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ORIGINAL ARTICLE

Kinematical changes in swimming front Crawl and Breaststroke with the AquaTrainer® snorkel

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Abstract The aim of the present study was to assess the kinematical changes when swimming maximal bouts in Front Crawl and Breaststroke with the AquaTrainer® snorkel. Thirteen male swimmers (7 at Breaststroke and 6 at Front Crawl) of national level performed randomly two maximal bouts of 100-m swims: one bout using the AquaTrainer® snorkel (snorkel swim) and another one without the snorkel (free swim). The swims were videotaped in sagital plane with a pair of cameras providing 2D kinematics evaluation. The following measures were assessed: swimming performance (T100), stroke cycle period (P), stroke rate (SR), stroke length (SL), swimming velocity (v), swimming efficiency as estimated by the stroke index (SI), speed fluctuation (dv) and the mathematical characterisation of dv. *T100* was significantly higher when swimming with the snorkel than in free swimming at Breaststroke ($\Delta = 6.26\%$) and at Front Crawl ($\Delta = 4.75\%$). P, SR and SL, as well as SI and dv did not present significant differences. The main finding of the study was that changes in the swimming velocity imposed by the use of the Aquatrainer® do not seem due to changes in general kinematics or swimming efficiency.

Keywords Competitive swimming · Stroke rate · Stroke length · Speed fluctuation · Swimming snorkel

Introduction

Presently, the K4 b^2 gas analyzer (Cosmed, Rome, Italy) is a frequently used apparatus for gas exchange measurements within sport and physical activity investigations. This can be attributed to some technical characteristics of the equipment, such as: (1) its portability due to its small size and weight, (2) the non-significant change of the centre of gravity location when a subject is using the equipment attached to himself, (3) the possibility of free movements which is related to its telemetric characteristics, and (4) the possibility of breath-by-breath data record.

Several studies have shown that this equipment recorded with acceptable accuracy, reliability and validity VO_2, VCO_2, FEO_2, $FECO_2$, VE and other cardiorespiratory parameters, in different exercise conditions (Duffield et al. 2004; Hausswirth et al. 1997; Maiolo et al. 2003; McLaughlin et al. 2001, 2006; Pinnington et al. 2001). The K4 b^2 has also several optional equipments that can be used with it in order to perform cardiorespiratory measurements in different types of activities and subjects with validity, accuracy and reliability (Art et al. 2006; Pinnington et al. 2001).

This gas analyzer was also used in recent published works related to competitive swimming (Barbosa et al. 2005, 2006a, b, 2008; Machado et al. 2006). In those studies the K4 b^2 was connected to the so called "Toussaint

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snorkel" (Toussaint et al. 1987). It was reported good validity and accuracy of the cardiorespiratory parameters throughout a wide physiological range when the "Toussaint snorkel" was connected to the K4 b^2 (Keskinen et al. 2003; Rodríguez et al. 2008).

On the other hand, one of the optional equipments for the K4 b^2 at disposal of researchers and evaluators is a specific snorkel developed by the COSMED® to be used in aquatic environments called AquaTrainer®. AquaTrainer® has a geometry, volume, density and dimensions similar to the "Toussaint snorkel" reported by Keskinen et al. (2003) and Barbosa et al. (2005, 2008). It is characterized by having a rod length of 210-cm, operating from the distance up to 400-cm and a breathing valve volume of 45-ml. Manufacture describes this snorkel as being light, hydrodynamic, ergonomic and comfortable, with waterproof design, high accuracy and reliability. However, until this moment little is known about the mechanical (kinematical) changes that such snorkel might induce to swimmers in any other stroke technique, except for Front Crawl (Kjendlie et al. 2003). It can be useful for future researchers using the AquaTrainer® to be aware of the kinematical modifications that might be attributed to its use. Therefore, ecological interpretation of biomechanical data will be more accurate. In this sense, the Front Crawl and the Breaststroke are appropriate strokes to be evaluated, as both of them are the ones with larger research interests within competitive swimming. Moreover, Front Crawl and Breaststroke have, respectively, different mechanical characteristics, such as for example, simultaneous versus alternated arms and legs coordination, low versus high speed fluctuations and different energy cost (Barbosa et al. 2006a, b).

The aim of the present study was to assess the kinematical changes when swimming maximal bouts in Front Crawl and Breaststroke with the AquaTrainer® snorkel.

