APPLYING BIOMECHANICAL TESTING
TO SWIMMING TRAINING

Raúl Arellano
Facultad Ciencias de la Actividad Física y el Deporte
Universidad de Granada (España)

1. INTRODUCTION:

Competition results and analyses help coaches and swimmers to obtain information about records, individual data and top performances enabling us to see actual and future performance trends. Race pace and technical components are scrutinised to ascertain why some swimmers perform better than others. During the 2003 World Swimming Championships in Barcelona a new computerised data collector system was developed to obtain the race information almost automatically. Before the competition finished, some events results were issued to the swimmers, coaches, teams, press and to the world through internet.
However, this information is not useful if it is a) not given to the swimmers and coaches, b) not applied by them to improve the individual technique and c) not used to modify the training plan.

To ensure the information collected is correctly used, a plan of biomechanical testing has to be implemented to compare the performances throughout the season with the competitive data. A relationship between the technical variables and the training program can be established thanks to biomechanical evaluation program to be proposed in this paper.

2. METHODS OF ANALYSIS:

Swimming competition analysis has been developed parallel to the video and electronic technology. At the beginning few data and variables were analyzed using months for finishing the reports.This technology is now substituted by more advanced systems where the results are produced a couple of hours (or quicker) after the finish of the competition session and they include data of all race components and participants. (Absaliamov & Timakovoy, 1990; T. Absaliamov, Shircovets, Lipsky, & Haljand, 1989; A.B. Craig, Boomer, & Gibbons, 1979; East, 1971). Some studies let the researchers to define the critical variables of swimming competition analysis. (Absaliamov & Timakovoy, 1990; Haljand & Absaliamov, 1989; Hay, Guimaraes, & Grimston, 1983). A block diagram of swimming performance (Hay, 1986) is shown in the figure 1, relations between variables are described in the figure.

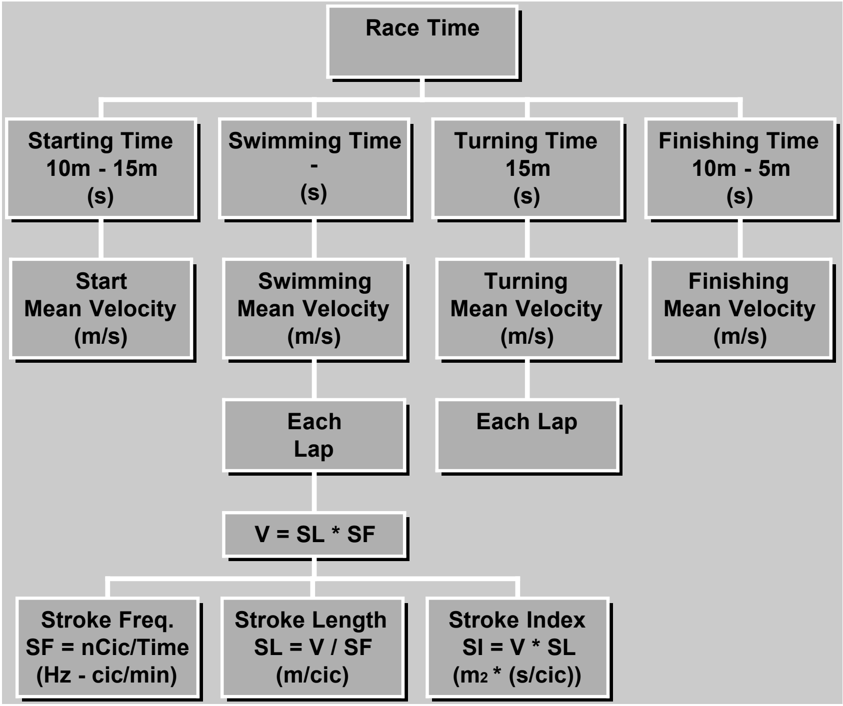


Figure 1: Technical components of the swimming race time. Names and units are shown for each race component.

At the page one of annexe, there is sample sheet of the reports provided during the World Swimming Championships in Barcelona 2003. Data values of every participant in final event are shown for each technical race component.

Analyses of many swimming championships can be found at the Rein Haljand's web page (www.swim.ee), the results of the las Word Swimming Championships (Barcelona-03) can be found in CAR of Sant Cugat Web (www.car.edu/finabcn03/) and the information about the analysis developed in Spain during the last ten years and information about the Swimming Research Group of Granada University will found in the Web page: www.swimmingresearch.com.

