

INTEGRATED DYNAMOMETRIC, KINEMATIC AND ELECTROMYOGRAPHIC CHARACTERISATION OF A SWIMMING TRACK START BLOCK PHASE — A PILOT STUDY

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Abstract This study presents a complete biomechanical analysis of the block phase of a swimming modified track start. Kinetic, kinematic and electromyography (EMG) data were collected. The forces produced by the swimmer on the block, the EMG of eight muscles and the kinematics of the centre of mass (CM) were recorded. A national-level swimmer performed three repetitions of a track start in a dynamometric starting block. Temporal instants 'reaction time', 'hands take-off', 'rear foot take-off' and 'front foot take-off' were identified. Results show the peak forces (Fmax) produced by the most dynamic limb in each sub-phase delimited by mentioned instants (right hand take-off: $F_{\text{max,vertical}} = 103 \text{ N}$; rear foot take-off: $F_{\text{max,antero-posterior}} = 524 \text{ N}$; front foot take-off: $F_{\text{max,vertical}} = 634 \text{ N}$). The CM revealed a descendent vertical trajectory along the block phase. Mean resultant speed at front foot take-off was 4.092m/s. The muscles with highest values of integral EMG (iEMG) were the tibialis anterior during hands take-off, Biceps Femoris and Gluteus Maximus during rear foot take-off, respectively 41.17%, 52.96% and 36.37% of the maximum isometric voluntary contraction (%MIVC). The study demonstrates an effective characterisation of the block phase in swimming starts with potential to evaluate the swimmers performance in the track start, using different back plate positioning.

Key words: Biomechanics, Dynamometry, Kinematics, Electromyography, Swimming

Introduction

In competitive swimming the start is determinant, especially in short distance events (Lyttle, Benjanuvatra, 2005). In the last decade the track start has become one of the most used start techniques by elite swimmers

(Garcia-Hermoso et al., 2013). According to the preferences of each swimmer (forward or backward positioning of the CM and rear foot placement on the starting block) there are some variations in the way track start is performed. Parameters like the reaction time (temporal delay from the start signal until the first mechanical expression) and the impulse on the block (integral of force in order to time) seem to assume relevance in the production of an effective start (Vantorre, Seifert, Fernandes, Vilas-Boas, Chollet, 2010). There are some biomechanical studies that focus on the start as a whole: block phase, flight, entry in water, underwater glide, leg kicking and swimming phase (Vantorre et al., 2010; Seifert et al., 2010; Vilas-Boas, Fernandes, 2003), but few did an exhaustive analysis of the block phase (Honda, Sinclair, Mason, Pease, 2012; Kibele, Biel, Fischer, 2013), defined by the time between the start signal and the instant the swimmer loses the contact of his feet with the block (Vantorre et al., 2010).

In 2008, the *Fédération Internationale de Natation* (FINA) authorized the inclusion of a back plate on the starting block for rear foot support (FR 2.7, 2009 2017). The placement of this back plate is adjustable and swimmers can choose one of the five possible positions to optimize their feet positioning on the block. With this improvement, the modified track start became the most used technique by elite swimmers (Kibele et al., 2013). However, the amount of research available about how the back plate influences the start is still scarce. The purpose of this study is to analyse the coherence of the kinematic, kinetic and electromyographic parameters involved in the block phase of the modified track start and their potential to characterise this event. Based on the findings of previous studies (de Jesus et al., 2011a, 2011b), it was hypothesised that it would be possible to develop a biomechanical method to characterise the block phase of the modified track start, using EMG, force plates and a motion capture system as main tools.

Methods

Participants

A female swimmer, proficient in the modified track start technique (age: 24 years; body weight: 62 kg; height: 1.64 m), performed three trials of this starting technique, with 10 minutes rest between repetitions. The Ethics Committee of Faculty of Sport from the University of Porto approved the research in accordance with the guidelines set by the World Medical Association Declaration of Helsinki (2013). The participant provided informed consent before data collection.

Experimental Procedure

The swimmer executed the established number of repetitions of the modified track start. For the present study the repetition whose data from the three domains of analysis presented the highest quality was selected. +65 this decision was made because two of the three systems used were products in development; the EMG was a non-commercial cable device, custom made, operating in the hostile aquatic environment and the dynamometric starting block was not fully water-resistant. These aspects, combined with the difficulty for the motion capture system to identify the 48 markers on the swimmer's body when she was positioned on the starting block, justify our option to select just one repetition of the track start to analyze, that in which the quality of data from the three devices was the highest.