Methods

Subjects

Thirteen male swimmers (7 at Breaststroke and 6 at Front Crawl) of national level volunteered and provided written informed consent to be included in the study. The mean (±SD) age, height and body mass of the Breaststroke swimmers were, 19.1 ± 4.3, 1.78 ± 0.62, and 70.4 ± 8.0, respectively. The mean (±SD) age, height and body mass of the Front Crawl swimmers were, 18.5 ± 2.51, 1.78 ± 0.53, and 73.03 ± 9.72, respectively. The subjects' best performance over 100-m was 69.10 ± 4.16 s in Breaststroke and 57.72 ± 2.92 s in Front Crawl, corresponding, respectively, to 672.0 ± 115.04 and to 598.20 ± 90.71 FINA ranking points. All the procedures were approved by the institutional Ethics Committee.

Design

The subjects were submitted to two maximal bouts of 100-m swims in a 50-m length indoor swimming pool with testing order randomized. One 100-m bout was performed in free swimming (without the use of the AquaTrainer® snorkel). Another 100-m bout was made swimming with a snorkel (with the use of the AquaTrainer® snorkel). Both trials were made with a start in water, one single swimmer per lane, swimming against himself (without other swimmers in the remaining lanes) and performing always the open turn to the side of the lateral wall of the swimming pool. The rest period between both evaluations was of at least 48 h. Previously to each and every bout the swimmers performed an individual standard warm-up at low intensity.

Data collection

The swims were videotaped in sagital plane with a pair of cameras providing a dual projection from both underwater (GR-SXM25 SVHS, JVC, Yokoama, Japan) and above (GR-SX1 SVHS, JVC, Yokoama, Japan) the water surface. The cameras were placed stationary at 25-m of the head-wall, in a lateral wall of the pool, perpendicular to the line of motion and 10-m away from the swimmer. The images of both cameras were recorded independently.

The study comprised the kinematical analysis of stroke cycles (Ariel Performance Analysis System, Ariel Dynamics Inc., USA) through a VCR (Panasonic, AG 7355, Japan) at a frequency of 50 Hz. Zatsiorsky's model with an adaptation by de Leva (1996) was used with the division of the trunk in two articulated parts. It was also digitized the water surface using the light reflection in the water (Colman et al. 1998). To create a single image of dual projection as described previously (Barbosa et al. 2005; Vilas-Boas et al. 1997), the independent digitalization from both cameras was reconstructed with the help of a calibration volume (cube with 12 m^3 and 20 point) and a 2D DLT algorithm (Abdel-Aziz and Karara 1971). For the analysis of the curve of the centre of mass's kinematics a filter with a cut-off frequency of 5 Hz was used, as suggested by Winter (1990). For the hands and feet's kinematics a cut-off frequency of 9 Hz was used, near to the value proposed by Winter (1990). A double-passage filtering for the signal processing was used. The digitise–redigitise reliability was very high (ICC = 0.97 ± 0.01 for Front Crawl and ICC = 0.98 ± 0.01 for Breaststroke). Stroke mechanics was measured by the stroke cycle period (P, s), the stroke rate (SR = $1/P$, Hz), the stroke length (SL, m) and the mean swimming velocity of the full stroke (v, m s^{-1}). Finally, the swimming efficiency was estimated with the stroke index ($SI = v$ SL, $m^2 c^{-1} s^{-1}$) as suggested by Costill et al. (1985) and the intra-cyclic variation of the horizontal velocity of the centre of mass (dv, %) by Barbosa et al. (2006a, b).

Statistical procedures

Coefficients of variation of the horizontal velocity of the centre of mass along the stroke cycle were calculated for the assessment of dv. All dependent variables are presented as mean ± 1 SD. Percentage difference (Δ) according to the exercise condition is also reported for all dependent variables.

Mean dv curves normalized to time were computed with MATLAB (version 6 R12, MathWorks Inc., Massachusetts, USA). Polynomial regression (7th power at Breaststroke and 8th power at Front Crawl) between centre of mass's horizontal velocity and normalized duration of the full stroke cycle ($P \leq 0.05$) were also calculated. The polynomial models were based in the Akaike Information, Amemiya's Prediction and Schwartz tests.

