The Validity and Reliability of a Procedure for Competition Analysis in Swimming Based on Individual Distance Measurements

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In swimming, competition analyses have been frequently performed according to three segments of the race, equal for all competitors. However, individual distance measurements during start and turn race segments have been scarcely assessed. The aim of the present study was: 1) to verify the validity and reliability of a 2D-DLT based system for competition analysis in swimming and, 2) to compare it with the commonly used technique. Higher values of accuracy (RMSE=0.05 m) and reliability (CV<1%) were obtained. 95% Limits of agreement revealed differences no longer than one frame (0.04 s) between the two compared procedures. The results showed that the 2D-DLT procedures are valid for competition analysis in swimming and that the differences between 2D-DLT and scaling technique are acceptable.

Key Words: Race analysis, 2D-DLT, accuracy.

INTRODUCTION

Every sport activity can be analyzed from a theoretical point of view trying to find out the important issues to improve performance. In the deterministic model suggested by Hay and Reid (1982), factors influencing the output in a specific sport activity (or performance criterions) are listed following a cause-effect relationship.

In swimming, biomechanical analyses have been frequently performed during competition to measure the performance criterions, according to three different segments in the race: start, swim and turn (Hay and Guimarães, 1983). Traditionally, the scaling technique has been used for this purpose, measuring the time spent to swim each segment. With this procedure, the distance of start and turn phases are equal for every competitor (on regular basis, 15 meter) allowing a comparison between competitors (Thompson et al., 2004).

Due to the use of scaling techniques, some distance variables influencing swimming performance like turn distance (Chow et al., 1984), have been scarcely measured in competition. Technical limitations in measurement systems could also explain the existing lack of publications about the performance criterions in competition according to Hay's deterministic model. Few studies (Pai et al., 1984; Chatard et al., 2003) measured the individual distance swam during start and turn segments, providing valuable information for performance enhancement.

Considering the use of photogrammetric techniques to measure distances during competition recently reported in other sports (Mallo et al., 2009), the aim of the study was: 1) to check the validity and reliability of a 2D-DLT based system for competition analysis in swimming and 2) to compare it with the commonly used scaling technique.

METHODS

Competition analysis was carried out during II and III Circuito Open Comunidad de Madrid, an international competition organized by Madrid Swimming Federation between July 2007 and July 2008. 128 swimmers participants in A and B Finals of 100 meters events of all four strokes were recorded in a 50x25 meters pool.

Three JVC GY-DV500E video cameras recording at a sampling frequency of 25 Hz were positioned at the stands, 7 m above and 12 m away from the side of the pool; each camera captured a different part of the race: start phase (from start blocks to 15 meter), swim phase (from

20 to 30 meter) and turn phase (from 35 to 50 meter). All cameras were connected to computers where the images were stored in real time. A light flash connected to the official timing system and captured by the camera filming start phase provided the beginning of the time code.

The same camera system was used for both competition analyses: i) using a linear scale system, vertical lines were overlaid on each camera view defining the beginning and/or end of the race segments during the analysis process; ii) using 2D photogrammetry, computerized analysis of the frames was carried out with software Photo 23D (Cala et al., 2009); and the algorithm with 2D direct linear transformation (2D-DLT) was used (Abdel-Aziz and Karara, 1971).

Forty control points (8 calibration and 32 reconstruction) for each camera were uniformly distributed on the horizontal plane delimitated by the water surface. Control points used for calibration purposes were pool-side building marks while reconstruction points were colored buoys from the floating lanes. Reference lines connecting the near and far sides of the pool were used to place the colored buoys at exactly the appropriate distance.

The accuracy of the 2D-DLT measurement system was assessed reconstructing the position of 32 control points in the field of view of one camera; distance between the control points was also reconstructed. Although these control points used for reconstruction purposes were easily recognized in the image, as the accuracy of the competition analysis depends on how well the competitors can be identified. There is no way to directly evaluate the accuracy of every measurement during competition (Challis, 1995), so sampling of the same action must be repeatedly checked for consistency.

For that purpose, two actions at the beginning and the end of the freestyle turn phase were repeatedly digitalized 30 times by the same experienced observer. The swimmer's hand entry of the last stroke before the wall represented the beginning of the turn; on the other hand, the mark where the swimmer's head passes completely the water surface after the underwater swim represented the end of the turn phase. No technical actions other than freestyle turn were assessed since both hand entry or head emersion are used in all four strokes. The digitization process was repeated in each lane of the pool, representing the lane 1 the nearest side in the field of view. Horizontal total distance (m) of the turn phase was obtained using the 2D-DLT measurement system.

Finally, 32 times of each stroke and race segment were measured using the two procedures for competition analysis separately. The variables were identified when swimmer's head pass every reference as follows: start time = start signal to 15 m mark; turn time = 7.5 m – 7.5 m before and after the wall; swim time = start time – turn time.

Root mean square error (RMSE) (Allard et al., 1995), ratio max-to-RMSE, mean error and absolute error were measured to check the accuracy of the 2D-DLT measurement system. Coefficient of variation (CV) as an index of the absolute reliability (Atkinson and Nevill, 1998) and standard deviation (SD) were used to evaluate the consistency of 30 repeated observations. Finally, the two procedures for swimming competition analysis were compared with the Bland and Altman's 95% limits of agreement (Bland and Altman, 1986); heteroscedasticity was previously checked using a Bland-Altman plot.

