Development of a pressure sensor for swimming turns

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Abstract

The turn has been identified as a key factor in swimming performance in all events over 50m in length, long course and 25m, short course, with turn time being positively correlated with swimming performance. The turn (time taken from 5m into and 10m out of the wall) has been found to contribute 21% of the overall race time for the 200m freestyle, where a 1% increase in turn performance would have resulted in the swimmer who finished third in the 200m freestyle Olympic final taking gold. Within competitive swimming the tumble turn is the preferred method to change direction when swimming freestyle. The tumble turn has been described as the movement of the body around a nearly horizontal transverse axis followed by a twisting action about the longitudinal axis as the swimmer pushes off the wall. Within the literature the turn has been split into five separate stages, approach; the turn; the push-off; the glide; and the pull-out. This paper focuses on the push-off stage of the turn, looking at the angle of the feet at push off, contact time and peak force. Current literature within this area focuses on peak force and impulse, but there is a lack of data regarding the foot positioning on the wall and its affect on performance, resulting in two conflicting stand points on turn technique. These differences in opinion are concerned with where in the turn you should rotate the body 180° about the longitudinal axis, whether it should be prior to foot contact or after, in the push off phase. this paper details the research and development of an automated system that enables in depth analysis of the contact and push off phases of a swimming turn, including contact time, foot orientation, distance between feet, and lane position, and a case study where the sensor has been used.

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1. Introduction

The turn has been identified as a key factor in swimming performance in all events requiring the swimmer to travel further than the length of the pool, with turn time being positively correlated with swimming performance [1]. For all four strokes and the individual medley there are specific turn techniques, which are both within the rules set by FINA (The Federation Internationale de Natation Amateur) and considered to be the most efficient.

Within competitive swimming the tumble turn is the preferred method to change direction when swimming freestyle. The tumble turn has been described as the movement of the body around a nearly horizontal transverse axis followed by a twisting action about the longitudinal axis as the swimmer pushes off the wall [2]. Within the literature the turn has been split into five separate stages, the approach; the turn; the push-off; the glide; and the pull-out [3].

The first stage within the turn, the approach, refers to the final stroke, where the main aim is to maintain swimming speed whilst setting the body in the correct position to turn. Throughout the final stroke the non-pulling arm is kept in the water beside the hip. Once the final stroke is completed the swimmer enters the turn phase, this is initiated through flexion of the head and a small dolphin kick to encourage forward rotation. As the swimmer begins to rotate, flexion of the knees and hips allow the knees to be brought up to their chest, reducing the moment of inertia about the axis of rotation (transverse axis), making it easier to rotate. During the turn phase the swimmer should encourage a slight twist by turning the head to the side in the second half of the summersault, enabling the feet to be planted on the wall with their toes facing up and out. As the turn phase is completed the arms need to be in an extended position, encouraging a streamlined position ready for the push-off and glide stages. Once the swimmer has completed the turn phase, the push-off stage commences, this stage is initiated by foot contact with the wall and finished at toe-off. According to [4] the feet should contact the wall at a depth of 0.3-0.4m, with the knees at an angle in the region of 110°-120° [5]. The push-off consists of a maximal extension of the knees, hips and ankles', to maximise the propulsion of the swimmer the ankles, knees and hips need to be aligned. As the swimmer leaves the wall and enters the glide stage of the turn, they will complete the twist action about the longitudinal axis in preparation for the pull-out stage. According to previous research the glide phase should be performed at a depth of 0.4-0.5m to minimise drag effect [6], which can be directly linked to improved turn time. Throughout the glide phase the swimmer must maintain a streamlined position to minimise the deleterious effect of drag on performance. Finally the pull-out phase is initiated by underwater kicking leading into the first stroke cycle. The underwater kicking technique can vary between a dolphin leg kick and a freestyle flutter kick. Generally the dolphin kick is the preferred technique as it has been found to minimise the deceleration during the pull-out phase [7]. To maximise performance the swimmer needs to recommence the stroke cycle prior to their speed dropping below that of their swimming speed, as this has been found to increase energy expenditure and to have a negative effect on swimming performance.

Current research has focused on the velocity and time into the turn [8], rotation phase regarding the tuck index [9,10], foot contact time and perpendicular force [10,11,12], velocity out of the turn [10] and stroke preparation phase (resumption time and distance) [10]. However, there is lack of data regarding the foot positioning on the wall and its affect on performance, resulting in two conflicting stand points on turn technique. These differences in opinion are concerned with where in the turn you should rotate the body 180° about the longitudinal axis, whether it should be prior to foot contact or after in the push off phase.

Therefore, this paper details the research and development of an automated system that enables in depth analysis of the contact and push off phases of a swimming turn, including contact time, foot orientation, distance between feet, and lane position. Two areas of development were undertaken to
enable a robust sensor suitable for a harsh environment, such as that experienced in a swimming pool, and algorithm development.

2. Sensor Selection

It was determined that a thin filmed pressure sensor would be utilised within this study, as this would allow more in depth information regarding the positioning/orientation of the feet throughout push off than other technologies such as strain gauges, force transducers and cantilever beams, whilst minimising the effect on pool length. There are a range of commercially available thin filmed sensors available on the market including Tekscan, Novel and X-Sensor. To determine the best sensor for this application a cross comparison of the three sensors was conducted. The specifications of the sensors were compared to the minimum required for this testing. From this analysis, it was determined that the X-sensor would be the most appropriate measurement system for this analysis, due to excellent hysteresis and drift performance, whilst maintaining accuracy at the same level as the other types of sensors. Another advantage of the X-sensor is its ability to hold its calibration, enabling the entire testing to be completed without recalibrating the sensor. Another decisive factor was the number of sensing elements, as the X-sensor can have up to 10,000 sensing elements per sensor, which allows good spatial resolution even for a large sensor.