Normality (defined as $Y \cap N$ ($\mu_{Y|X1, X2,..., XK}$, σ^2) was determinate by Shapiro–Wilk test. Since, the very low value of the N ($N < 30$) and the rejection of the null hypothesis (H_0) in the normality assessment, non-parametric procedures were adopted. Wilcoxon test was computed to compare significant differences in the dependent variables (performance, stroke mechanics and efficiency variables) according to the independent variable (free versus snorkel swim). Z values presented are based on positive ranks. The level of statistical significance was set at $P \leq 0.05$.

Since a limited sampled is used, effect size was computed with Cohen's d for all dependent variables. It was considered a (Cohen 1988): (1) small effect size if $0 \leq |d| \leq 0.2$; (2) medium effect size if $0.2 < |d| \leq 0.5$ and; (3) large effect size if $|d| > 0.5$.

Results

Swimming performance

Figure 1 presents the comparison of the 100-M bout duration (*T100*) in both swimming conditions. *T100* was significantly higher when swimming with the snorkel when compared with the free swimming in Breaststroke ($\Delta = 6.26\%$, $Z = -2.366$, $P = 0.02$, $d = 1.15$) and at Front Crawl ($\Delta = 4.75\%$, $Z = -2.023$, $P = 0.04$, $d = 0.88$). In Breaststroke, swimmers performed the *T100* during free swimming at 109.09 ± 2.23% of their personal record and at 115.94 ± 3.31% swimming with the snorkel. In Front Crawl, swimmers performed *T100* at 105.05 ± 2.45 and 109.99 ± 3.47% of their personal records without and with the snorkel, respectively.

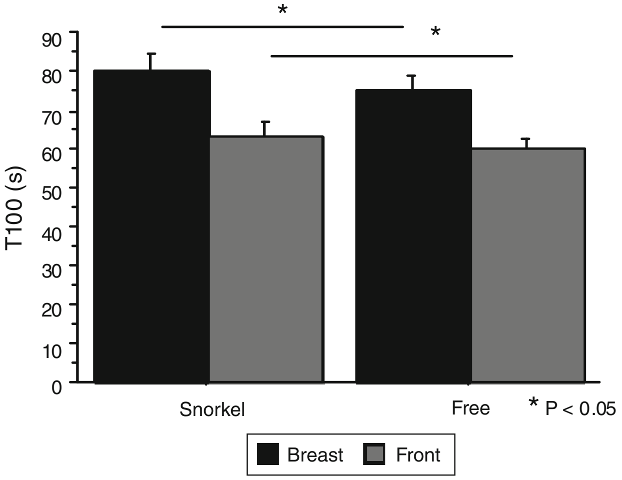

Fig. 1 Comparison of swimming performance (*T100*) in free and snorkel swimming at Breaststroke (Breast) and Front Crawl (Front)

Stroke mechanics

Figure 2 presents the comparison of the stroke parameters in both swimming conditions. In Breaststroke, there were no significant differences between free and snorkel swim. However, there was a slight tendency for the increase of the SR ($\Delta = 3.56\%$, $Z = -1.214$, $P = 0.23$, $d = 0.37$) and P ($\Delta = -3.24\%$, $Z = -1.472$, $P = 0.14$, $d = 0.33$) swimming with the snorkel. On other hand, a decrease tendency of the SL ($\Delta = -3.62\%$, $Z = -1.352$, $P = 0.18$, $d = 0.66$) and the v ($\Delta = -5.98\%$, $Z = -0.745$, $P = 0.40$, $d = 0.53$) was verified during snorkel swim.

In Front Crawl, the SR ($\Delta = -1.58\%$; $Z = -0.524$, $P = 0.60$, $d = 0.29$), the SL ($\Delta = -3.62\%$, $Z = -0.943$, $P = 0.35$, $d = 0.33$), the v ($\Delta = -5.75\%$, $Z = -0.943$, $P = 0.345$, $d = 0.58$) and the P ($\Delta = 1.63\%$, $Z = -0.422$, $P = 0.67$, $d = 0.19$) did not presented significant differences.

Swimming efficiency estimation

Figure 3 presents examples from two swimmers of individual curves of the intra-cyclic variation of the horizontal velocity of the centre of mass at Front Crawl and Breaststroke during free and snorkel swims. Figure 4 presents the mean intra-cyclic variation of the horizontal velocity of the centre of mass for both swimming conditions. In Breaststroke, for both exercise conditions, dv was characterized by a bi-modal profile. In Front Crawl, dv was more stable, with fewer variations.