Calculations needed to obtain the results are easy to perform but with large quantity of data due to number of participants, variables and laps (see table 1). The results can be analyzed statistically to find the differences between gender, event distance, stroke or the variables can be related, defining prediction equations between the variables and race final time (Absaliamov & Timakovoy, 1990; Raul Arellano, Brown, Cappaert, & Nelson, 1994, 1996; Raúl Arellano et al., 2001; Raúl Arellano, Sánchez-Molina, Navarro, & Aymerich, 2002; Hellard, Caudal, Avalos, Knopp, & Chatard, 2002; Sánchez-Molina & Arellano, 2001).

Table 1: Recorded variables and calculations needed to obtain the results of swimming competition analysis of 100m event at 50m swimming pool.

Tiempos Registrados (s)	Tiempos parciales (s)	Velocidad media (m/s)	Frecuencia De ciclo (Hz)	Longitud De ciclo (m/cic)	Índice de ciclo $m^2/(s*cic)$
T0					
T10m	**TS1**=T10 – T0	**VS1**=10/ST1			
T15m	**TS2**=T15-T10	**VS2**=5/ST2			
T25m	**TN1**=T25-T15	**VN1**=10/S1	**Fc1**=3/$t3c_1$	**Lc1**=V1/Sf1	**Ic1**=V1* SI1
T42.5m	**TN2**=T42.5-T25	**VN2**=17.5/S2	**Fc2**=3/$t3c_2$	**Lc2**=V2/Sf2	**Ic2**=V2* SI2
T50m	**Tapr**=T50-T42.5	**Vapr**=7.5/Ti			
T57.5m	**Tsep**=T57.5-T50	**Vsep**=7.5/To			
T75m	**TN3**=T75-T57.5	**VN3**=17.5/S3	**Fc3**=3/$t3c_3$	**Lc3**=V3/Sf3	**Ic3**=V3* SI3
T95m	**TN4**=T95-T75	**VN4**=20/S4	**Fc4**=3/$t3c_4$	**Lc4**=V4/Sf4	**Ic4**=V4* SI4
T100m	**TF**=T100-T95	**VF**=5* /FT			
Parciales:	**P1**=T50-T0	**PP1**=T25-T0	**PP3**=T75-T50		
	P2=T100-T50	**PP2**=T50-T25	**PP4**=T100-T75		

<u>2.1. Swimming competition: Analysis and Simulation</u>

Two systems were developed in the Faculty of Sport Science to evaluate the technical variables during the training cycle:

1. Swimming competition analysis: An adapted system similar to the instrumental used during the international swimming competitions (Raúl Arellano et al., 2002; Balius, Escoda, & Arellano, 2003).
2. Swimming competition simulation: An application of the method developed in the Sierra Nevada Training Centre "50m plus turn test" to a 25m swimming pool (Raul Arellano, 2000; R. Arellano, Pardillo, & García, 1999).

We will explain a sample of <u>swimming competition simulation</u>: ***50m at 25m swimming poo***. It was composed of five video cameras connected to a video-recorder through a video-timer and a video switcher The image from the first two video cameras was mixed to see the over- and under-water phases of the start in the same frame (2.5m, 5m, and 7.5m). A third camera was used to measure the 10-m time. A fourth camera was put in the middle of the swimming pool to record at least one complete underwater stroke cycle and the 15-m time (with the head) and 17.5m time. The fifth camera was placed at the end of the swimming pool for video recording the turning phase (20m, 22.5m and 25m). All the cameras were recording at a distance of 7 m from the sagital plane of the swimmer's displacement. The 1st was placed over the water. The other cameras were placed one m below the water surface (see pictures 2,4 and 5). One simple reference system was put in the sagital plane of the swimmer's displacement and recorded before the swimmer's group performances. Thanks to this reference, it was possible to draw vertical lines on the computer screen (video-overlay) to measure the frame where the swimmer's head crossed these reference lines. The evaluation was executed after a swimming start following the FINA rules. The starting signal was synchronised with the video-timer. After video recording, the timing data was collected directly from the digital video file, a developed database was able to read the time code from the digital video film, to put in the specific field of the database the numeric time code value and to printout the analysis for information for coaches and swimmers.