Active pre-amplified bipolar surface electrodes were used to collect EMG data. The amplifier common rejection ratio was 110 dB and the total gain was set to 1100x. The muscle fibres orientation was respected and the

electrodes were placed in the centre of the muscle belly during a concentric contraction. The reference electrode (ground) was positioned in the *olecranon*. These cable electrodes were placed over eight muscles from the right side of the swimmer body (the front foot side) – *triceps brachii*, *deltoideus anterior*, *biceps brachii*, *tibialis anterior*, *biceps femoris*, *gastrocnemius medialis*, *rectus femoris*, *gluteus maximus* (Figure 1). For the placement of the surface active electrodes the recommendations from the project Surface Electromyography for the *Non-Invasive Assessment of Muscles* (SENIAM) were respected.

The eight cables were grouped in the lower back region of the swimmer and conducted through a specific hole in the swimming body suit. These cables drove the EMG signal to a data acquisition system composed by an analogue-to-digital converter (A/D) (BIOPAC Systems, Inc., USA), with a sampling rate of 1000 Hz. To normalize the signal, data from the maximum voluntary isometric contraction (MVIC) of the evaluated muscles was also collected. Three MVIC were performed per muscle (5 seconds of duration with 5 minutes of rest between contractions) and the contraction with the highest voltage value was chosen as reference (Figueiredo, Rouard, Vilas-Boas, Fernandes, 2013). Thereafter, using the Matlab® software (The MathWorks, Inc., USA) the raw EMG signals were processed using a digital pass-band Hamming window (35–450 Hz), followed by full wave rectification and smoothing with a low pass filter of 10Hz. The procedures of isolation, cables fixation and signals normalization were done according to previous studies (Figueiredo et al., 2013; de Jesus et al., 2011b).



Figure 1. Electrodes positioning for EMG

To ensure the electrodes protection and to guarantee the correct marking of the 48 anatomical points of interest for the kinematical evaluation, a complete fastskin™ suit (Speedo®, USA) filled with retro-reflective quasi-spherical elements in specific locations was used. Twelve infrared cameras (Qualisys AB, Sweden), with a sampling frequency of 100 Hz, allowed registering kinematic parameters (position, time and derived quantities) of the marked

anatomical points of the participant. This way the principal instants or phases of relevance for the swimming start characterisation were obtained (Ribeiro et al., 2014). The previous system calibration has ensured the coverage of the entire volume of performance of the swimmer allowing the motion capture of the anatomical points identified with reflective markers. The markers setup (Figure 2) chosen was based on the anatomical anthropometric model of the *Istituto Ortopedico Rizzoli* (IOR Gait Full-Body Model) which enabled the creation of a 3D kinematical model on Visual3D software (C-Motion, USA).

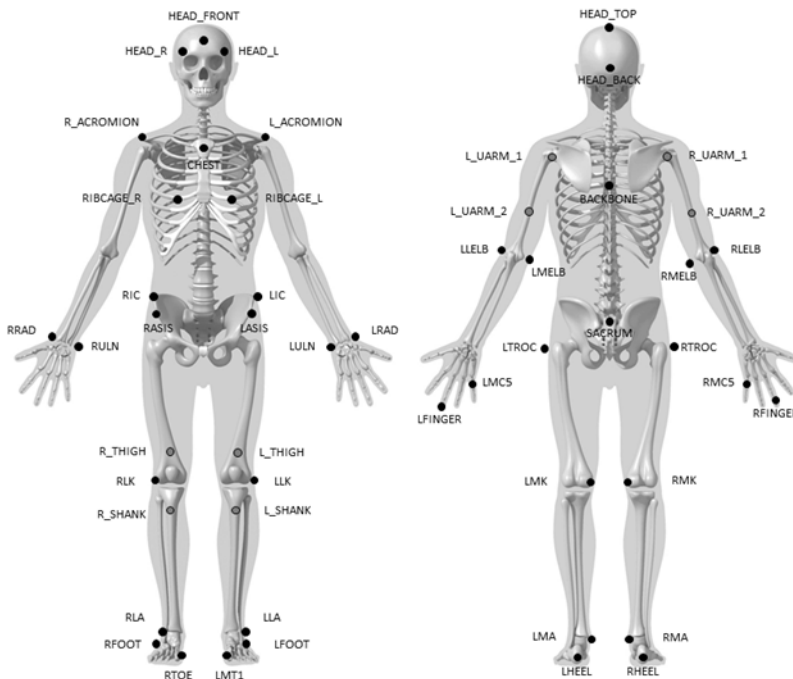


Figure 2. Marks setup of relevant anatomical spots

For the dynamometric analysis of the swimming start, an instrumented starting block was used. This was built with several extensometric triaxial force plates (Figure 3) for full contact force assessment. The force plates with a natural frequency of 60 Hz operate with 2 N sensitivity, error <1% and a sampling rate of 2000 Hz (de Jesus et al., 2011a). The dynamometric system was picked as reference to define the initial and final temporal instants of each sub-phase of the block phase. This choice was due to the fact that this system can measure, in an independent and direct way, the block reaction forces (BRF) produced by each upper and lower limbs of the swimmer, at any instant.