Table 1 presents the computed dv's mathematical model for both swim strokes. All mathematical models were

Fig. 2 Comparison of stroke rate (SR, **a**), stroke length (SL, **b**), swimming velocity (v, **c**) and cycle period (P, **d**) in free and snorkel swimming at Breaststroke (Breast) and Front Crawl (Front)

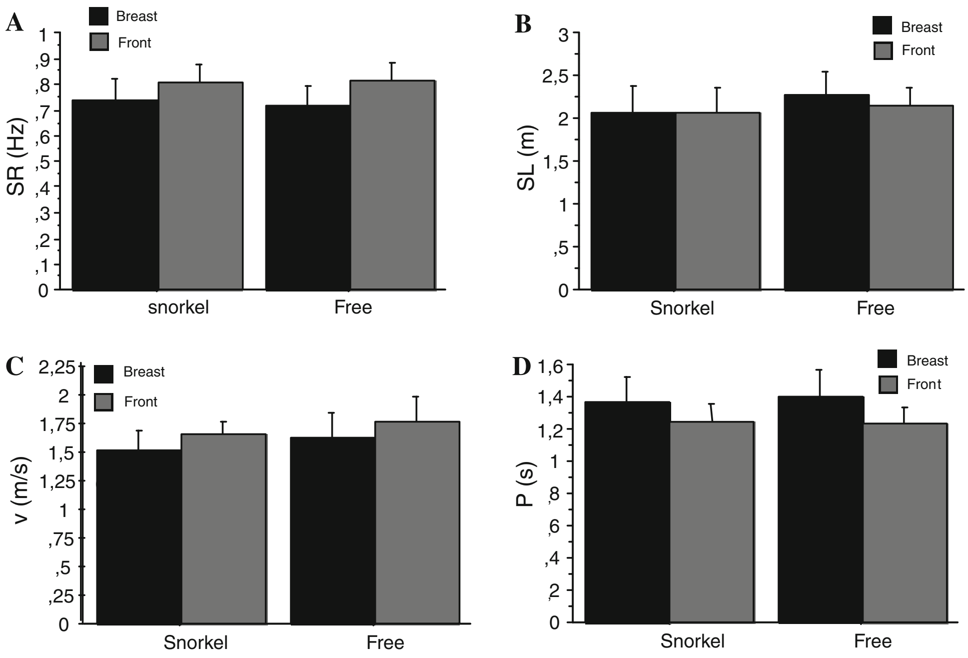

Fig. 3 Individual intra-cyclic variation of the horizontal velocity of the centre of mass in free and snorkel swimming from two swimmers

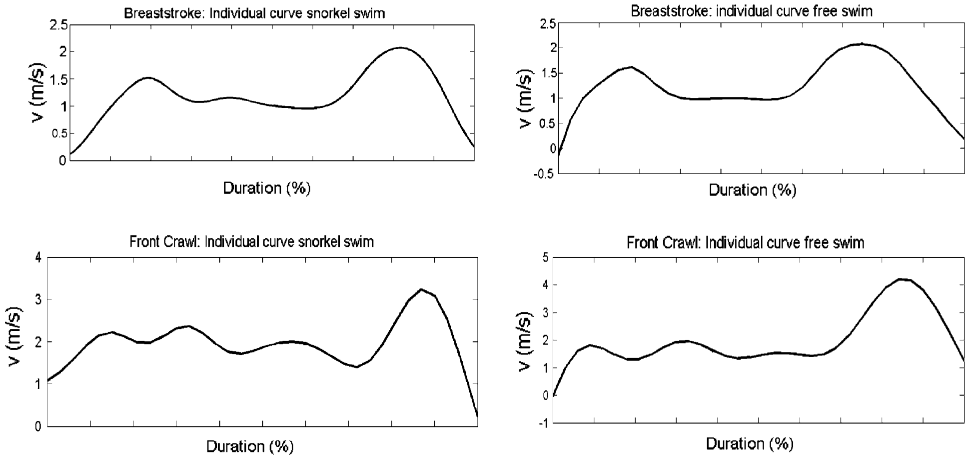

Fig. 4 Mean intra-cyclic variation of the horizontal velocity of the centre of mass in free and snorkel swimming