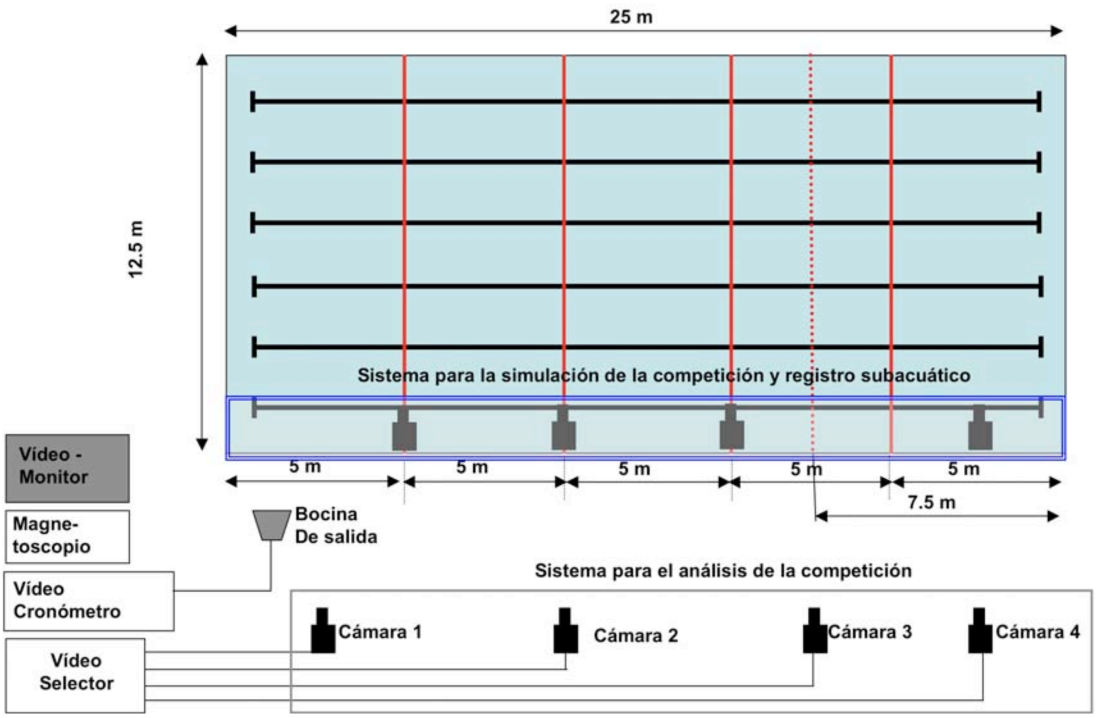
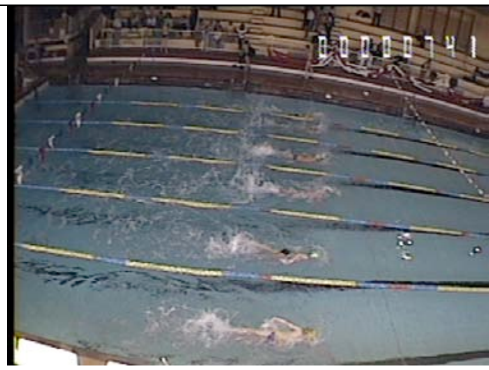
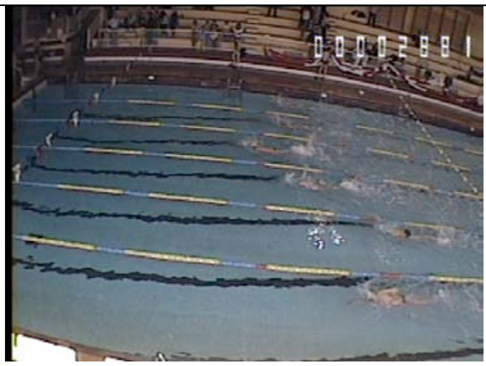


Figure 2: Recording system applied to the analysis of swimming competition and competition simulation installed at the Faculty of Sport Science of University of Granada.

Cámara 1: salida y llegada



Cámara 2: tiempo en 10m



Cámara 3: tiempo en 15m

Cámara 4: tiempo en 20m y 25m

Figure 3: Pictures sequentially obtained from each camera locate near of the ceiling of the indoor 25m swimming pool.

