SD**
Peak Propulsive Force (N)	1189.6 ± 246.0
Total Propulsive Impulse (Ns)	204.0 ± 54.9
Push-off Time (s)	0.218 ± 0.054
Total Wall Contact Time (s)	0.324 ± 0.040
Peak Drag Force (N)	-570.0 ± 238.0
Total Drag Impulse (Ns)	-62.6 ± 41.8
Final Push-off Velocity (m/s)	2.45 ± 0.45

The stepwise regression yielded three variables in the equation: push-off time, peak drag force and peak propulsive force (see Table 2) with a multiple R value of 0.80. Beta values (β) in the final model indicated that the peak drag force carried the highest weighting of the three variables. Total propulsive impulse and total drag impulse failed to significantly add to the regression equation.

Table 2. Results of Multiple Stepwise Regression. Final model: F(3,26)=15.5;p=0.00

Order	**Variable**	**Correlations**		**B**	**β**
		Push-off Time	Peak Drag Force		
1	Push-off Time	1.00		5.71	0.69
2	Peak Drag Force	-0.08	1.00	0.00	1.15
3	Peak Prop. Force	-0.18	-0.77	0.00	0.93
	Constant			0.42	
Multiple R = 0.80; R Square = 0.64; Adjusted R Square = 0.60					

The stepwise multiple regression revealed that the wall push-off time was the best single predictor (R=0.42) of a swimmer's velocity immediately after leaving the wall, accounting for 18% of the variance. The positive correlation indicated that longer wall push-off times resulted in faster final push-off velocities for the swimmers. A rapid push-off might not allow sufficient time to develop an optimal impulse, thus reducing the potential to effectively increase the acceleration of the CG. Peak drag force was the second factor in the stepwise regression (R=0.59; R^2=35%). Since the drag forces were recorded as a negative force, a positive correlation indicated that the less negative (or smaller) the drag force, the higher the swimmer's final push-off velocity. The inclusion of the peak drag force in the regression equation highlights the importance of drag in turning technique. Factors such as high push-off forces or exaggerated movements may lead to higher peak drag forces which, in turn, may be detrimental to the overall turning performance.

The third and final factor to be included in the stepwise regression was the peak propulsive force (R=0.80; R^2=64%). This indicated that a higher peak push-off force resulted in a higher final velocity for the swimmer. A higher peak force results in higher instantaneous acceleration and therefore higher push-off velocities. However, this only applies if drag force is not appreciably increased simultaneously. As such, a trade-off exists where too high a peak push-off force is likely to create an excess peak drag force. This is evidenced by the significant negative correlation between peak push-off force and peak drag force (R= -0.77, p=0.00).

The total push-off impulse and total drag impulse did not add significantly to the ability of the regression equation to predict the final push-off velocity and were not included in the final regression equation. Blanksby et al. (1996) also reported that the swimmer's impulse on the wall did not add significantly to the ability of a stepwise regression equation to predict 5m round trip time. The failure of the push-off impulse to add significantly to the regression equation cannot fully be explained but may add support to the idea that push-off force should be developed gradually.

Despite push-off time being included in the regression equation first, the final model indicates that this variable had the lowest weighting once all three variables were included. Peak drag force recorded the highest weighting followed by peak propulsive force. In essence, the weightings reveal that the peak drag force is the most important of the three variables in the regression equation, because it has the greatest ability to predict the swimmer's final push-off velocity. Hence, attempts to improve the swimmer's final push-off velocity should not be at the expense of increasing the peak drag experienced by the swimmer. A streamlined transition from a flexed position at the start of push-off to a fully extended position at the end of push-off is necessary also to prevent excess drag from being produced (Clarys

1979). This could explain previous findings that the larger the tuck index during a flip turn (ie. straighter legs), the faster were the turn times (Blanksby et al., 1996).

To optimise the swimmer's push-off velocity, all of the variables in the regression equation should be examined together, rather than focussing on each variable individually. The stepwise multiple regression yielded the combination of variables which produced the highest velocity of a swimmer's CG. An optimal combination of a low peak drag force, high peak propulsive force and a wall push-off time of sufficient period to develop this force are required. Only a turn that satisfies all of these criteria will result in a high push-off velocity.

An optimal balance is therefore required between the amount of peak push-off force, time spent pushing off the wall and the resultant peak drag that is produced. Also, the size and timing of the peak drag force plays a major role in determining the final velocity. If the peak propulsive force is developed early in the push-off, peak drag could also occur early, decelerating the swimmer prior to the feet leaving the wall. It may be advantageous for swimmers to plant the feet after the forward somersault and gradually develop force. This will allow peak force to be achieved closer to leaving the wall without excessive drag being developed prior to this point. An advantage of the peak drag occurring closer to toe-off is that the swimmer is in a more streamlined position and is therefore subject to less form drag.

CONCLUSIONS: Turning technique is an important component in overall swimming performance, with turn times positively correlating with the final event times. Until recently, little was known about the wall push-off mechanics during freestyle turns. The results of this study indicate that an optimal combination of low peak drag forces, high peak propulsive forces and increased wall push-off time are conducive to a high push-off velocity for the swimmer.

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