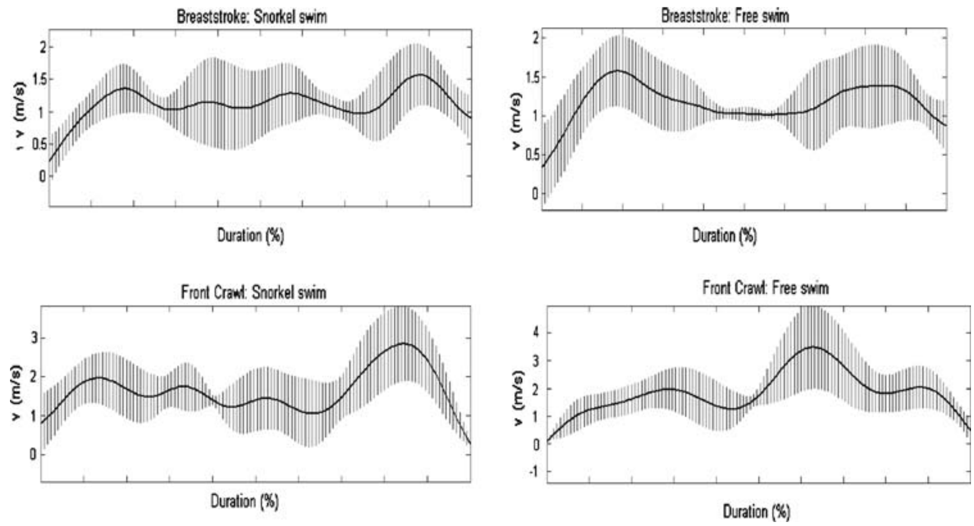

Table 1 Mathematical models of the intra-cyclic variation of the horizontal velocity of the centre of mass computed for both strokes techniques in free and snorkel swims

Stroke	Condition	Equation	R^2	R_a^2	P	s
Front	Free	$y = 0.289 + 0.576x - 0.096x^2 + 0.008x^3 - 3.403\text{E}{-}4x^4 + 7.909\text{E}{-}6x^5 - 1.009\text{E}{-}7x^6 + 6.627\text{E}{-}10x^7 - 1.752\text{E}{-}12x^8$	0.32	0.21	<0.01	1.0
Front	Snorkel	$y = 0.783 + 0.222x + 0.004x^2 - 0.002x^3 + 1.103\text{E}{-}4x^4 - 2.898\text{E}{-}6x^5 + 3.928\text{E}{-}8x^6 - 2.665\text{E}{-}10x^7 + 7.152\text{E}{-}13x^8$	0.33	0.31	<0.01	0.97
Breast	Free	$y = 0.714 + 0.128x - 0.002x^2 - 1.689\text{E}{-}4x^3 + 6.646\text{E}{-}6x^4 - 1.026\text{E}{-}7x^5 + 7.61\text{E}{-}10x^6 - 2.264\text{E}{-}12x^7$	0.37	0.35	<0.01	0.37
Breast	Snorkel	$y = 0.875 + 0.123x - 0.005x^2 + 6.84\text{E}{-}5x^3 + 9.79\text{E}{-}7x^4 - 4.092\text{E}{-}8x^5 + 4.561\text{E}{-}10x^6 - 1.735\text{E}{-}12x^7$	0.47	0.45	<0.01	0.25

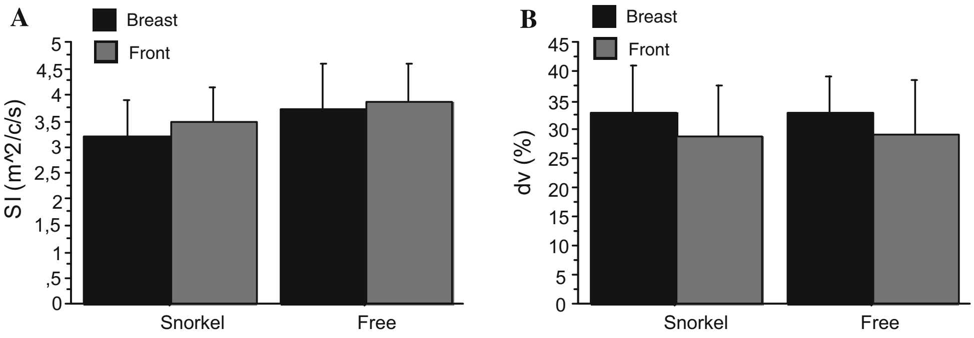

Fig. 5 Comparison of stroke index (SI, **a**) and speed fluctuation (dv, **b**) in free and snorkel swimming at Breaststroke (Breast) and Front Crawl (Front)

statistically significant. The determination coefficients were moderate ($0.31 \leq R^2 \leq 0.47$).

