AN INVESTIGATION IN THE USE OF A PRESSURE MAT TO MONITOR TURN PERFORMANCE IN SWIMMING

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A purpose built pressure mat was designed and developed by Loughborough University in order to characterise the wall contact phase of swimming turns. In-house software enabled information concerning horizontal and vertical foot locations as well as orientation of the feet, wall contact time and peak force data that was extracted automatically. Two elite male swimmers on two separate days performed three maximal effort turns that resulted in similar values for wall contact time, peak pressure, as well as vertical and horizontal locations on the wall. Subject two produced greater peak forces (1.69 and 1.76BW) than subject one (1.34 and 1.20BW). Future testing will use larger subject numbers to obtain the statistical significance of the measured values.

KEY WORDS: swimming, turns, pressure.

INTRODUCTION: Swimming turns can be divided into a number of different phases including the approach, rotation, wall contact, underwater and stroking phases (Lyttle & Benjanuvatra 2007) within the 15m distance measured during competitions. The approach phase is defined as the time from the head passing the 5m distance into the wall until the last hand entry in freestyle (FR) and backstroke (BK), or the hand touch in breaststroke (BR) and butterfly (BF). The rotation is defined as the period from the end of the approach phase until the feet touch the wall in all turns while the wall contact phase is the period of time that the hands and/or feet are in contact with the wall. As the swimmer leaves the wall after the turn they glide and kick in the underwater phase before commencing stroking through to the 10m mark from the wall. Improvements in any one of these phases can affect the overall race result during competition (Slawson, Conway, Justham, Le Sage & West, 2010).

Turning technique in swimming has been measured extensively to date using *vision systems*, (Tourny-Chollet, Chollet, Hogie, & Papparodopoulos, 2001; Prins & Patz, 2006; Slawson et al. 2010; Slawson, Conway, Justham & West, 2010; Kishimoto, Takeda, Sugimoto, Tsubakimoto, & Takagi, 2010; Pereira, Ruschel, Souza, Araujo, Goncalves, Fernandes, Roesler, & Vilas-Boas, 2011) *force platforms* (Lyttle & Mason, 1997; Blanksby, Simpson, Elliott, & McElroy, 1998; Cossor, Blanksby, & Elliott, 1999; Lyttle, Blanksby, Elliott, & Lloyd, 1999; Blanksby, Skender, Elliott, McElroy, & Landers, 2004; Araujo, Pereira, Gatti, Freitas, Jacomel, Roesler, & Vilas-Boas, 2010; Puel, Morlier, Mesnard, Cid, & Hellard, 2010) and *tethered devices* (Lyttle et al., 1999; Lyttle & Blanksby, 2000; Lyttle, Blanksby, Elliott, & Lloyd, 2000; Lyttle & Benjanuvatra, 2007) but no testing results have been reported in the literature regarding the use of pressure mats in swim turn testing.

The benefits of using a pressure sensor mat rather than a force platform includes: cost, portability, protrusion of the sensor on the wall, and information available. Force platforms used in turn analysis can comprise single or multiple axis transducers in order to measure the overall force, impulse and centre of pressure during the wall contact phase. Pixelated pressure sensor mats enable forces to be measured for each leg individually to enable a greater understanding of their relative contribution to turn performance. Information on vertical depth from the water surface, horizontal distance between feet as well as the orientation angle between the two feet can be measured using this technology. The aim of the present study was to use a novel method of measuring swimming turns that enabled both individual and combined values from the left and right legs to be reported.

METHODS: A custom, high pressure sensor mat with flexible design (XSENSOR model IX500:40:64.02) with an active area of 51cm x 81cm was encased within a waterproof bag and then attached to a rigid polycarbonate backing for mounting on the pool wall. Velcro strips on the rear of the pressure mat allowed for changes in the position of the sensing area on the wall in relation to the surface of the water. The sensor array included 2,560 individual sensor elements with a resolution of 12.7mm in both the vertical and horizontal directions. Data were sampled at 40 Hz with a pressure range of 10-200psi. Two elite male swimmers performed multiple swimming turns over consecutive days in order to evaluate the repeatability of the pressure mat data and associated analysis and visualisation software. Swimmers were required to conduct three maximal effort turns on their best stroke in each of the testing sessions to ensure that the data was consistent for each swimmer.

