Reproducibility, repeatability and accuracy analysis of three-dimensional kinematics of the front crawl stroke trajectories in impaired swimmers

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Abstract:

Kinematic analysis is important to swimming performance improvement. Kinematic error of trajectories reconstruction need to be tested in impaired swimmers. The aim of this study was to evaluate the reproducibility, repeatability and accuracy of three dimensional underwater stroke trajectories of impaired swimmers. Ten operators manually digitized the trajectories of the markers to assess reproducibility. Three operators repeated three times the manual digitization to repeatability calculation. Intraclass correlation coefficient (ICC) was performed to determine reproducibility and repeatability. In addition, coefficient of variation between digitizing was evaluated. Accuracy was determined by the RSM between resultant of arm reconstruction and the real arm length. Stroke trajectory showed high reproducibility and repeatability (ICC ranged from 0.99 to 1.0). Coefficient of variation ranged from 2 to 7. Accuracy error was 8.8 and 8.3 mm to right and left arms, respectively. The reconstruction error of stroke trajectory may be considered acceptable for kinematic analysis in impaired swimmers digitized by experienced operators.

Key words: swimming, biomechanics, measurement, disabled people.

Introduction

Three-dimensional kinematic analysis is a common method used for sports performance assessment. However, analysis of water sports is a challenging problem in the field of biomechanics, namely identifying body markers, due to the liquid environment, (Ceseracciu et al., 2011). Indeed, underwater movement reconstruction is influenced by light refraction (Gourgoulis et al., 2008; Kwon, 1999), turbulence and entrapment of air flow around the body (Payton & Bartlett, 1995). In addition, due the lack of accessible design equipment for automatic tracking underwater, videos are analyzed by manual digitization of a set of body markers on the subject, which is influenced by the ability of the operator in identifying these points (Ceseracciu et al., 2011).

Kinematic analysis in swimming is fundamental in order to establish technique efficiency and have merely focused on able-bodied swimmers (Fernandes, Ribeiro, Figueiredo, Seifert, & Vilas-Boas, 2012; Figueiredo, Seifert, Vilas-Boas, & Fernandes, 2012; Figueiredo, Vilas Boas, Maia, Goncalves, & Fernandes, 2009; McCabe & Sanders, 2012; Payton, Bartlett, Baltzopoulos, & Coombs, 1999). However, to our knowledge, no study has developed a three-dimensional analysis of physically impaired swimmers. Thus, this information is crucial to gain a greater understanding of such a distinct population. Nonetheless, reproducibility, repeatability and accuracy of impaired swimmers regarding kinematic assessments needs to be tested to ensure that reliable data has been analyzed. In fact, the confidence of the interpretations depends on the reliability of the data which, in turn, depends on the effect of random error introduced during the manual digitizing process (Sanders, Gonjo, & McCabe, 2015). The aim of this study was to evaluate the reproducibility, repeatability and accuracy of three-dimensional stroke trajectories in front crawl swimming of physically impaired swimmers. It was hypothesized that the trajectories during the stroke show moderate to high reproducibility, repeatability and low accuracy error.

Material & methods

Reproducibility, repeatability and accuracy of three-dimensional kinematic were established by the proposed concept in the “Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results” (Taylor, 2009). Reproducibility was analyzed by the closeness of the agreement between the results of same measurements carried out by different operators, while repeatability was defined by proximity between the results of successive measurements carried out by the same operator. Finally, accuracy was determined by the proximity between the actual value and measurement results.

Participants and procedure

A video recording was randomly selected from a sample of 11 impaired swimmers (20 years, stricken with cerebral palsy from IPC class S6) to determine the reproducibility, repeatability and accuracy of the digitizing procedures. The swimmers were monitored during a 50m maximum front crawl test, when passing through a specific pre-calibrated space. The calibration volume consisted of 3.5 x 1.0 x 0.75m dimensions (x, y and z axis respectively) with 45 control points. Four underwater video cameras (GoPro Hero 4black) synchronized by a light pulse were used to capture the swimmers arm movements. Three markers were positioned on the middle fingertip, styloid process and epicondyle lateral of the radius on the right and left forearms of the impaired swimmers. The cameras field of view was set in medium option (127°) and any possible distortion effect was removed by applying a “lens adjustment” setting in the GoPro studio software. In addition, the images were cropped and converted to AVI using the same software. SIMI Reality Motion Systems at 60 Hz was used to manually digitize each frame of the right and left stroke of the swimmer. No filter was applied to enable a more realistic comparison between digitizing procedures.

Ten operators whom were experienced with manual digitization identified the trajectories of the markers in order to test for inter-operator variability (i.e., reproducibility). In addition, the manual digitization was repeated three times by three of the operators in order to assess intra-operator variability (i.e. repeatability). Accuracy was determined by the variance between resultant of right and left forearm reconstruction calculation (3 axis from elbow and wrist) and the forearm length, which was previously assessed with a tape measure (0.26 m).

