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TETHERED SWIMMING AS AN USEFUL TOOL TO MEASURE UNBALANCE BETWEEN ARMS AND FORCE PRODUCTION DECREASE

Pedro G. Morouço[1,2,3], Daniel A. Marinho[3,4], Ricardo J. Fernandes[5,6] and Mário C. Marques[3,4]

Department of Sport Sciences, Polytechnic Institute of Leiria, Leiria, Portugal[1]
Research Center for Human Movement Sciences, Leiria, Portugal[2]
Research Centre in Sport, Health and Human Development, Portugal[3]
Department of Sport Sciences, University of Beira Interior, Covilhã, Portugal[4]
Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal[5]
Porto Biomechanics laboratory, LABIOMEP, University of Porto, Portugal[5]

Our aim of present study was to investigate the differences in force production between arms during front crawl tethered swimming (TS). Firstly, 14 young male swimmers (14.2 ± 1.09 yrs; 168.3 ± 2.22 cm; 59.9 ± 4.77 kg) undertook a 30 s maximum front crawl TS test. It was observed that preferred arm (P_Fmax) produces a maximum force higher than non-preferred arm (NP_Fmax). Additionally, was verified that the decrease in maximum force was higher for P_Fmax than NP_Fmax. In the second part of the study, 6 elite male swimmers (19.8 ± 2.23 yrs; 183.6 ± 3.64 cm; 77.3 ± 3.64 kg) replicated the methodology, being the individual curves assessed trough polynomial curves, which allowed identifying the unbalance between arms. This methodology may detect a limiting factor of performance being a useful tool for coaches training prescription.

KEY WORDS: biomechanics, strength, training, front crawl.

INTRODUCTION: One of the main goals of swimming biomechanics is to determine the swimmer's propulsive force, identifying its relationship with swimming efficiency, in order to enhance performance (Akis & Orcan, 2004; Barbosa et al., 2010). However, to obtain the magnitude of these forces in the aquatic environment is highly complex. Tethered swimming (TS) is one of the reliable methodologies used to achieve part of this goal, particularly by measuring the propelling force exerted by a swimmer in water (Costill et al., 1986; Dopsaj et al., 2003; Kjendlie & Thorsvald, 2006; Filho & Denadai, 2008). In fact, by using a load cell system it is possible to assess individual force to time curves, improving the possibility of characterization and comparison of stroke patterns, and allowing a more accurate knowledge of the propulsive forces sequence during swimming (Morouço et al., 2010).
In addition, TS may help coaches, in real time, with technique prescription, and can provide answers to some practical issues that remain controversial. The unbalance between arms in terms of force production is one of these cases. Research on this topic is scarce, and some ideas are passed among members of the swimming community with little scientific (experimental or numerical data) support. Swimming performance is highly related to the propulsive forces (Rouard et al., 1996) and, in front crawl and backstroke, arm actions are alternated. Thus, it is useful to evaluate the differences of force production between arms. However, studies conducted in this domain are scarce.
Complementarily, Reischle (1998) indicated that specificity should be aimed in the training process. As a result, coaches may orientate their work with adequate strategies to a correct planning, control and evaluation. Special attention should be given to the role of the arms, as it is generally agreed that 85% of the total thrust is due to arms in front crawl stroke (Toussaint et al., 2000). Even though force production capacity is expected to be related to muscle mass, this particular relationship in swimming may be affected by specific swimming ability, traducing the subjects' capacity to apply force in water. Therefore, the main purpose of this study was to measure the differences of force production between arms in front crawl tethered swimming. Complementarily, the decrease in force production during a 30 s maximum effort was analysed.

METHODS: In the first part of the study (GR1), 14 young male swimmers of regional level were evaluated (age 14.2 ± 1.09 years; height 168.3 ± 2.22 cm; weight 59.9 ± 4.77 kg). In the second part (GR2), 6 elite swimmers were tested (age 19.8 ± 2.23 years; height 183.6 ± 3.64 cm; weight 77.3 ± 3.64 kg). The participants were primarily sprint and middle distance trained swimmers. Their personal best for 100 m freestyle averaged 63.32 ± 1.69 s and 51.86 ± 0.63 s, for GR1 and GR2, respectively. All tests were conducted in a 50 m indoor swimming-pool (27º C of water temperature) during the competitive period of the spring macrocycle to ensure that the subjects were in a high training stage. After an 800 m (GR1) or 1200 m (GR2) low intensity warm-up, each subject performed one 30 s all-out front crawl tethered swimming test. The subjects were wearing a belt attached to a non-elastic steal cable with 5 m length. A load-cell system connected to the cable was used as a measuring device, recording at 100 Hz with a measure capacity of 5000 N. The load-cell was connected to a Globus Ergometer data acquisition system (GlobusTM, Italy) that exported the data to a PC. Preceding the starting signal, swimmers adopted a horizontal position with the cable fully extended; the data collection only started after the first stroke cycle was completed. This procedure was used to avoid the inertial effect of the cable extension usually produced immediately before or during the first arm action. The end of the test was set through an acoustic signal. The experiments conducted in normal swimming pool conditions, using an appropriate methodology (cf. Dopsaj et al., 2003; Kjendlie & Thorsvald, 2006), allowed real time access to data.
Individual force to time - F(t) - curves were assessed and registered to obtain the values of maximum force production for the preferred (PF_max) and non-preferred (NP_Fmax) arm. Preferred and non-preferred distinction was based in visual inspection of the F(t) curve, being considered the preferred arm the one with higher maximum force production. Additionally, mean force production for each stroke cycle was calculated for GR2 being calculated correspondent polynomial curves. The swimming velocities (v) were obtained by the official electronic chronometric times of long course swimming competitions (100 m freestyle) within the 25 days following the tethered swimming experiments.
Statistical analysis was made using SPSS v15.0 package. To obtain the descriptive statistics (mean ± SD) standard statistical methods were used. The Kolmogorov-Smirnov normality test was applied to examine the distribution of variables. For the preliminary study, an independent samples t-test was performed in order to detect differences between the arms force production. In order to establish relationships between variables, a Pearson's correlation coefficient (r) was used for force production values and swimming velocity. In the second study, for the same analysis, Mann-Whitney test and Spearman correlation coefficient were applied. The level of statistical significance was set at $\alpha = 0.05$.

