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QUANTIFYING THE UNDERWATER TRAJECTORY OF A SWIMMING START

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The underwater phase of the swimming start has been found to be the most important factor in determining overall start performance. This research project aimed to find the minimum number of anatomical landmarks, which when digitised still provide a sufficient characterisation of the whole body centre of gravity (CoG) trajectory during the underwater phase of a swimming start. In order to assess this, 10 dive trials were analysed using a variety of combinations of anatomical landmarks to allow for determination of the 2D CoG of each body segment. It was found that five landmarks is the most accurate representation of total body CoG, however fewer can be used. The findings from this study will allow for a more efficient and less time consuming method of quantifying the underwater trajectory of a swimming start in future studies.

KEY WORDS: Dive, Digitise, Centre Of Gravity, Video

INTRODUCTION: The swimming start is typically broken into three phases: the on block phase (including the reaction time), the flight phase and the underwater phase. Previous research has identified the underwater phase of the start as the most decisive in order to achieve an efficient start (Cossor & Mason, 2001; Elipot et al., 2009; Thow, Naemi, & Sanders, 2012). The underwater phase is the interval from when the swimmer enters the water to when the swimmer transitions into free swimming. This is the longest phase of the start as it includes the glide phase and the underwater kicking phase. It is also when the swimmer is travelling at their fastest.

Few studies have determined effective methods to quantify the trajectory of the underwater phase, highlighting the need to develop a case study which focuses on digitising the centre of gravity (CoG) of the swimmer throughout the underwater phase of a swimming start. While trajectory can be determined using 3D motion capture analysis systems, access to these sophisticated systems is costly and sometimes not practical due to the timely process of digitising 3D data (Psycharakis & Sanders, 2009). Therefore, this study aimed to identify a method to quantify the swimmer's underwater trajectory with the use of only high speed 2D video footage.

METHODS: Ten (5 male and 5 female) freestyle dive start trials were selected from the Wetplate Analysis System Start Database collected by the AIS ATTRU (Mason, Mackintosh, & Pease, 2012). The Wetplate system incorporates an instrumented start block and four specifically calibrated high-speed gigabit Ethernet (GigE) cameras (Pulnix, TMC-6740GE), collecting at 100 frames per second and positioned normal to the direction of the line of motion of the subject. One camera is positioned above the water to capture the start and entry into the water, while the other three cameras are positioned underwater to capture the subject swimming from 0 m to 15 m. The start signal is integrated into the analysis system and acts as a trigger for data collection from all force plates and cameras. The interval timing can be done using the analysis system but is faster and more accurate using an additional system which runs simultaneous to Wetplate. This system is called Swimtrak and is also proprietary software developed by the AIS ATTRU. Swimtrak is comprised of eight analogue video cameras (Samsung, SCC-C4301P) located perpendicular to the plane of motion at 0 m, 5 m,

7.5 m, 10 m, 15 m, 20 m and 25 m approximately 3 m above the surface of the pool. The time intervals are recorded as the centre of the swimmer's head passes through specific points.
To quantify the underwater phase of the swimming start nine landmarks were identified to track throughout the duration of the dive start for each trial (Figure 1). These nine landmarks were; toes, lateral malleolus, knee, iliac spine, acromion, fingertips, wrist, elbow, centre of head. This study assumes that both sides of the swimmer's body are symmetric. The nine landmarks were chosen based on a previous study done by (Elipot et al., 2009). Elipot et al. (2009) stated that the rationale behind choosing these points was to limit the error during the digitising process. Using the high speed video footage collected by the Wetplate Analysis System the nine landmarks were collected at a number of different time points. These time points were; on the block before the start signal, when the swimmer's toe left the block, fingertip entry, the first frame which the swimmer was fully submerged and every four frames after that (resulting in a sampling rate of 25 Hz). This was done so that there was a sufficient amount of points to later form a curve to represent the swimmer's underwater trajectory.
After all of the extra anatomical landmarks were digistised the x and y coordinates were inputted into a Microsoft Excel Spreadsheet before the data was filtered using a 6 Hz Butterworth low pass filter (6 Hz was chosen as a result of a residual analysis). The CoG of each body segment was then calculated using the x and y coordinates identified from the video and using segmental parameters described in Winter (2009). These segments were then utilised to determine the 2D total body CoG. In order to determine if it was possible to utilise fewer landmarks/segments and still obtain a sufficiently accurate representation of the subjects' underwater trajectory, different body segment combinations were evaluated and compared to the full body.
The CoG calculations were completed for five different combinations of body segments. These were trunk (T), trunk and arms (TA), arms, trunk and thigh (ATT), head, trunk and upper arm (HTU) and head, trunk and thigh (HTT). Each combination was assessed against the total body CoG by calculating the sums of squares of the residuals for the x and y coordinates. The smaller the sum of squares of the residuals, the more similar the CoG calculations for the combination were to the total body CoG calculations. To practically represent the swimmers' CoG underwater trajectory, the underwater trajectory was plotted (y vs x) and then smoothed using local polynomial regression (LOESS) (Cleveland & Devlin, 1988).