Figure 5 presents the comparison of the parameters adopted to estimate the swimming efficiency in both conditions. In Breaststroke, there was no significant differences neither in SI ($\Delta = -13.94\%$, $Z = -1.183$, $P = 0.24$, $d = 0.66$) nor in dv ($\Delta = -0.16\%$, $Z = -0.338$, $P = 0.74$, $d = 0.07$). The same phenomenon was verified at Front Crawl for SI ($\Delta = -9.27\%$, $Z = -1.153$, $P = 0.25$, $d = 0.50$) and dv ($\Delta = -2.21\%$, $Z = -0.314$, $P = 0.75$, $d = 0.07$).

Discussion

The aim of the present study was to assess the kinematical changes when swimming maximal bouts in Front Crawl and Breaststroke with the AquaTrainer® snorkel. The main finding of the study was that both swim strokes with Aquatrainer® presented changes in the swimming velocity but not in the mechanical variables that were assessed.

Swimming performance

T100 was significantly higher during snorkel swimming when compared with free swimming in Breaststroke ($\Delta = 6.26\%$) and at Front Crawl ($\Delta = 4.75\%$). A swimming event can be decomposed in four moments (start, swim, turn, and finish). Wearing the snorkel might impose constrictions during some or all these moments. For example, the gliding phases after the start and the turns are usually less demanding when the swimmer is connected to the snorkel. Moreover, at Front Crawl, the turning technique must be changed from the rolling to the open turn. Wearing such apparatus can impose an increase of the passive and active drag, despite the reduced frontal area of the snorkel. This increased drag, for a given propulsive force, might decrease the swimming velocity and therefore the swimming performance. In fact, Toussaint et al. (1987) reported an increase of drag force up to 10% wearing his snorkel. Kjendlie et al. (2003) also suggested the existence of an increased drag for swims with a snorkel. Nevertheless, a deeper study (experimental and/or numerical) about passive and active drag swimming with a snorkel can be very useful.

Stroke mechanics

It should be noted that the normal biomechanical pattern between v, SR, and SL is that the v will increase with the increase in SR while SL tends to decrease. Now the normal behavior seems to be changed by snorkel swimming. There is a change in v in favor of free swimming which is a normal reaction. However, there is a minimal or no change in SR for Front Crawl which is an abnormal behavior. In breaststroke SR is even decreasing with the increased v. This all means that in snorkel swimming the swimmers must do relatively more work in terms of SR to obtain lower v as compared to free swimming. This finding was confirmed by SL which was increasing in both Front Crawl and Breaststroke along with the increase in v.

In Breaststroke and Front Crawl there were no significant differences in any stroke parameter. These data confirm the non-existence of significant differences reported by Kjendlie et al. (2003) for the “Toussaint snorkel”. Nevertheless, a tendency for the change in those variables was verified when swimming with the snorkel similarly for all swimmers. For example, in both techniques, the v and the SL decreased. The decreased v for snorkel swim can be attributed to a higher active drag as discussed previously. The decreased SL induces a decrease of the v, since this last one depends from SR and SL. The SR behavior was not so clear, since it increased in Breaststroke and decreased in Front Crawl when using the snorkel. The SR behavior seems logical when referring to normal biomechanical pattern between v and SR. It seems that added drag was higher in Breaststroke as compared to Front Crawl during snorkel swim. On other hand, P increased in both strokes. These results can be explained by different motor control strategies adopted by swimmers. Motor control (i.e. inter-limb coordination) in competitive swimming is influenced by environmental constrains, task constrains, organismic constrains, subjects competitive level and anthropometrical or disability characteristics (Seifert and Chollet 2008). Environmental constrains are related to environment physical characteristics, submitting swimmers to external forces that will impose different inter-limb coordination patterns. This was reported at least for swimmers submitted to added active drag in other swimming situations (e.g., Seifert et al. 2008). Since snorkel swim will induce as well an added drag, it might be speculate that changes will happened in the swimmers motor control strategies.