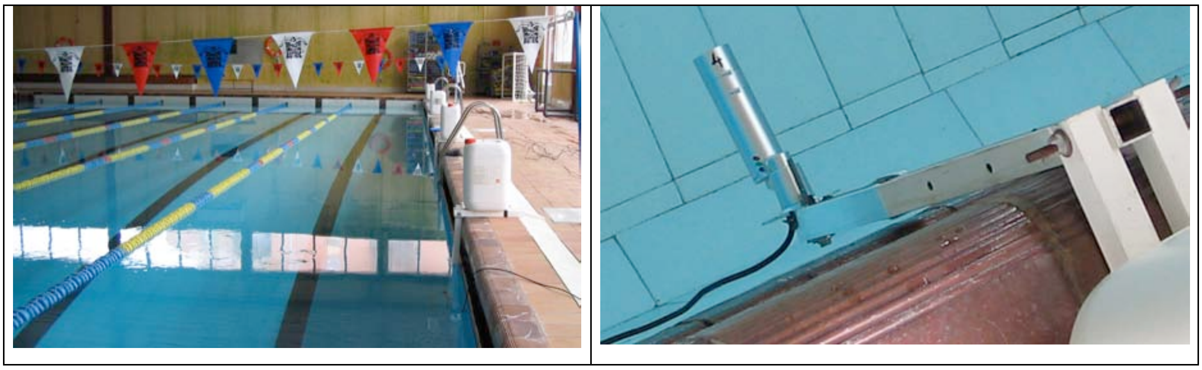


Figure 4: Details of location and installation of the underwater micro-cameras (IP:68).