RESULTS: A summary of the main results found by this study are shown in Table 3. An example of the smoothed underwater trajectory of one swimmer is also shown in Figure 1.

Table 3 Sum of squares of residuals for the CoG x and y coordinates for each combination

X	Combination					Y	Combination				
Swimmer	T	TA	ATT	HTU	HTT	Swimmer	T	TA	ATT	HTU	HTT
1	0.98	2.92	0.31	2.92	0.11*	1	0.11	0.18	0.03*	0.17	0.11
2	1.64	5.04	0.56	5.09	0.21*	2	0.15	0.20	0.04*	0.17	0.21
3	1.42	4.47	0.50	4.64	0.22*	3	0.19	0.30	0.05*	0.23	0.22
4	1.55	4.65	0.52	4.57	0.19*	4	0.15	0.22	0.05*	0.17	0.19
5	1.34	4.20	0.48	4.29	0.21*	5	0.10	0.18	0.02*	0.14	0.21
6	0.53	1.61	0.16	1.72	0.08*	6	0.10	0.16	0.02*	0.17	0.08
7	1.46	4.50	0.48	4.67	0.25*	7	0.15	0.21	0.04*	0.21	0.25
8	1.16	3.84	0.41	3.82	0.15*	8	0.13	0.22	0.04*	0.18	0.15
9	0.80	2.53	0.29	2.54	0.11*	9	0.16	0.20	0.03*	0.16	0.11
10	0.02	0.05	0.00*	0.05	0.00*	10	0.00*	0.00*	0.00*	0.00*	0.00*

T – Trunk, TA – Trunk and Arms, ATT – Arms, Trunk and Thigh, HTU – Head, Trunk and Upper arms, HTT – Head, Trunk and Thigh.
***** Indicates the best combination for each swimmer.

