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### Biomechanical Factors Influencing Tumble Turn Performance of Elite Female Swimmers

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The aim of this study was to examine the effects of kinematic and dynamic parameters on the turn performance (3mRTT). Eight elite female swimmers were analysed during a crawl tumble turn at maximum speed. The movements were filmed using 5 underwater cameras and a 3D force platform recorded wall forces. Results showed that the time of maximum horizontal force and the glide duration were related to the performance criterion. The best female swimmers were able to develop maximal horizontal force earlier during the push-off phase. Further studies with an extended population (elite male and less-skilled female swimmers) would analyse the effects of more parameters, especially from the contact phase.

#### Key words: Swimming, Kinematics, Dynamics, Turn, Performance

#### INTRODUCTION

In elite swimmers, only few opportunities are available to improve performance. Swimming performance can be defined as the time taken to complete a race. It can be subdivided into starting, stroking and turning.

Turns represent a paramount factor for determining the final performance of a swimming race. Blanksby et al. (1996) and Cossor et al. (1999) reported significant correlations with 50 m freestyle times and both 2.5 m (r = 0.72 to 0.85) and 5 m (r = 0.90 to 0.97) round trip times (RTT). In addition, Blanksby et al. (1996) found that the fastest and slowest young freestyle swimmers differed significantly between the 50 m time and these two measures of turning performance (2.5m and 5m RTT). Chow et al. (1984) found that the correlation between the total turn time and the event time increased with the distance of the event. It is noticeable too that turning is faster than stroking (Blanksby et al., 1996 and 2004).

A successful swim turn results from a multitude of factors and requires a complex series of moves to optimise the total turning performance. The freestyle tumble turn can be divided in the approach, rotation, wall contact, glide, underwater propulsion, and stroke resumption phases. For the contact phase, Prins and Patz (2006) distinguished passive ("braking") and active ("push-off") sub-phases. Lyttle et al. (2000) studied gliding position and kicking technique and established an optimal range of speeds (1.9 to 2.2 m/s) at which to begin underwater propulsion in order to prevent energy loss from excessive active drag.

The first aim of this study was to analyse relations with both kinematic and dynamic factors from each phase and the 3 m round trip time (3mRTT) as measure of turning performance. The second aim was to develop a model for performance using a stepwise multiple regression.

#### METHODS

Eight elite female swimmers participated in this study (Table 1).

Table 1. Swimmer's general characteristics (n = 8, SD: standard deviation, WR: world record, PB: personal best).

|      | Age (years) | Body mass (kg) | Height (cm) | 200 m freestyle<br>WR / PB (%) |
|------|-------------|----------------|-------------|--------------------------------|
| Mean | 22.3        | 62.2           | 174.7       | 96.73                          |
| SD   | 4.1         | 6.2            | 5.8         | 2.25                           |

The swimmers were analysed during a crawl tumble turn at maximum speed, when passing through a specific pre-calibrated space with mean dimensions of 4.2 x 1.1 x 1.9 m for the horizontal (main movement direction), vertical (pool depth) and lateral (lane width) directions, respectively placed in contact with the turning wall and the water surface. Five stationary mini-DV video cameras (Sony DCR-HC62E and DCR-HC96E) were located underwater at different depths in waterproof cases. The angle between axes of adjacent cameras was approximately 45° and the five cameras were located on a semi-ellipse centred on the turning wall. Twelve to 14 calibration points were used, and the synchronization of the images was obtained using an underwater strobe flash (Epoque ES-150 DS  $\alpha$ ) visible in the field of each video camera. An underwater piezoelectric 3D force platform (Kistler 9253B12) was also mounted on the turning wall recording at a frequency of 2000 Hz. One complete turn was analysed for each swimmer. The testing session took place in a 50 m indoor pool.

The anatomical reference points of interest were digitized manually, frame by frame (at a frequency of 50 Hz). The points digitized for each camera were: centre of the skull (head), shoulders, elbows, wrists, fingertips, hips, knees, ankles and tiptoes. Image coordinates were transformed to 3D object-space coordinates using the Direct Linear Transformation algorithm (Abdel-Aziz & Karara, 1971). Reconstruction precision of calibration points was  $14.1 \pm 9.1$  mm with a maximal error of 42.8 mm. Missing coordinates were interpolated by a cubic spline function and then smoothed by the Savitzky-Golay filtering method (interpolation order: 2, window size: 13).