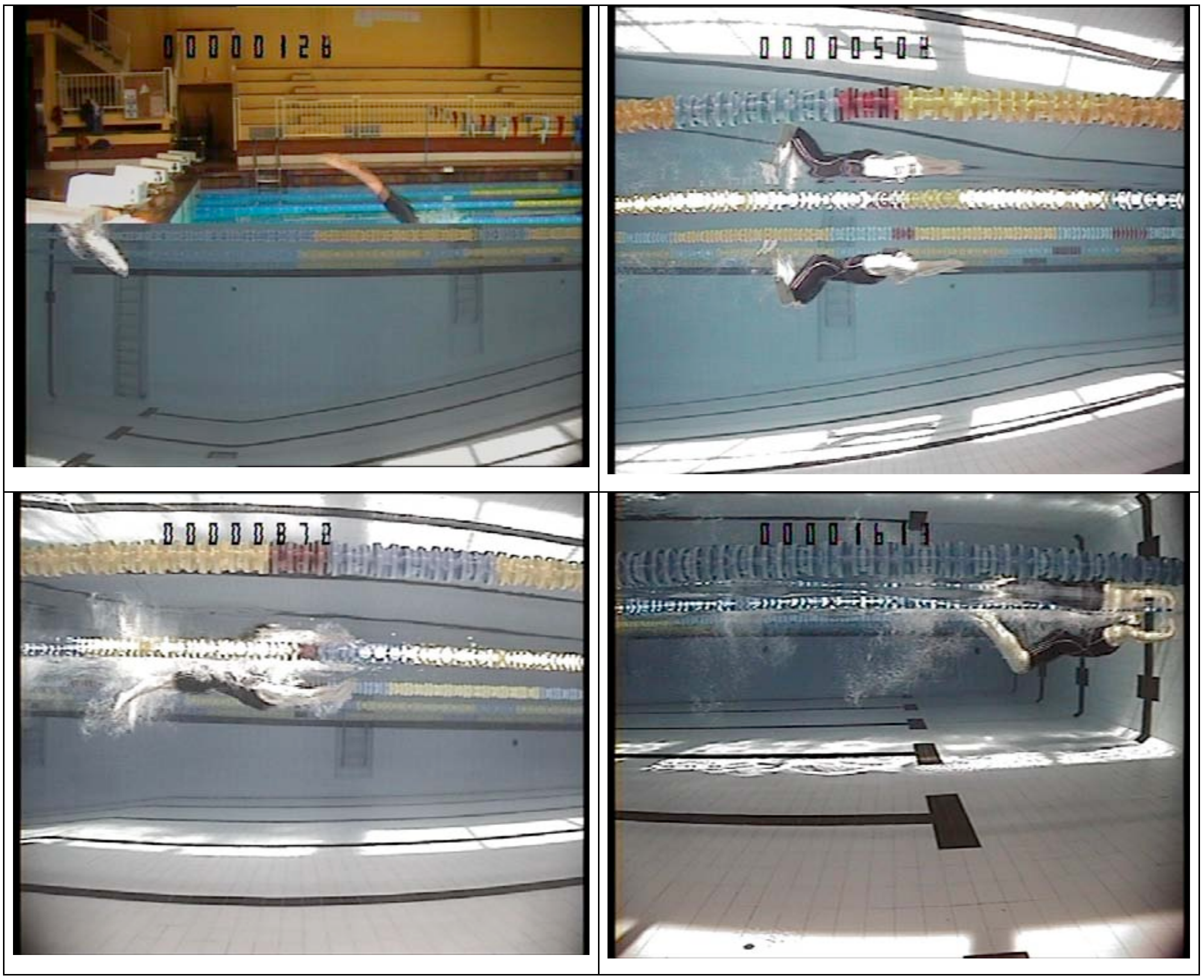


Figure 5: Recorded pictures during the race simulation test with underwater video-tracking of the swimmer performance. Detailed observation of the starting, swimming, turning and finishing phases can be performed.

2.2 Isolated Starts and Turns Analysis

These testing procedures are targeted to measure the start and turn evolution during the training season. The methodology and parameters measured are the same as race simulation procedures.

Starts: The procedure is to measure three start trials until the head crosses the 15 m mark (full rest is permitted after each trial). The mean of the three trials is kept to measure the improvement during the training season. Timing analysis allowed us to record the 5m, 10m and 15m times plus the velocities on each phase (see figures 5a,5b,5c). An aquatic force plate has been included in our starting protocols. This will give kinetic results and make the system more accurate.

Turns: The procedure is to measure 7,5 m in and 7,5 m out of the turn and their phases utilising the turn phase of the race simulation test. The swimmer starts swimming 12 m before the wall to ensure a speed as high as possible before the 7,5 m mark. Two or three trials are recorded each evaluating session. Actually this test can be performed measuring a turn-in of 5m and a turn-out of 10m. It depends of the race analysis performed previously in the competition.

2.3. Progressive Technical Test

The objective is to analyse the swimming technical components (MS, SF & SF) by means of a set of swimming incremental speed repetitions (Costill, Maglischo, & Richardson, 1992). The basic model proposed is a set of 6 or 8 repetitions of 50 m progressive utilising a 50 m swimming pool. During the first trials of this test a similar recovery time was used for all repetitions, for example leaving each minute. We introduced some modifications to make sure to obtain a sufficient speed at the last repetitions: four times 50s increasing the speed leaving each minute, two 50s leaving each two minutes and two more leaving each three minutes.

Instrumental: To be able to evaluate a large group of swimmers simultaneously, three cameras were placed along the swimming pool: two at 10 m from both ends and one in the centre. References were placed at 10 m prior to the subjects' trials and recorded. The swimmers were asked to start relatively slowly (almost aerobic threshold) and finishing as close as possible to the competitive pace. The graphs obtained from the data let us relate SL and SF with MS. We can measure the technical improvement of the swimmer if at similar speeds the SL is increased and SF decreased or if higher speeds are obtained with similar SF and longer SL. These effects are produced with a relatively long period of training (at least one messo-cycle). This test has been adapted to a 25 m swimming pool and it can be arranged without equipment. The swimmer performs eight times 25 m progressive in a similar way as described above. The coach starts measuring the time at the instant the head crossed the 5 m line, measuring the SR in the middle of the swimming pool and stopping the timer when the swimmer touches the wall. Mean speeds for 20 m are calculated. This test modification is very useful with age group and master swimmers.

2.4. One Repetition Standarized Speed Test

The swimmer has to perform a distance between 200m and 800m (400m) with a constant swimming pace, and a speed clearly over the anaerobic threshold (Costill et al., 1992). The pace is demonstrated to the swimmer by a underwater lane of lights. The stroke length and the stroke frequency are recorded each lap plus the pulse rate and the blood lactic acid. The evolution of this test can demonstrate the evolution of stroke efficiency during the training season.

2.5. Active drag assessment

The swimmer has to perform two 50m or 25m trials, one swimming his own stroke and the other one swimming at the same stroke but displacing a body of known drag. Applying the equation (1) that compares the mean velocity obtained in each trial (V_1 y V_2) it is possible to calculate the active drag. It is supposed that the energy expenditure on each trial is the same in both cases. The hypothesis is that the swimmer decreases his active drag when is obtaining his better shape for competing.

$$\mathbf{RA = (Rc * V_2 * V_1^2) / (V_1^3 - V_2^3)} \quad \mathbf{(1)}$$

Figure 6: Isometric muscular force recording: 90º shoulder extension with arms extended.