RESULTS AND DISCUSSION: The maximum force values collected for GR1 presented differences between arms (P_Fmax 169.85 ± 14.38 N vs. NP_Fmax 137.44 ± 26.32 N, $p < 0.01$), being possible to assume that the swimmers tested cannot produce the same levels of force with both arms. In this first study, the average swimming velocity for the 100 m correlated significantly with P_Fmax ($r = 0.92$, $p < 0.001$), but not with NP_Fmax ($r = 0.48$, $p > 0.05$). Relationship between swimming performance in sprint events and variables obtained trough TS is assumed in specialized literature (Costill et al., 1986; Keskinen et al., 1989; Morouço et al., 2010).
Concerning the second part of the study, no statistical differences in maximum force values were obtained between arms (P_Fmax 255.86 ± 15.31 N vs. NP_Fmax 228.83 ± 19.93 N, $p > 0.05$). The inexistence of statistical significance difference can be due to the small number of subjects evaluated. Therefore, an individual analysis of force pattern during the 30 s effort was carried. Two different patterns of polynomial curves of maximum force production according to arm are shown in Figures 1 and 2. In Figure 1 it is noticeable that the non preferred arm can maintain the same level of force production during the 30 s test, while the preferred arm presents a decrease of 34.76 %. In Figure 2 it is possible to diagnosis the lack of force production by the non-preferred arm, being compensated with higher values from the

preferred arm. It is possible to infer that increasing the force production of the non-preferred arm, would enhance the swimming performance for both swimmers presented.

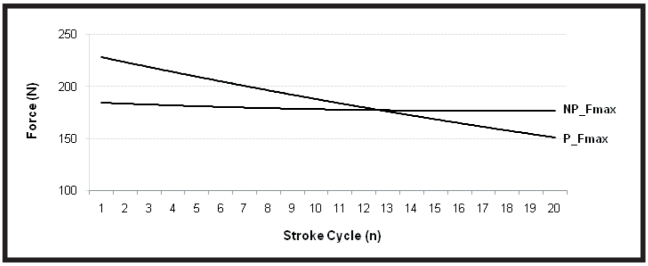

Figure 1: Polynomial regression curves of swimmer #2 maximum force production per stroke cycle. P_Fmax, maximum force produced by the preferred arm; NP_Fmax, maximum force produced by the non preferred arm.

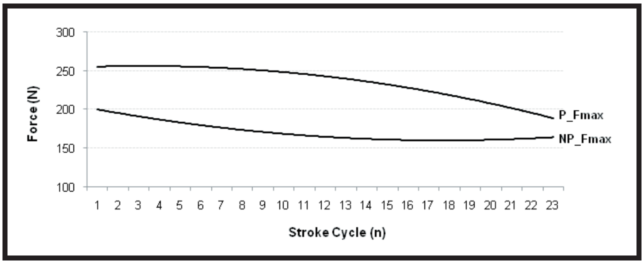

Figure 2: Polynomial regression curves of swimmer #3 maximum force production per stroke cycle. P_Fmax, maximum force produced by the preferred arm; NP_Fmax, maximum force produced by the non preferred arm.

Complementarily, average swimming velocity in the 100 m presented a significant correlation with P_Fmax and NP_Fmax ($r = 0.91$, $p < 0.05$ and $r = 0.86$, $p < 0.05$, respectively). This data suggest that higher level swimmers can approximate the levels of force production between arms. This fact may be due to the superior dry-land training that elite group does.
It has been suggested a decline in force production to be due to fatigue (Morouço et al., 2010; Soares et al., 2010). Figure 3 shows the patterns of mean force production for the elite swimmers. The average decrease of 5 swimmers is 32.5 ± 4.0 %. However it is possible to identify one of the swimmers (dashed line) that present a decrease of 47.5 %. Concerning that as the swimming distance diminish, the role of maximum force increases, and as the distance increase, the endurance force takes a major role (Wilke & Madsen, 1990), TS may be a useful tool to identify profiles particularly adapted to short or long distance swimming.