The temporal synchronization of the three systems was performed with a trigger (TTL wave, 0–5V). This device was coupled to a starter (Pro Start, USA) that emitted simultaneously the starting signal and the electrical pulse to trigger the acquisition system.

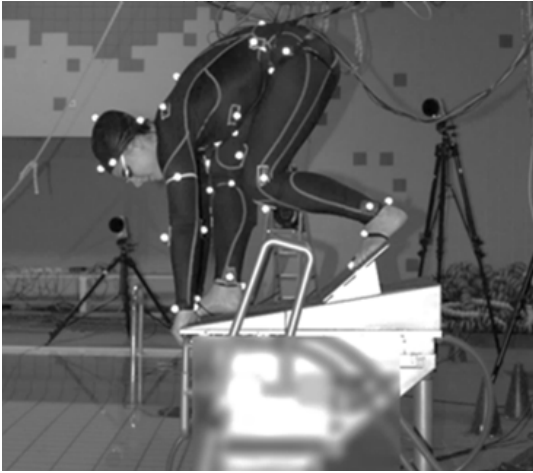


Figure 3. Starting block and markers setup

Measurements

The electromyographic integral (iEMG) was obtained from the collected EMG data to evaluate the electrical activity of each muscle. To calculate the iEMG, signals were normalized to the MVIC, integrated in order to time duration of each sub-phase and then normalized to the same temporal interval. This procedure was done in order to discard the phase duration effect (Figueiredo, Sanders, Gorski, 2012). In the *Results* the values of iEMG will be presented in the form of percentages. The kinematical parameters obtained through the optical motion capture system Qualisys™ were: (i) displacement and average speed of the CM from the instant of the starting signal to the first mechanical reaction of the swimmer; (ii) from this instant to the loss of contact of the hands with the block; (iii) from this moment to the rear foot take-off and (iv) from this instant to the loss of contact of the front foot with the starting block. The vertical, antero-posterior and medium-lateral components of the reaction forces, produced on the block by the action of each of the swimmer lower and upper limbs during the block phase, were registered.

Results

The kinematics results, presented in Table 1, were determined for the sequence of time intervals described in the previous section. The selected parameters were: the time duration and percentage of total time spent in each sub-phase of the block phase; the displacement of the CM in the sagittal plane (antero-posterior – Δx – and vertical – Δz) and the average resultant speed of the CM in the sagittal plane, for each sub-phase.

The values of BRF as function of time, produced by the action of the swimmer upper and lower limbs are presented in Figure 4. Graphic A shows the components of BRF resulting from the action of the right hand and the graphics B and C present the components of BRF of the rear foot and front foot, respectively. In panel D the graphic shows the superimposed curves of the BRF components produced by the action of upper and lower limbs. Analysing the force curves it is possible to see that the vertical and antero-posterior components are those with bigger contribution for the propulsive action on the block, for both upper and lower limbs.

Table 1. Kinematical variables studied in each sub-phase of the block phase for the modified track start

	Reaction time	Hands take-off	Rear foot take-off	Front foot take-off
Time (s)	[0.00–0.13]	[0.13–0.50]	[0.50–0.77]	[0.77–0.90]
Time (%)*	14.45	41.10	30.00	14.45
Δx (m)	0.021	0.492	0.895	0.487
Δz (m)	0.001	-0.059	-0.197	-0.187
V_{avg} (m/s)	0.159	0.974	2.808	4.092

* % of total time on the block; Δx – antero-posterior displacement; Δz – vertical displacement; v_{avg} – average speed.

