Validity of underwater motion capture system for swimming

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INTRODUCTION

Motion analysis has been one of the major research tools in the biomechanical analysis in swimming. To date multiple video cameras have been used in analysis to quantify three-dimensional coordinates. Kinematic data is obtained by manually digitizing anatomical landmarks on the swimmer from the recorded images taken from multiple points of view which is time consuming. The underwater video techniques involve errors in angles of approximately 10° in the hand motion [1]. Recently, high-speed underwater optical motion analysis systems have been developed to capture and digitize motion which brought about reduction in measurement and analysis time compared to video techniques. However, the validity of using such high-speed underwater optical systems for swimming has yet to be investigated. E.g. Bubbles generated by hand motion may interfere with the capture of markers, and, measurement error may be large. The aims of this study were to establish the accuracy of the underwater optical motion analysis systems, and to trial the use of the underwater optical systems in the analysis of hand motion in freestyle swimming.

METHODS

The Qualisys underwater passive marker system (Qualisys, Sweden) and the Motion Analysis passive marker system (Motion Analysis Corporation, USA) were used in this study. Data on the Motion Analysis system captured on land was used as a reference because a high-speed optical system on land has been widely used due to the accuracy. Data from the seven camera systems were captured underwater and on land separately. The Qualisys system was set up at a pool (12 x 16 x 1.2 m). After the calibration, the L-shaped calibration frame of the Qualisys system was moved underwater within a volume (1 x 3 x 1 m). Motion Analysis system was set in the laboratory at Republic Polytechnic, and the same L-shaped frame as used in the underwater testing was moved in the laboratory. The four reflective markers on the L-shaped frame were recorded at the pool and in the laboratory at 100 Hz for 1 minute. Root mean square (RMS) and maximum (Max) errors of the angle and three different lengths between the markers on the L-shaped frame were computed. A swimmer was asked to swim the front crawl stroke at sub-maximum and maximum sprinting paces with three reflective markers on the left hand (the third finger tip, lateral and medial wrist). One stroke of the left hand was captured by the Qualisys system in the same volume as for the calibration measurement.

RESULTS AND DISCUSSION

The RMS error in the angle was 0.2° in the Qualisys system, and the average of RMS errors in the 3 lengths was 1.2 mm (Table 1). Those errors were small and may be neglected in the biomechanical analysis in swimming. The results showed that the Qualisys underwater passive marker system acquired data that were close to that derived from the Motion Analysis passive marker system based on measurements of the markers on the L shaped frame (Table 1). The results in errors acquired by the Motion Analysis system were similar to that reported in a previous study when the length and angle of an object were known [2]. The maximum speed of the markers was computed from the position data and was 2.2 and 2.6 m/s in Qualisys and Motion Analysis system, respectively. For the swimming analysis, the sampled time of the left hand entry to exit was 1.0 and 0.91 seconds for the sub-maximum and maximum sprinting paces, respectively. The maximum hand speed was 3.1 m/s. The markers were well captured in the middle of the stroke underwater even though the markers could not be captured in some frames during the entry and at the end of upsweep (Table 2). Nevertheless, the frames with missing markers may not be crucial for the analysis of the stroke technique with regards to propulsive forces exerted by the hand during swimming. This is because the swimmer is likely to exert only relatively small propulsion during those phases. This study examined the validity of the Qualisys underwater passive marker system in the capture of kinematic data during a swimming stroke. The results indicate that the system provides accurate position data for the analysis of the important part of hand motion for propulsion that could be acquired within a short period of time as compared to manual digitization adopted in previous swimming studies.

REFERENCES

1. Lauder MA, et al. *J Biomechanics*, **34**: 31-39, 2001.
2. Richards JG. *Human Movement Science*, **18**: 589-602, 1999.

Table 1: RMS and Max error in the angle (90°) and three lengths between the markers on the L-shaped frame (750, 550, 200 mm).

	Angle (°)		Length 1 (mm)		Length 2 (mm)		Length 3 (mm)	
	RMS error	Max error	RMS error	Max error	RMS error	Max error	RMS error	Max error
Qualisys	0.2	0.6	1.7	3.8	0.9	2.4	1.0	1.0
Motion Analysis	0.2	1.2	0.8	3.7	0.6	2.3	0.7	4.3

Table 2: Capture rate of the markers over a sampled time and depth of markers captured from the water surface.

	Sub-maximum sprinting pace			Maximum sprinting pace		
	Finger tip	Lateral wrist	Medial wrist	Finger tip	Lateral wrist	Medial wrist
Capture rate of marker over a sampled time (%)	94	96	100	98	96	97
Depth of markers initially captured (mm)	1.3	3.9	29.9	1.3	3.7	54.1
Depth of markers lastly captured (mm)	226.5	52.5	34.1	202.1	79.3	92.7