Therefore, the present findings together with data from Kjendlie et al. (2003) confirm that the normal biomechanical pattern was changed due to snorkel swim. In this sense, it can be also useful to perform further comparative studies on segmental coordination swimming with a snorkel. A theoretical relationship between swimming efficiency and SL is often considered (Toussaint and Hollander 1994). So, it is questionable if a higher SL in free swim is also related with an increased swim efficiency. Therefore, the comparison of the swimming efficiency between free and snorkel swims is important.

Swimming efficiency estimation

In Breaststroke, for both exercise conditions, dv was characterized by a bi-modal profile. One peak is related to arm’s actions and the other one to the leg’s action (Capitão et al. 2006; Craig et al. 2006). When wearing the snorkel, due to added drag, it is obvious that the decrease of v between arms and leg’s actions are less smooth and with a high standard deviation. Probably this large variation can be again related to different segmental coordination strategies for snorkel swim. This data confirms the need of motor control studies in a near future. In Front Crawl, dv is more stable, with fewer variations than Breaststroke. Higher peaks are related to arm’s actions and lower peaks to leg’s actions (Craig et al. 2006). From the curve analysis it can be verified that the two higher peaks present different maximal velocities. Those maximal values are related to the most propulsive phases of each arm. It seems that there is an asymmetrical application of propulsive force from both arms, at least in these subjects. While the sample size is limited, new highlights about the asymmetrical application of propulsive force should be obtained in a near future in a larger sample, characterizing inter-arms differences.

All computed mathematical models were statically significant and can predict satisfactorily the dv ($0.31 \leq R^2 \leq 0.47$, $0.25 \leq s \leq 1.0$). The determination coefficients were moderate, since swimmers present different individual dv curves. For example, some swimmers adopted a one peak velocity pattern ($N = 4$) and others a two-peak velocity patterns ($N = 2$) by arm action at Front Crawl (Maglischo 2003). At Breaststroke, swimmers can use a longer or shorter gliding phase between arms and legs actions (Chollet et al. 2004; Maglischo 2003). The relationship between mean curves and individual curves is the base of discussion about universal perspective versus the individual one for data analysis. Universal changes, for a given swim stroke are described by mean curves. The mean curves express intra-individual changes that are shared by almost every swimmer. It is assumed the non-variance between swimmers and it is stressed the modal or normative behavior of dv. Individual profiles are considered as residual variances with no significance for the mean curve. Consequently, the s value might increase and the R^2 decrease in a direct proportion of intra-individual changes. However, there is main curve pattern that it is shared by all swimmers, based in what is considered as the “biomechanical model” that allows the subject to be more efficient performing a given stroke. Nevertheless, some individual changes are verified in those curves, according to the swimmers analyzed, expressing his individual interpretation of the swim technique.

High SI values are inversely associated with the energy cost of swimming (Costill et al. 1985). On other hand, dv is directly related with energy cost of swimming (Barbosa et al. 2006a, b). Moreover, energy cost of swimming has an inverse relationship with swimming efficiency (Zamparo 2006). So, SI and dv are appropriate variables to estimate swimming efficiency. There were no significant differences in SI and in dv at Breaststroke and Front Crawl. Once again, this confirms data from Kjendlie et al. (2003). The dv was slight lower, for both strokes during snorkel swim. The dv has a polynomial relationship (inverse "U") with *v* (Barbosa et al. 2006a, b). So, the lower dv wearing the snorkel must be related to the lower *v* that swimmers achieved in such exercise condition. At free swim, subjects achieved a slightly higher *v* and, therefore a larger speed fluctuation.

Conclusions

As a conclusion, the AquaTrainer® snorkel imposes changes in the normal biomechanical pattern when swimming Breaststroke and Front Crawl. However, more data is warranted to confirm our findings. Probably, the AquaTrainer® constrictions are mainly related to the gliding phases after the start and turn moments. Some smooth kinematical changes were verified for the stroke technique due to added drag. So, evaluators when interpreting and discussing data collected with such apparatus must take into account the underestimation or overestimation associated to its adoption, despite the snorkel reduced frontal area.

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Conflict of interest statement The authors declare that they have no conflict of interest.

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