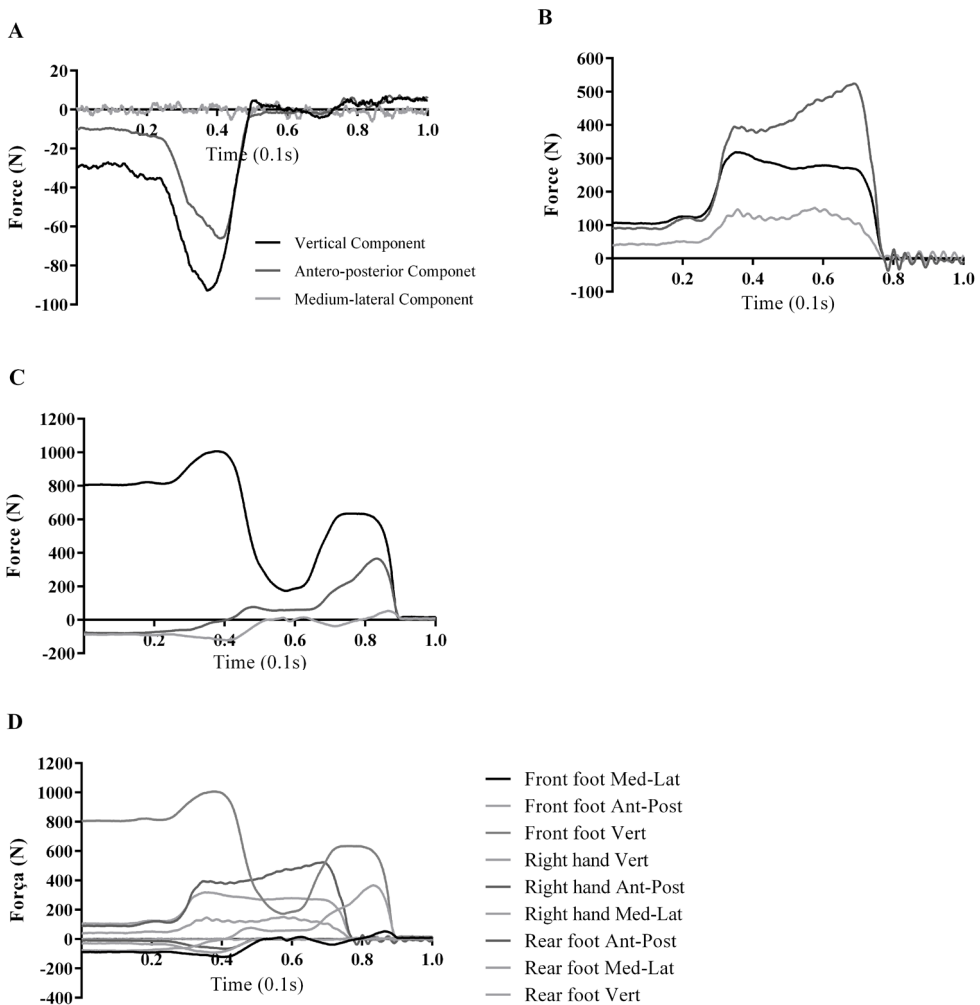


Figure 4. Block reaction forces vs. time from right hand (A), rear foot (B), front foot (C), upper and lower limbs superimposed (D)

Table 2 presents the peak absolute values of the forces produced by the right upper limb and the two lower limbs in the sub-phase where their action is the most characteristic a. The values of the left upper limb are not showed because its behaviour is identical to the right limb, so the information would be redundant.

Table 2. Absolute values of peak forces of the most characteristic limb during the last three sub-phase of the block phase

	Hands take-off	Rear foot take-off	Front foot take-off
F_{\max}	Right hand	Rear foot	Front foot
F_{vertical} (N)	103	279	634
$F_{\text{antero-posterior}}$ (N)	66	524	366

In both hands take-off and front foot take-off sub-phases the vertical component of the force produced the highest peak value, respectively 103 N and 634 N. In contrast, the rear-foot take-off sub-phase is the only one where the force antero-posterior component has the highest value, 524 N (Table 2).

Table 3. shows the iEMG values in percentage of maximal mioelectric activation from each of the eight muscles studied, during each sub-phase of the block phase.

Table 3. Values of EMG integral of the muscles studied, in each sub-phase of the block phase (%)

	Reaction time	Hands take-off	Rear foot take-off	Front foot take-off
iEMG BB	1.88	6.58	11.81	5.76
iEMG BF	0.79	13.76	52.96	32.16
iEMG DA	0.41	0.26	4.07	5.76
iEMG GM	0.86	3.24	7.46	22.77
iEMG GL	5.00	15.36	36.37	26.50
iEMG RF	0.00	0.00	1.70	0.82
iEMG TA	2.20	41.17	6.69	2.20
iEMG TB	0.00	5.34	4.39	3.77

Note: BB – biceps brachii; BF – biceps femoris; DA – deltoideus anterior; GM – gastrocnemius medialis; GL – gluteus maximus; RF – rectus femoris; TA – tibialis anterior; TB, triceps brachii.