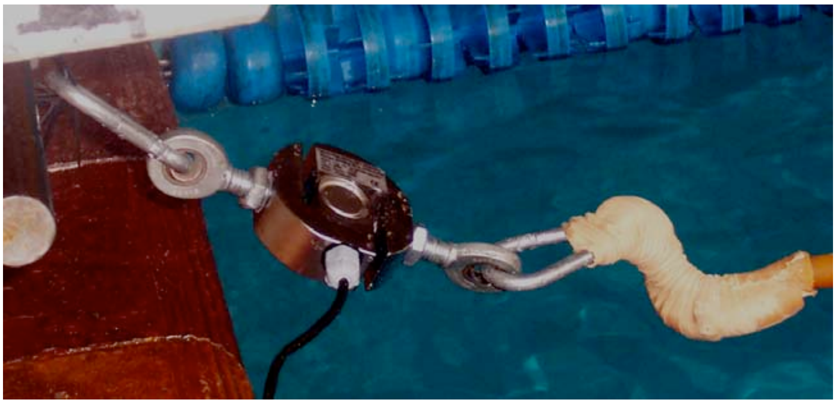


Figure 7: Dynamometer applied for recording the tethered swimming force and the muscular isometric force.

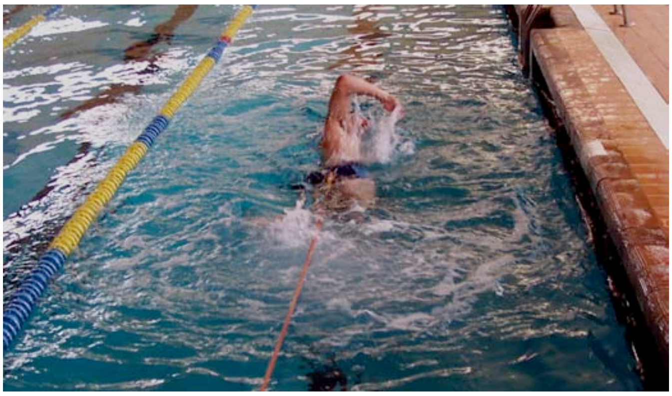


Figure 8: Recording the tethered propulsive force with an elastic cord.

2.6 Isometric Muscular Force

Several studied correlated the isometric muscular force with the swimming speed or the observation of technical stroke mistakes (Colman & Persyn, 1991; Persyn et al., 1988; Vorontsov, Dyrco, Binevsky, Solomatin, & Sidorov, 1999). This procedure helps to the coach to measure the force improvement after a cycle of strength training. The force improvement is not transferred to the propulsive force immediately. It is necessary a period of swimming specific training to improve the swimming speed. (see figure 6).

2.7 Tethered Swimming Force Recording

Tethered swimming force recording is the unique to record directly the force applied for the swimmer in the water. The problem is the swimmer is not displacing freely in the water, it has to be fully tethered and some changes in his stroke technique can be observed. If the swimmer is permitted to displace the force recording decreases until zero value when the swimming speed is normal. (Adams, Martin, Yeater, & Gilson, 1983; Martin,1989). The force recorded in this way demonstrated to be correlated with the swimming speed in short distances (50m) (Adams et al., 1983; Raúl Arellano, 1992; Albert B. Craig & Boomer, 1980; Goldfuss & Nelson, 1971; Magel, 1970), that its improvement is related to the children development (Boulgakova, 1990; Vorontsov et al., 1999) and, this tethered swimming force improvement is related to the muscular power improvement in land after a cycle of strength training (Raúl Arellano, 1992).

2.8 Intra-Cycle Velocity Recording

The observation, digitalization or recording of a hip point during the stroke cycle, it can help us to evaluate indirectly the impulse variation. Similar paths with different values were found between the centre of gravity and the hip point in breaststroke (Maglischo, Maglischo, & Santos, 1987). A intra-cycle description of the body speed can be evaluated thanks to instrumental that can record this horizontal speed in real time and mixed with the video observations (Costill, D'Acquisto, & D'Acquisto, 1987; Costill et al., 1992).