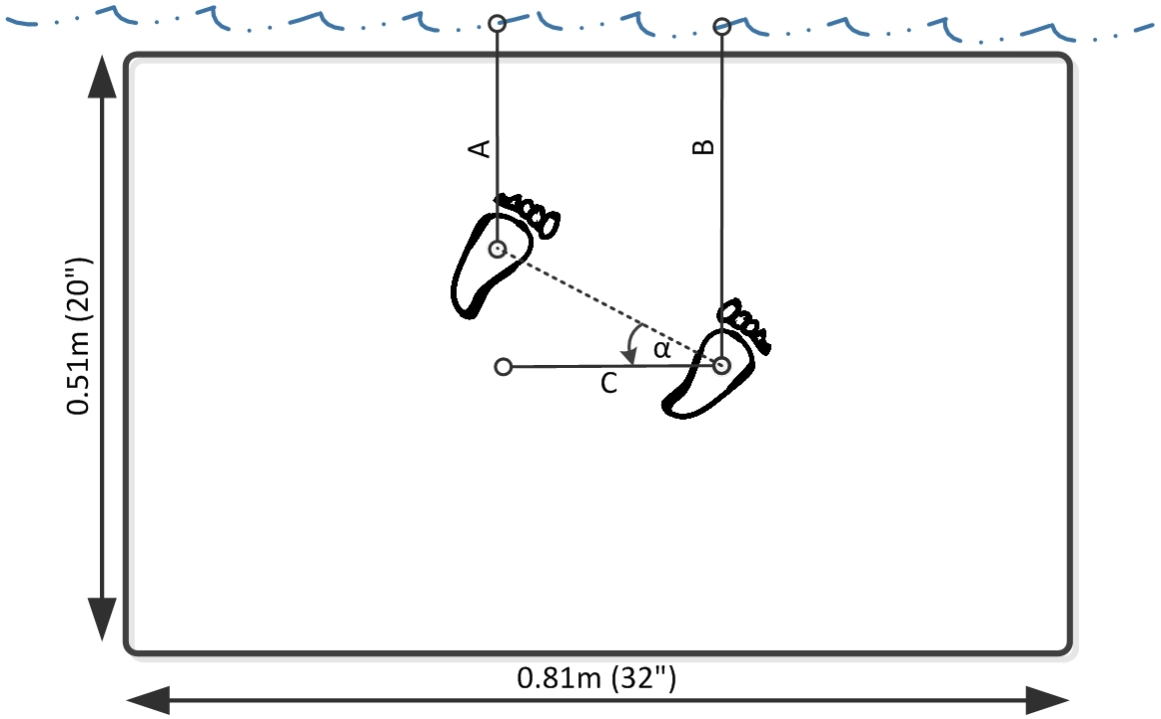

Figure 1: Schematic of the feet contacting the sensor area of the pressure mat.

The measurement area of the pressure mat with two feet contacting the wall is seen in Figure I. The left foot vertical distance from the surface of the water is line A while the same distance for the right foot is represented by line B. The horizontal distance between the two feet is line C and the orientation angle between the feet is shown as α in Figure 1. Peak pressure and wall contact time (WCT) were also measured while a fixed Sony HQ2 camera operating at 25Hz was also used to obtain the WCT results from the pressure system. Values derived from the pressure mat were used in the final analysis due to the higher capture rate compared to that of the camera. Force was derived from the pressure data using the equation: $F = P.A$ [1]
where *F* is force, *P* is pressure and *A* is the contact area. Details on the methodology used to calculate the distances and angles can be found elsewhere (Chakravorti, Slawson, Cossor, Conway, & West, 2012).