Relatively to the EMG data it can be noticed in Table 3 and Figure 5 that the muscles which present highest electrical activity in the reaction phase were the *Gluteus Maximus*, the *Tibialis Anterior* and the *Biceps Brachii*. From the subsequent instants to the hands take-off, the *Tibialis Anterior*, the *Gluteus Maximus* and the *Biceps Femoris* presented the most expressive signal and the *Tibialis Anterior* showed its highest activation levels of the whole block phase. After the hands take-off till the rear foot take-off, the *Biceps Femoris*, the *Gluteus Maximus* and the *Biceps Brachii* were the muscles most recruited and, together with the *Rectus Femoris*, they all present in this sub-phase their activation peak considering the whole block phase. In the front foot take-off sub-phase, the three most active muscles were the *Biceps Femoris*, the *Gluteo Maximus* and the *Gastrocnemius Medialis*.

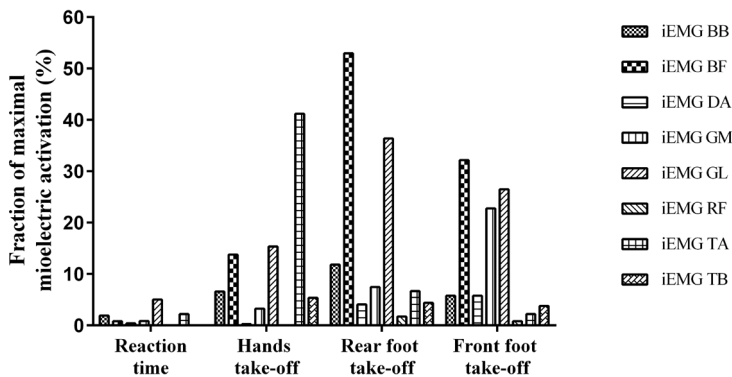


Figure 5. Graphical representation of iEMG data

Discussion

As it was hypothesised, the method developed to characterise the block phase of the modified track start revealed capability to describe the behaviour of important biomechanics parameters related with kinetics, kinematics and muscular electrical activity of a swimmer, during the first determinant part of a swimming competition, the block start.

The processed data from dynamometry, kinematics and EMG revealed coherency in the different sub-phases of the swimming start block phase. Once temporal synchronization was ensured from the beginning, it was possible to get complementary information from the three techniques used to describe the swimmer behaviour on the starting block. Crossing the signals of dynamometry with kinematics, it could be seen that the instants delimiting each of the sub-phases of the block phase were observed either by the inflections of the force curves, or by visual inspection of the 3D model created by Qualisys Track Manager® software.

The sub-phase with greater temporal duration was that between the swimmer reaction time to the starting signal until the hands take-off. This was the period in which the horizontal displacement truly began. Although the calculation of impulse has not been performed in this study probably its value would reach the maximum at this sub-phase, considering the time duration of force application and the high magnitude of its vertical component. The prevalence of this component up to the moment of hands take-off is also a reflex of the swimmer weight.

Considering the iEMG data, it was seen that the sub-phase which lasted from the hands take-off until the rear foot take-off was the one where a greater number of the analysed muscles reached its myoelectric activation peak. In this sub-phase, comparing to all the others, there was also a greater increase of the resultant average speed of the CM and, consequently, the greater acceleration throughout the whole block phase. The speed kept increasing considerably until the moment when the front foot (and the whole body) lost contact with the block, allowing the swimmer to leave the starting block with maximum speed.

In what concerns to the sequence of phases analysed it is, as predicted, accordant with literature (Honda et al., 2012; Kibele et al., 2013) but the magnitude of forces, the displacements of the CM and the muscular activation pattern still need confirmation since this is a pilot study which results refer to a single trial. Aspects like the

competitive level, laterality, gender and age surely have an influence on the measured parameters and will probably condition the results observed if this characterisation procedure is applied to other swimmers with different profiles.

In future studies, a wider sample of participants and a strict inclusion criteria should be considered to make the statistical analysis and interpretation of the results possible. It would also be interesting to have the EMG data of muscles from the left side of the body to understand their relative contribution to the swimmer movement on the starting block.