2.9 Qualitative Observation of Technique

The qualitative assessment of stroke technique is the more frequent system to evaluate the swimmers technique. Coach's observation can be improved using underwater video recording combined with some quantitative data. Numbers from technical model can help to find more accurately the qualitative stroke faults. Some mistakes seem to be very frequent during different phases of the long-term swimmers' life. The natural development of the young swimmers will to reduce its observed frequency year by year (ARELLANO & SÁNCHEZ-MOLINA, 2002; García, Arellano, Sánchez, Ureña, & López, 1990; Gavilán, 2002).

3. TRAINING PROCEDURES

The analysis tools previously described can be applied almost directly in a swimming training program to provide immediately information of the swimmer's biomechanical condition. Having an appropriate facility for this, such as in the CAR of Sierra Nevada or our Faculty swimming pool greatly assists the real development of an assessment program. Actually, thanks to technological development it is possible to adapt the evaluation protocols to other types of facilities or even develop a portable equipment.

Planning its application is the most difficult phase. The simplest option is to measure some quantitative data to give extrinsic feedback (FB) to the swimmer, who wants to correct a mistake or improve some technical aspect. This FB can be combined with qualitative information that the swimmer will add to his own intrinsic FB. The FB can be developed in two ways: knowledge of the results (KR) and knowledge of the performance (KP) (Schmidt & Wrisberg, 2000).

The swimming coach naturally applies both types of FB, but the information is not totally reliable and valid. The underwater cameras and a time recording system allows the reliability of trainer recording to improve. For example, if a coach tries to time manually the start at 15m, his error can be greater than the improvement made by an elite swimmer, after a cycle of specific start training (Fuente, 2003).

The FB process is improved because the application of biomechanics methodology thanks to (Bartlett, 1999):

- An improvement in the accuracy and reproducibility of the results.
- The possibility to provide information that it is not able to observe by a expert coach.
- Wrong and correct performances are differentiated with more accuracy.

Let me give you an example: the target is to reduce the start time. We developed an automatic system to measure it. A wall structure was attached perpendicular to the side of the swimming pool at 10m from the front edge, this wall structure supported and ALGE "timing wall". After the start signal the swimmer dives and glides until touching the wall. Two times are obtained: 1) block time and; 2) 10m time. The swimmer and coach had KR of the start with total accuracy. After that changes in the start movements cab be suggested by the coach and performed by the swimmer to try to reduce the start time. KP can be added to the system video-recording the start performance. Our research work demonstrated, using KR alone, that a cycle of swimming start training (two weeks, three sessions a week and 5 or 6 timed repetitions per session) produced improvements in the start time (Fuente, 2003).

A second study was developed for improving the underwater undulatory swimming velocity. The 5m to 15m time, mean velocity and underwater video-recording of swimmer's performance were the combined KR and KP. The swimmer had to observe in the video screen the critical points of his technique and relate them to the quantitative results. Also, a short period of work similar to the previous study demonstrated improvements in the swimmer's performance (Gavilán, 2002).

A model is proposed to combine Biomechanical testing and the training plan (see table 2). In a simplified way the type of cycles of training can be reduced to: development of basic endurance, increase of basic strength, improvement of specific technique and competitive cycles. These data could be combined with the classic physiological testing (sometimes the only testing).

Each described testing procedure measures a different group of technical variables. Some variables are more sensible to the specific training than others and it will be necessary to relate each procedure to each type of training cycle whit different duration.

Table 2: Proposed distribution of technical testing procedures in each type of training cycle.

Cycle of basic endurance development	Cycle of basic strength training	Cycle of specific technique improvement	Cycle of competition
• One Repetition Standardized Speed Test • Swimming Competition Simulation • Progressive Technical Test • Active drag assessment	• Isometric Muscular Force • Tethered Swimming Force Recording • Isolated Starts and Turns Analysis • Force plate vertical force	• One Repetition Standardized Speed Test • Progressive Technical Test • Intra-Cycle Velocity Recording • Active drag assessment • Qualitative Observation of Technique	• One Repetition Standardized Speed Test • Isolated Starts and Turns Analysis • Progressive Technical Test • Swimming Competition Analysis • Active drag assessment

4. CONCLUSIONS:

Planning the technique and its control is one of the least developed aspects in modern coaching methodology, which focuses more on the development of general training period or bio-medical control of performances.

The current situation allows the application of many means of objective assessment of technique that often, are not far from coaches' possibilities, or are available in Training Centres (CARs in Spain) or some Research Centres such us develop in our Faculty. Proposals such as those described in the present work are a step forward in the development of a methodology in the evaluation of swimming technique related to the swimmer's training cycles.