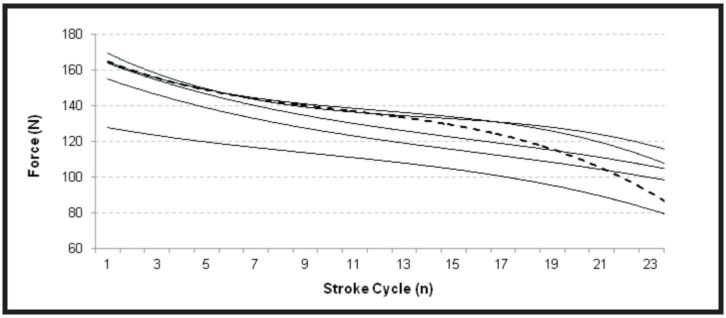

Figure 3: Polynomial regression curves of elite swimmers mean force production per stroke cycle.

CONCLUSION: The used methodology allowed gathering individual, easy to obtain and up to date information related with the force that swimmers can exert in the water. Differences between arms in force production can be assessed, as well as the percentage of force production decrease, identifying a tendency of each swimmer for short or longer swimming distances. Thus tethered force, as measured in this study, may be a useful methodology to identify factors that are related to swimming performance. In future studies, an analysis of synchronized TS and underwater video may be able to identify the specific factors that limit performance.

REFERENCES:

Akis, T. & Orcan, Y. (2004). Experimental and analytical investigation of the mechanics of crawl stroke swimming. *Mechanics Research Communication,* 31, 243-261.

Barbosa, T., Bragada, J., Reis, V., Marinho, D., Carvalho, C. & Silva, A. (2010). Energetics and biomechanics as determining factors of swimming performance: Updating the state of the art. *Journal of Science and Medicine in Sport*, 13, 262-269.

Costill, D.L., Rayfield, F., Kirwan, J. & Thomas, R. (1986). A computer based system for the measurement of force and power during front crawl swimming. *Journal of Swimming Research*, 2, 16-19.

Dopsaj, M., Matkovic, I., Thanopoulos, V. & Okicic, T. (2003). Reliability and validity of basic kinematics and mechanical characteristics of pulling force in swimmers measured by the method of tethered swimming with maximum intensity of 60 seconds. *Physical Education & Sport*, 1(10), 11-12.

Filho, D.M. & Denadai, B.S. (2008). Mathematical basis for modelling swimmer power output in the front crawl tethered swimming: an application to aerobic evaluation. *The Open Sports Sciences Journal*, 1, 31-37.

Keskinen, K.L., Tilli, L.J. & Komi, P.V. (1989). Maximum velocity swimming: Interrelationships of stroking characteristics, force production and anthropometric variables. *Scandinavian Journal of Sports Science*, 11, 87-92.

Kjendlie, P.L. & Thorsvald, K. (2006). A tethered swimming power test is highly reliable. *Portuguese Journal of Sport Sciences*, 6(S2), 231-233.

Morouço, P., Keskinen, K., Vilas-Boas, J.P. & Fernandes, R.J. (2010). Relationship between tethered forces and performance in the four conventional swimming techniques. *Journal of Applied Biomechanics* (in press).

Reischle, K. (1998). Objectives and requirements for technique diagnosis in swimming. In K. Keskinen, P. Komi, A. Hollander (Eds.) *Biomechanics and Medicine in Swimming VIII* (pp 147-152). Jyvaskyla: Gummerus Printing.

Rouard, A.H., Schleihauf, R.E. & Troup, J.P. (1996). Hand forces and phases in freestyle stroke. In J.P. Troup, A.P. Hollander, D. Strasse et al. (Eds.) *Swimming Science VII* (pp 35-44). London: E & FN Spon.

Soares, S., Silva, R., Aleixo, I., Machado, L., Fernandes, R.J., Maia, J. & Vilas-Boas, J.P. (2010). Evaluation of Force Production and Fatigue using an Anaerobic Test Performed by Differently Matured Swimmers. In P-L. Kjendlie, R. Stallman, J. Cabri (Eds.) *Book of proceedings of the XI Symposium on Biomechanics and Medicine in Swimming* (pp 291-293). Oslo: Norwegian School of Sport Sciences.

Toussaint, H.M., Hollander, A.P., Berg, C. & Vorontsov, A. (2000). Biomechanics of swimming. In W.e. Garret & D.T. Kirkendall (Eds.) *Exercise and Sport Science* (pp. 639-660). Philadelphia: Lippincott, Williams & Wilkins.

Wilke, K. & Madsen, O. (1990). *Coaching the Young Swimmer*. Sports Support Syndicate.

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