On a more conceptual level, it should be considered the possibility that within a little time a more extensive practical approach of the referred method would be plausible: from the calculation of the impulse produced by the application of forces on the block over time, knowing the angular momentum of the swimmer body and the behaviour of the CM from the take-off instant until the water entry, it might be possible to predict the take-off angle and take-off velocity. With this information, the flight trajectory and the entry angle of the swimmer can be assessed. These parameters will be valuable for researchers and swimming coaches in the sense they can give feedback to the swimmers immediately after the execution of a start, and contribute objectively to the starting technique optimization.

Conclusions

The adopted method revealed potential to produce an exhaustive biomechanical characterisation of the swimming track start block phase and it could be extended to other starting techniques, with the necessary adaptations.

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References

- de Jesus, K., de Jesus, K., Figueiredo, P., Gonçalves, P., Pereira, S., Vilas-Boas, J.P., Fernandes, R.J., (2011). Biomechanical analysis of backstroke swimming starts. *International Journal of Sports Medicine*, 32, 546–551. DOI: 10.1055/s-0031-1273688.
- de Jesus, K., de Jesus, K., Figueiredo, P., Gonçalves, P., Pereira, S., Vilar, S., ..., Fernandes, R.J. (2011). Electromyographic analysis of the backstroke start with different feet positions. *Medicine Science in Sports Exercise*, 43, 619. DOI: 10.1249/01.MSS.0000401709.20735.41.
- Figueiredo, P., Rouard, A., Vilas-Boas, J.P., Fernandes, R.J. (2013). Upper- and lower-limb muscular fatigue during the 200-m front crawl. *Applied Physiology, Nutrition, and Metabolism*, 38, 716–724. DOI: 10.1139/apnm-2012-0263.
- Figueiredo, P., Sanders, R., Gorski, T., (2012). Kinematic and Electromyographic Changes During 200m Front Crawl at Race Pace. *International Journal of Sports Medicine*, 34, 49–55. DOI: 10.1055/s-0032-1321889.
- Garcia-Hermoso, A., Escalante, Y., Arellano, R., Navarro, F., Domínguez, A.M., Saavedra, J.M. (2013). Relationship Between Final Performance and Block Times with the Traditional and the New Starting Platforms with A Back Plate in International Swimming Championship 50-M and 100-M Freestyle Events. *Journal of Sports Science Medicine*, 12 (4), 698–706.

- Honda, K., Sinclair, P., Mason, B., Pease, D. (2012). The effect of starting position on elite swim start performance using an angled kick plate. In: E.J. Bradshaw, A. Burnett, P.A. Hume (eds.), *Proceedings of the 30th International Symposium on Biomechanics in Sport* (pp. 72–75). Melbourne, Australia.
- Kibele, A., Biel, K., Fischer, S. (2013). Optimizing individual stance position in the swim start on the OSB11. In: Bundesinstitut für Sportwissenschaft (ed.), *BISp-Jahrbuch Forschungsförderung 2012/13* (pp. 61–67). Köln: sportverlag strauß.
- Lyttle, A.D., Benjanuvattra, N. (2005). Start Right? A Biomechanical Review of Dive Start Performance. Retrieved from: <http://coachesinfo.com/category/swimming/321>.
- Ribeiro, J., Morais, S.T., Figueiredo, P., de Jesus, K., Vilas-Boas, J.P., Fernandes, R.J. (2014). Effect of fatigue in spatiotemporal parameters during 100 m front crawl event monitored through 3D dual-media automatic tracking. In: B. Mason (ed.), *Proceedings of the XIIIth International Symposium for Biomechanics and Medicine in Swimming* (pp. 218–222). Canberra: Australian Institute of Sport.
- Seifert, L., Vantorre, J., Lemaitre, F., Chollet, D., Toussaint, H.M., Vilas-Boas, J.P. (2010). Different profiles of the aerial start phase in front crawl. *Journal of Strength and Conditioning Research*, 24, 507–516. DOI: 10.1519/JSC.0b013e3181c06a0e.
- Vantorre, J., Seifert, L., Fernandes, R.J., Vilas-Boas, J.P., Chollet, D. (2010). Kinematical profiling of the front crawl start. *International Journal of Sports Medicine*, 31, 16–21. DOI: 10.1055/s-0029-1241208.
- Vilas-Boas, J.P., Fernandes, R.J. (2003). Swimming starts and turns: determinant factors of swimming performance. In: P. Pelayo, M. Sidney (eds.), *Actes des 3èmes Journées Spécialisées de Natation* (pp. 84–95). Lille: Université de Lille.

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