Statistic

Reproducibility and repeatability of the data digitizing were assessed by the intraclass correlation coefficient (ICC). Accuracy was assessed by root mean square (RMS) to quantify the agreement between manual reconstruction and actual arm length. In addition, coefficient of variation between axes resulting from the operators digitizing, was calculated.

The statistical analyses were performed using a customized routine (Matlab 7.0). Significance level was set at $p < 0.001$

Results

Reproducibility to right and left trajectory between different operators and repeatability between successive measurements of the same operator are presented in Table 1. All coordinates show high reproducibility and repeatability between measurements.

Table 1. Reproducibility and repeatability to right (R) and left (L) impaired swimmer trajectories to x,y and z axes

		Reproducibility		Repeatability					
				Operator 1		Operator 2		Operator 3	
		ICC	F	ICC	F	ICC	F	ICC	F
L	x	0.99	13996	0.99	6883	0.99	8988	0.99	15312
	y	0.99	4557	0.99	1932	0.99	1548	0.99	3355
	z	0.99	25283	0.99	8618	0.99	18838	1.00	42785
R	x	0.99	18849	0.99	10604	0.99	12376	0.99	6091
	y	0.99	7820	0.99	2991	0.99	4494	0.99	3223
	z	0.99	39306	0.99	15542	1.00	38827	1.00	25946

= $p < 0.001$

The coefficient of variation between operators digitizing ranged from 3 to 4 in right stroke reconstruction and 2 to 7 in the left stroke. Results produced by the digitization of the ten operators in both strokes at the x, y and z axes are presented in Figure 1.

Fig.1 Graph of stroke trajectories to left and right forearms at x, y and z axes digitizing by 10 operators.

The RMS of the right and left arms were similar (8.8 and 8.3 mm, respectively) and corresponded to 3.2-3.4% of the segment length.

Discussion

This study was designed to evaluate the reproducibility, repeatability and accuracy of three dimensional underwater stroke trajectories of impaired swimmers. The results showed high reproducibility and repeatability that are in agreement with other studies (Fernandes et al., 2012; Figueiredo, Machado, Vilas-Boas, & Fernandes, 2011). These findings are crucial as assurance is gained in movement reconstruction, mainly when working with a specific population, such as impaired swimmers whom expectedly present unique motor patterns due to limitations imposed by the disability itself. Indeed, Pelayou et al. (1999) reported differences in stroke parameters (velocity, stroke length and stroke index) between swimmers and para-swimmers of distinct severity disability. Coordination, range of movement, force and limb length according to the degree of physical disability may explain these differences (Pelayo, Sidney, Moretto, Wille, & Chollet, 1999). The results of this study showed reliable image reconstruction to stroke trajectory in impaired swimmer.

The RSM accuracy was larger than that reported during the aforementioned water stroke analysis (Figueiredo et al., 2011; Gourgoulis et al., 2008; Silvatti et al., 2013). This may be explained due to image distortion in the water. Gourgoulis et al. (2008) observed lower accuracy error underwater in comparison to the present study (ranging from 4.5 and 5.92 to resultant axis with two different volumes). The large calibration volume used in this research may explain the results, due to the fact large calibrated areas increase 3D reconstruction errors. This may be related to the reduced image of the swimmer with respect to the dimension of the calibration volume (Gourgoulis et al., 2008). However, an extensive volume is required when more than one stroke is analyzed (e.g., assessing symmetry between right and left stroke, inter cycle variation, etc.). In addition, calibration volume should be large enough to enable the swimmer to perform a full stroke cycle within the calibrated area (Lauder et al., 1998).

The results in the present study may be considered suitable for 3D swimming kinematics. These findings may be deemed as satisfactory, especially due to the use of commercial cameras. In this view, these cameras are inexpensive and portable to allow high resolution and speed during underwater recordings (Bernardina, Cerveri, Barros, Marins, & Silvatti, 2016). This camera has previously been used for kinematic analysis in swimming (Bernardina et al., 2016; McDonnell, Hume, & Nolte, 2012; Silvatti et al., 2013). Silvatti et al. (2013), found accuracy error 9.72mm using the same cameras while applying classic DLT reconstruction. They also reported greater accuracy when using different calibration approaches. This study used a standard calibration method of Direct Linear Transform, which was based on a known pre-defined volume (Chen, Armstrong, & Raftopoulos, 1994; Figueiredo et al., 2011; Gourgoulis et al., 2008). Furthermore, reliability, reproducibility and accuracy were determined during a realistic stroke, rather than a rigid bar which may not reflect all swimming characteristics (Schreven, Beek, & Smeets, 2015). For instance, estimates obtained in a more realistic condition may include artifacts provoked by small movements of soft tissues (Barré, Jolles, Theumann, & Aminian, 2015) and may be larger than those obtained in non-realistic conditions, which are less prone to real-world artifacts (i.e., rigid bars).

Conclusion

The study showed high reproducibility and repeatability. The confirmed accuracy of the cameras may be considered acceptable for underwater analysis. This is important, due to the fact that the cameras has features which are appropriate for motion analyses, are inexpensive, portable and can be a useful tool to evaluate impaired and non-impaired swimmers kinematics.

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