RESULTS

The root mean square error of the 2D-DLT measurement system when reconstructing the position of 32 control points was 0.050 meter, less than 0.5% of control space in x axis. Reconstructing the distance between the control points, the RMSE was 0.046 meter, lower than 1.2% of the total distance. (Table 1)

Table 1: Accuracy (m) of the position and the inter-control points distance reconstruction's using 2D-DLT procedure.

	Position	Distance
RMSE (root mean squared error)	0.050	0.046
Ratio max-rmse	2.064	1.941
Mean error	0.012	0.028
Absolute error	0.045	0.031

The consistency in the repeated digitization of the swimmer position during the turn phase is shown in Table 2. Considering the total distance of the turn, differences in the measurements are consistently lower than 1%.

Table 2: Consistency (m) of digitizing the beginning (hand entry), the end (head emersion) and the total distance of freestyle turn using 2D-DLT procedure. (SD: standard deviation; CV: coefficient of variation)

	Hand entry (SD)	Head emersion (SD)	Turn distance (SD)	Turn distance (CV)
Lane 1	0.0127	0.0092	0.0155	0.5292%
Lane 2	0.0206	0.0109	0.0208	0.5906%
Lane 3	0.0236	0.0159	0.0243	0.8487%
Lane 4	0.0243	0.0143	0.0274	0.7267%
Lane 5	0.0216	0.0192	0.0313	0.9343%
Lane 6	0.0241	0.0188	0.0255	0.7857%
Lane 7	0.0225	0.0178	0.0272	0.9247%
Lane 8	0.0262	0.0214	0.0343	0.9338%

The limits of agreement between the scaling technique and the 2D-DLT photogrammetry in each segment of the swimming race are shown in Table 3. Maximum systematic differences between procedures occur during freestyle and backstroke turn time (0.05 s), being random error higher in the breaststroke turn.

Table 3: 95% limits of agreement (s) between 2D-DLT and scaling technique during competition analysis

Stroke	Start time	Swim time	Turn time
Freestyle	0.0062 ± 0.0711	0.0344 ± 0.1231	0.0474 ± 0.1341
Backstroke	0.0164 ± 0.0860	0.0208 ± 0.1088	0.0474 ± 0.1191
Breaststroke	0.0164 ± 0.1553	0.0348 ± 0.2074	0.0192 ± 0.2365
Butterfly	0.0167 ± 0.1223	0.0325 ± 0.2083	0.0128 ± 0.1479

DISCUSSION

Application of 2D-DLT technique for analysis of swimming competition shows great accuracy. In comparison to studies analyzing activities with a smaller field of view (Table 4), the 2D-DLT procedures in swimming shows similar accuracy values, with errors reported around 0.05 meter. The only study measuring RMSE with 2D-DLT technique (Challis, 1998) reports similar values corrected to dimensions of the field of view. Even if the errors presented are concerned with easily identifiable points in the image, and not anatomical landmarks, the protocol used provides an appropriate method for assessing the accuracy of the reconstruction technique.

Table 4: Accuracy of reconstructing the position in x axis when analyzing different activities with DLT procedures. RMSE corrected to the dimensions of the control space.

STUDY	ACTIVITY	PROCEDURE	RMSE
Lauder et al. (2001)	Swimming	3D Peak Performance	0.15%
Payton et al. (2002)	Swimming	3D-DLT	0.154%
Challis and Kervin (1992)	Laboratory	3D-DLT	0.160%
Sanders et al. (1998)	Swimming	3D-DLT	0.273%
Challis et al. (1998)	Vertical jump	2D-DLT	0.3%
Present study	Swimming	2D-DLT	0.333%
Cappaert et al. (1995)	Swimming	3D-DLT	0.618%

About the consistency of the digitization process, the identification of body landmarks in swimming competition with 2D-DLT technique shows high levels of intra-rater reliability; even in the farthest side of the pool (lane 8) the coefficient of variation of the measured distances is less than 1%. It is suggested that no corrections are necessary if errors reported are less than 3% of the total distance (Blanksby et al., 2004). Two technical actions successfully tested during the digitization process (hand entry and head emersion) allow multiple possibilities in the measurement of any variable during competition.

Although validity of DLT techniques has been confirmed in the video-analysis of underwater footages in two dimensions (Kwon, 1999) and three dimensions (Sanders et al., 1998), no other studies applied DLT techniques to swimming competition analysis; most of the studies use the scaling technique, superimposing digital lines onto the video playback based on pool-side calibration markings (Thompson et al., 2000); with this procedure the distance of the race segments is equal for every competitor. However, no information relating the validation of such a technique has been previously published.

In this study, the measurement of the traditional race segments with both 2D-DLT and scaling techniques showed systematic differences no longer than a frame of standard-speed video (0.04 s.). Random error, however, rise to 0.20 s. in some strokes (breaststroke and butterfly) where the swimmer's head moves underwater as part of the swim cycle; during these frames, the identification of the swimmer's position on the image seems to be difficult. Since the use of 2D-DLT technique is shown as accurate and reliable in this study, the differences with the scaling technique could be acceptable for its practical use in competition analysis. However, precautions must be taken when measurements are made during underwater parts of the race.

CONCLUSION

In summary, the application of 2D-DLT technique to the competition analysis in swimming shows to be highly accurate and reliable. Position of the swimmer and distance swam during race segments can be measured within ±0.05 m, allowing the measurement and comparison of different factors influencing performance in competition. For practical implications, time measurements during the different parts of the race using 2D-DLT can be compared with the traditional scaling technique.

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