The kinematic data were the horizontal velocity of the head at the beginning of the turn (when the head was 3 m before the wall, VIn in m/s), 1 m before the rotation phase (V1mR in m/s), at the beginning of the rotation phase (VR in m/s), at the maximum horizontal force peak (VPe in m/s), at the end of the push-off (VG in m/s), at the end of the glide (VU in m/s) and at the end of the turn (when the head was 3 m after the wall, VOut in m/s). The delimitation between the approach and the rotation phase was determined when the swimmer increased her head depth (vertical displacement). The horizontal position of the head when rotation began was also computed (RD in m). The end of the push-off (synchronisation point with dynamic data) and the delimitation between the glide and the underwater propulsive phase was obtained by observing video data. This time ended the glide duration (GT in s).

The dynamic data recorded were: maximum horizontal force peak (Pe in N) and final contact time (synchronisation point with kinematic data). Vertical and lateral forces helped to discern the first contact time and the delimitation between the braking and the push-off phases. PeT (in s) was the time between the beginning of the push-off and the maximum horizontal force peak. %PeT (in %) was the ratio between PeT and the push-off duration (PoT in s).

Pearson correlation and linear regression tests were used to identify the relationships among the tumble turn performance criterion (3mRTT as the time taken to swim from 3 m in to 3 m out the turning wall, in s) and both kinematic and dynamic factors. The level of significance was set at 95 % (p<0.05).

#### RESULTS

High correlation coefficient values were observed between 3mRTT and GT (r = 0.82, p = 0.044), %PeT (r = 0.75, p = 0.031), PeT (r = 0.72, p = 0.044), and V1mR (r = 0.71, p = 0.046, Figure 1).

The best model was  $3mRTT = 0.817 \times GT + 0.155 \times PeT + 2.464$  (F =  $38.1, r_{adi}^2 = 0.91, p < 0.001$ ).



Figure 1. GT, PeT, %PeT, and V1mR as functions of the tumble turn performance.

#### DISCUSSION

The major aspect of this study was that the best female swimmers (with turning time as criterion of performance) were able to develop their maximal horizontal force earlier during the push-off phase. This result should be compared to the model of Klauck (2005) who presented that a later maximal horizontal force leads to a maximal speed at the end of the push-off phase. No significant correlation existed between VG and PeT. Klauck suggested that peak force should occur close to the end of the push-off i.e. at full leg extension. This model could be discussed about its biomechanical pertinence. Takahashi et al. (1983) reported indeed that the knee joint was at about 120° of flexion when peak force was observed during the push-off phase of the tumble turn. These researchers also stated that peak force during the vertical jump was observed at a similar range of motion (120-140°). Hence, Blanksby et al. (1996) suggested that coaches should implement leg strength and power programmes to decrease the time to achieve peak force.

The correlation between 3mRTT and V1mR showed that increasing speed at the start of the turn tended to decrease the time taken to complete the turn. This idea is well accepted by swimmers and coaches who claim to "attack" the wall.

A stepwise multiple regression was computed to seek the best possible predictors of the 3mRTT. The results indicated that the best predictors were GT and PeT. The role of PeT was discussed just above. It could be surprising that 3mRTT and GT were showing the same tendencies: shorter glide resulted in a better turn. Lyttle et al. (2000) established an optimal range for VU and only one of our swimmers ended gliding above these speeds.

#### CONCLUSION

The purpose of this study was to examine the effects of kinematic and dynamic parameters on the crawl tumble turn performance. Results showed that the time of maximum horizontal force is preponderant. The glide phase is also critical. In the future, it would be interesting to analyse the effects of more computed parameters, especially during the contact phase (e.g. impulses and push-off angles) and to extend the population (recreational female swimmers and elite male swimmers). More subjects with the same protocol may help to provide a deeper understanding of turning performance and develop a new hypothesis about the swimming level (which could affect the ability) or the gender (which could have an effect upon physical factors).

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