After comparing the different types of sensor, it was determined that an X-sensor pressure mat would be used within this testing, utilising a custom made PX100 40-64-02 sensor with dimensions of 700 mm by 1000 mm (Fig.1). The sensor had an operating pressure range of 0.7-20 kPa, incorporating 2480 sensing points with a resolution of 1.5 cm, which could be sampled at 50 Hz.

Fig.1. X-sensor pressure mat.

One main negative with these sensors is that they are not waterproof. Therefore, the sensor needed to be waterproofed and mounted on a stiff back plate to make the measured pressures representative of those exerted on the wall. This was done by encasing the sensor in a dry-bag, which was then mounted on a 6mm thick piece of polycarbonate and covered by a rubber sheet, to make the surface look like the end of the pool. The polycarbonate was mounted in a 30mm x 20mm x 3mm stainless steel angle frame to minimise bending when impacted and suspended on two stainless steel poles to allow for height adjustment.
3. Algorithm Development

To determine contact time, foot position and orientation, an image processing algorithm was developed. The pressure data was separated into individual frames. The contact phase was using a threshold of 10.3kPa, to remove noise from the data, contact time was calculated as:

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\text{Contact time} = \text{Number of frames where contact pressure was above 10.3 kPa}
\]

Once the contact phase was identified within the data, the data for each frame was turned into binary image with all values >10.3kPa given a value of 1 and all pressure values <10.3kPa given a value of 0. The conversion of the pressure data into a binary image allowed the edge of the foot print to be identified and in turn the centre of each foot to be located. The centre position of each foot was then used to calculate the position of each foot relative to one another (Fig. 2) and relative to the top left sensor which was in a known location within the swimming lane.

Fig. 2. Example of how foot angle and depth were calculated.

4. Sensor Testing

The sensor was tested by two swimmers to ensure that the waterproofing of the system and the algorithm were robust. The pressure sensor was suspended against the wall in the centre of the lane with the centre of the pressure pad located 300mm below the water surface, as this has previously been identified as the ideal foot depth [6]. Two swimmers completed 5 tumble turns on the pressure sensor. Using algorithms developed in MatLab, the contact phase of each of the turns was analysed in terms of contact time, foot angle (angle between the centre of the two feet in relation to the horizontal, horizontal and vertical distance between the centre point of the feet, and absolute vertical and horizontal distance (the distance from sensor 1 (top left of the sensor) which is at a known position in the pool).
5. Results

Two swimmers were analysed using the pressure sensor (Fig 3), swimmer 1 was an elite swimmer and swimmer 2 a recreational swimmer. It was found that using the pressure sensor and algorithm, that the contact time, foot position and orientation could be calculated. The results showed that for both swimmers there was no significant differences in contact time (Fig 3 (a)), 0.314 and 0.315 ($p > 0.05$) respectively, however, there was significantly greater variation in contact time for swimmer 2 (0.1 s) when compared to swimmer 1 (0.016 s) ($p < 0.05$). The foot angle data (Fig 3 (b)) identified a significant difference in average angle ($p < 0.05$) and variation ($p < 0.05$) between the two swimmers, with swimmer 1 having a mean foot angle of $87^\circ$ ($\pm 7.67^\circ$) compared to swimmer 2, where the mean foot angle was significantly lower and more varied at $67^\circ$ ($\pm .14^\circ$). Swimmer 1 was also found to be more consistent in terms of the distance between the feet, with an average horizontal (Fig 3 (c)) and vertical distance (Fig 3 (d)) of 99.2 mm ($\pm 15.10$ mm) and 140.40 mm ($\pm 20.62$) respectively, compared with 90.3 mm ($\pm 26.88$ mm) and 108.62 mm ($\pm 45.77$ mm) for swimmer 2. In terms of absolute foot position (Fig 3 (e) and (f)) no significant difference was found between the 2 swimmers in terms of horizontal distance ($p > 0.05$), however, swimmer 1 was found to plant the feet with significantly more consistency, 263.24 mm ($\pm 12.81$ mm) compared to 261.62 mm ($\pm 33.54$ mm) for swimmer 2. Finally, a significant difference was found between the 2 swimmers in terms of foot depth for swimmer 1 and 2, 278.63 mm ($\pm 5.08$ mm) and 246.23 mm ($\pm 39.41$ mm) respectively, with swimmer 1 placing the feet closer to the 300mm mark with more consistency. These results have identified that although there were only subtle differences found between the contact phase of the turn between an elite and recreational swimmer in terms of average contact time, foot position and orientation, the key difference was the consistency of the turn technique.

6. Discussion and Conclusion

The development of a turn pressure sensor and analysis algorithm has been discussed. It was found that this sensor could be robustly used to analyse the contact phase of the swimming turn. The algorithm can be used to compare swimmers performance, in terms of on an individual basis or between swimmers. Future work should include the development of a higher rated pressure sensor, enabling peak force to be calculated. Also, the system should be integrated with a motion tracking system to allow a more comprehensive analysis of the effect of the contact phase on overall turn performance. The main limitation of this study was the number of subjects used, to gain a fuller understanding of the differences between elite and novice swimmers a larger data set is needed.
Fig. 3. Average of all 5 turns ±1 standard deviation for swimmers 1 and 2 for (a) contact time, (b) foot orientation, (c) horizontal distance between feet, (d) vertical distance between feet, (e) horizontal absolute position of feet and (f) vertical absolute position of feet.

References