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ANEXO I: Sample of analysis of swimming competition sheet distributed throught the results Web page of X FINA World Swimming Championships 2003.

X FINA World Championships, BCN2003

50m Breaststroke M Finals

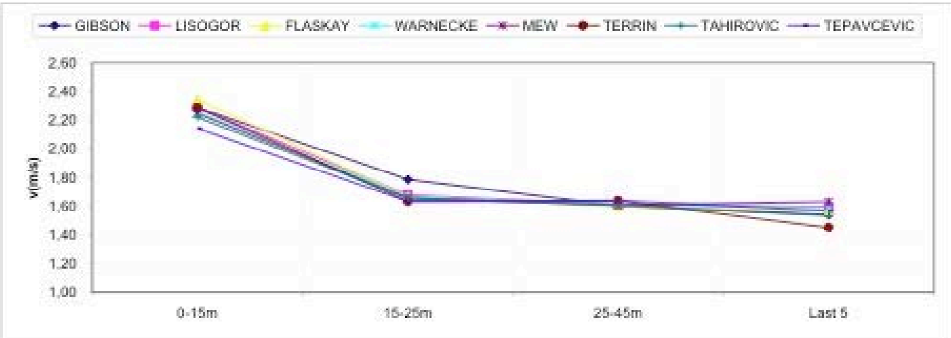
COMPETITION ANALYSIS

23/07/2003

Individual reports: http://www.e-plash.org http://www.car.edu/finabcn03

						Swimming Stroke Averages					
Swimmer	Country	Ln	Time	Average Event Velocity (m/s)	Start Speed 15 m (m/s)	Veloc. (m/s)	Freq (c/min)	Str. L. (m/c)	Str. Index (m/s*m/c)		Finish (5m) Mean Speed (m/s)
GIBSON	GBR	4	0:27.56	1,81	2,29	1,66	60	1,68	2,86		1,54
LISOGOR	UKR	5	0:27.74	1,80	2,29	1,63	70	1,40	2,31		1,60
FLASKAY	HUN	2	0:27.79	1,80	2,34	1,62	69	1,41	2,31		1,57
WARNECKE	GER	3	0:27.87	1,79	2,26	1,63	69	1,42	2,33		1,59
MEW	GBR	6	0:27.92	1,79	2,25	1,62	67	1,47	2,40		1,63
TERRIN	ITA	7	0:27.98	1,79	2,29	1,64	64	1,53	2,50		1,45
TAHIROVIC	SLO	8	0:28.17	1,77	2,22	1,62	63	1,54	2,52		1,54
TEPAVCEVIC	YUG	1	0:28.19	1,77	2,14	1,64	57	1,72	2,82		1,57
	Average		0:27.90	1,79	2,26	1,64	65,07	1,52	2,51	0,00	1,56

Start, Swimm,Turn & Finish Speeds (m/s)	0-15m	15-25m	25-45m	Last 5
GIBSON	2,29	1,79	1,60	1,54
LISOGOR	2,29	1,68	1,61	1,60
FLASKAY	2,34	1,67	1,60	1,57
WARNECKE	2,26	1,67	1,61	1,59
MEW	2,25	1,66	1,61	1,63
TERRIN	2,29	1,63	1,64	1,45
TAHIROVIC	2,22	1,66	1,61	1,54
TEPAVCEVIC	2,14	1,63	1,64	1,57



	GIBSON	LISOGOR	FLASKAY	WARNECKE	MEW	TERRIN	TAHIROVIC	TEPAVCEVIC
0-15	0:06.56	0:06.56	0:06.40	0:06.64	0:06.68	0:06.56	0:06.76	0:07.00
15-25	0:05.60	0:05.96	0:06.00	0:06.00	0:06.04	0:06.12	0:06.04	0:06.12
25-45	0:12.48	0:12.40	0:12.52	0:12.40	0:12.44	0:12.20	0:12.44	0:12.20
Last 5	0:02.92	0:02.82	0:02.87	0:02.83	0:02.76	0:03.10	0:02.93	0:02.87
Lap Time 25	0:12.16	0:12.52	0:12.40	0:12.64	0:12.72	0:12.68	0:12.80	0:13.12
Lap Time 50	0:15.40	0:15.22	0:15.39	0:15.23	0:15.20	0:15.30	0:15.37	0:15.07

Official partners:

CAR Catalunya / Universidad de Granada / INEF Galicia / IVEF-SHEE Gasteiz