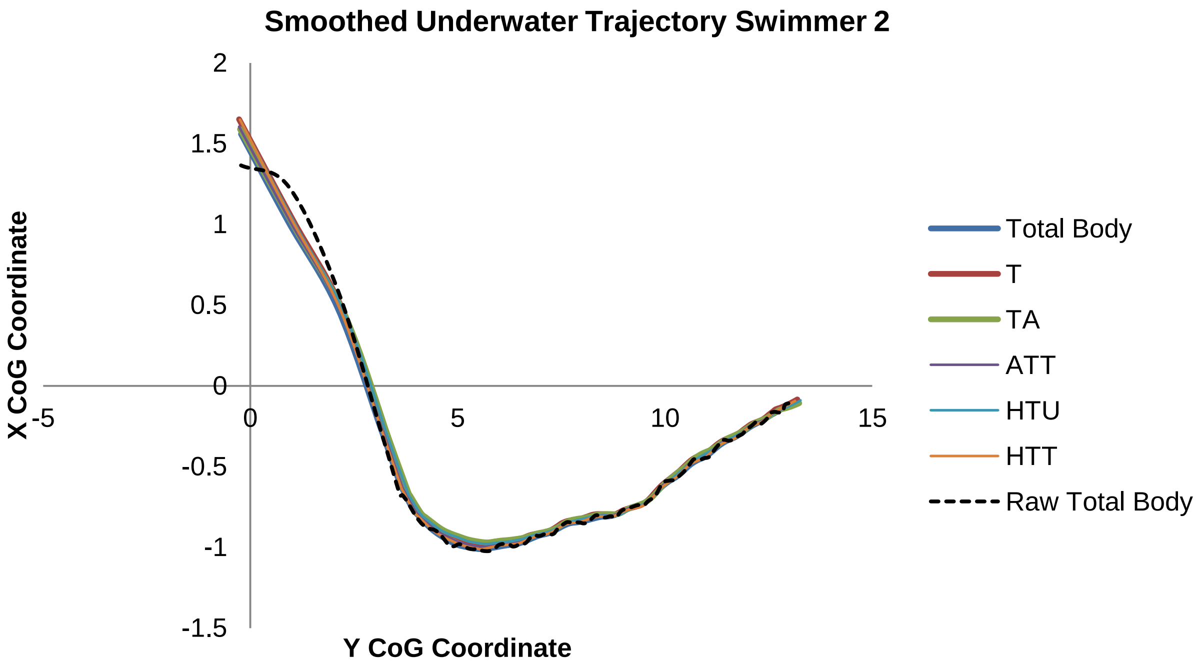

Figure 8 An example of a smoothed representation of a swimmer's underwater trajectory compared with the swimmer's raw total body underwater trajectory

DISCUSSION: This study aimed to quantify the swimmers' CoG during the underwater phase of a swimming start. The standard technique of calculating the horizontal displacement of the total body CoG requires the knowledge of the specific location of the CoG of each individual body segment (Contini, 1972; Eng & Winter, 1993). There are two common methods used to achieve this. These are the segmental approach which determines the total CoG from a weighted sum of body segments and the single marker method which relies on the anterior/posterior displacement of a single marker at the level of the hip joint, pelvis and mid-thorax (Eng & Winter, 1993). Previously it was assumed that a rough estimation of the total body CoG can be attained by assuming that the coordinates of a single marker on the body can reflect the actual total body CoG. For example as the height of the total body CoG is approximately at 60% of the total stature, a single marker on the trunk or the hip joint is often chosen to represent full body CoG (Eng & Winter, 1993). However, previous studies have found a single marker on the hip joint cannot be used to accurately represent full body CoG, particularly during the underwater phase of the swimming start (Eng & Winter, 1993; Figueiredo, Vilas-Boas, Maia, Goncalves, & Fernandes, 2009; Psycharakis & Sanders, 2009). This is because the total body CoG is a representation of the sum of all the forces acting on the body and cannot be used to interpret individual segment effects (Eng & Winter, 1993).

This study used the segmental approach to quantify the underwater trajectory of a swimming start by plotting total CoG for each time point of data collection. While this has often been used as the gold standard for total body CoG displacement, the calculations are based on the location of the segment centre of mass and the magnitude of the segment masses are based on anthropometric estimations. Given this, there can be some errors associated with this method (Kingma, Toussaint, Commissaris, Hoozemsn, & Ober, 1995). However, these errors can be avoided if larger body segments are included in the analysis to represent total body CoG (Eng & Winter, 1993). The results from this study reflect this with the five combinations chosen all including the large body segments of trunk, thighs and arms. The trunk was selected in all combinations as it contributes to a large percentage of total body mass which will in turn have considerable influence on the total body CoG (Kingma et al., 1995). The sum of squares of residuals showed that ATT and HTT were marginally the best combinations.

Further, the smoothed data plots that represented the underwater trajectory of the swimmer for all combinations were all very similar. Given that sport scientists are more likely to use the smoothed data plots as a visual representation of the swimmers' underwater trajectory; when using the segmental approach instead of total body approach to quantify the swimmers' underwater trajectory, as little as one landmark can be used. This will make quantifying the underwater phase of a swimming start more time efficient for future studies.

CONCLUSION: An efficient segmental approach to quantifying the underwater phase of the swimming start was developed in this study. Contrary to previous research this study found that the trajectory of the CoG during the underwater phase of a swimming start is able to be accurately calculated using as little as one segment (trunk). This process of digitising can now be applied to future research projects to accurately and efficiently track a swimmers' underwater trajectory from 2D video.

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