RESULTS: The mean and standard deviations of the three trials performed by each swimmer on both of the two testing sessions are shown in Table 1. The distance (in cm) from the surface of the water to the left and right feet is also noted along with the horizontal distance between the two feet at wall contact. The orientation angle in degrees provides an indication of the position of the two feet on the wall. Subject one performed freestyle turns while subject two performed backstroke turns as these were their preferred strokes. Subject one had a mean WCT of 0.25 s on the first session and 0.30 s on the second and subject two showed similar values (0.29 s compared with 0.31 s). The peak pressure values were

similar between the two sessions for subject two (20.45 psi and 19.59 psi) while there was a much greater variation in the averages (i.e. 31.57 psi and 43.85 psi) and standard deviation (SD) values (12.51 and 10.42 SD) for subject one. The peak forces produced by subject one (1.34 and 1.20 BW) were less than those produced by subject two (1.69 and 1.76 BW) even though they were both performing the more traditional flip turns with only the feet contacting the wall. Values for depth and horizontal distance between the feet were similar on both testing occasions for both swimmers. The area with the greatest variation was the orientation of the feet with values of 6.47° and 26.90° for subject one and 31.40° compared with 24.37° for subject two over the two testing sessions.

Table 1: Descriptive statistics (means and standard deviations (in brackets)) for testing trials

Subject	Session	WCT (s)	Peak Pressure (psi)	Force (BW)	Left Foot (cm)	Right Foot (cm)	Horizontal (cm)	Orientation (°)
1	1	0.25(0.06)	31.57(12.51)	1.34(0.10)	31.33(3.52)	31.73(2.14)	10.97(1.78)	6.47(1.01)
	2	0.30(0.02)	43.85(10.42)	1.20(0.28)	30.50(6.93)	30.50(0.00)	10.60(4.95)	26.90(11.03)
2	1	0.29(0.02)	20.45(2.50)	1.69(0.06)	21.57(2.83)	26.57(2.14)	13.33(1.79)	31.40(10.78)
	2	0.31(0.05)	19.59(7.59)	1.76(0.23)	21.53(4.60)	24.10(2.08)	12.93(2.35)	24.37(13.09)

DISCUSSION: The pressure mat was designed specifically to ensure that there was a minimal protrusion from the wall of the testing equipment so that the swimmers did not need to alter their approach phase during the turn. The protrusion into the pool of wall mounted force platforms range from 4.5cm (Blanksby et al., 1998) to 20cm (Araujo et al., 2010) where the markings on the bottom of the pool needing to be adjusted for the swimmers. As well as only being 4mm thick, the pressure mat was painted yellow with a black cross to replicate the touchpads used during competitions. This was done after receiving feedback from the subjects following pilot testing.

Data from the turn pressure mat were able to provide information on the peak pressure which was then converted to force. Values from previous research varied due to the wide range of ages and strokes used. Age group swimmers from 10-13 years old produced 0.55BW (backstroke), 1.22BW (breaststroke) and 1.24BW (freestylers) (Blanksby et al., 1998; Cossor et al., 1999; Blanksby et al., 2004). Subject one in the current study was a senior elite male freestyler. As previous research reported values of 1.66-1.92BW (Lyttle & Mason, 1997) and 1.60BW (Lyttle, Blanksby, et al., 1999) this swimmer needed to improve his force exerted on the wall during the contact phase of the turn when compared to the force exerted by swimmers in similar events. No data for elite male backstrokers were found in the literature for a comparison with subject two although they were comparable to the freestyle values.

One of the benefits in using the pressure mat is the ability to identify automatically the depth of each foot on the wall during the contact phase to highlight the differences between the two subjects. The freestyle swimmer (subject one) had his feet at approximately 10cm below the surface of the water which was deeper than subject two at an average depth of 1.5cm for the left foot and 5cm for the right foot. These results are consistent with unpublished data demonstrating greater maximum contact depths for backstroke swimmers when compared to freestylers. The values for both swimmers are less than the 30-40cm depth suggested by (Maglischo, 1993) and 40-60cm proposed by (Lyttle et al., 1998; Lyttle et al., 1999; Lyttle, et al. 1999; Lyttle & Benjanuvatra, 2007).

CONCLUSION: This study using two elite male swimmers has demonstrated the use of a pressure mat designed specifically to monitor swimming turns in real time. Results showed that it was possible to measure forces, wall contact time, vertical and horizontal distances of the feet as well as their orientation, through the use of the equipment. The advantages of using a pressure mat rather than a traditional force platform includes cost, portability and the ability to differentiate between the two legs during the contact phase of the turn. Future research will involve greater subject numbers and the use of all four strokes to completely evaluate the hardware and software capability.

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