

Influence of different breathing patterns on front crawl kinematics

Influência de diferentes padrões respiratórios na cinemática do nado crawl

José Guilherme Machado do Couto¹
Marcos Franken¹
Flávio Antônio de Souza Castro¹

Abstract – The aim of this study was to investigate the effects of different breathing patterns on the kinematics of front crawl. Eleven college swimmers (10 men and one woman) performed seven 25-m front crawl trials at maximum intensity, with 2-min intervals between trials. One trial was performed in the breath-holding condition and six trials were performed using variable breathing frequencies (every two, four and six strokes) and sides (preferred and opposite side). Twenty-five meter time (T25) and average stroke rate (SR), stroke length (SL) and swimming velocity (SV) were obtained by video analysis and compared between conditions. The results showed that breathing side had no effect on T25, SR, SL, or SV. The breathing frequency was unable to change SV, but T25 and SR were higher for the two-stroke breathing pattern. Stroke length was greater when the swimmer breathed every two strokes compared to six strokes. The breath-holding condition produced lower T25 values and higher SV and SR compared to the other breathing patterns. In conclusion, the breathing side does not seem to interfere with the kinematic variables and breath-holding resulted in shorter swim times.

Key words: Breathing frequency; Performance; Swimming.

Resumo – O objetivo deste estudo foi verificar os efeitos da execução de diferentes padrões de respiração sobre a cinemática do nado crawl. Onze nadadores universitários (10 homens e uma mulher) realizaram sete repetições de 25 m em intensidade máxima no nado crawl, com dois minutos de intervalo. Das sete repetições, uma foi realizada com respiração bloqueada e seis repetições com variação da frequência respiratória (a cada duas, quatro e seis braçadas) e de lado (preferência e oposto). Tempo nos 25 m (T25), frequência média de ciclos de braçadas (FC), distância média percorrida por ciclo de braçada (DC) e velocidade média de nado (VN) foram obtidos com cinemática e comparados entre as condições. Resultados: lado da respiração não apresentou efeitos sobre T25, FC, DC e VN. Frequência respiratória não foi capaz de alterar a VN, porém, o T25 e a FC foram maiores quando a cada duas braçadas. A DC foi maior na respiração a cada duas braçadas em comparação a cada seis braçadas. Respiração bloqueada possibilitou menores valores de T25 e maiores valores de VN e FC, quando comparada aos demais padrões respiratórios. Assim, o lado da respiração parece não interferir nas variáveis cinemáticas e o nado bloqueado apresenta menores tempos quando comparado aos nados com maiores frequências respiratórias.

Palavras-chave: Desempenho; Frequências respiratórias; Natação.

¹ Universidade Federal do Rio Grande do Sul. Escola de Educação Física. Porto Alegre, RS. Brasil.

Received: 15 January 2014
Accepted: 11 June 2014



Licence
Creative Commons

INTRODUCTION

Coaches and researchers have particular interest in the factors that determine swimming performance, which include biomechanical (related to the swimming technique), anthropometric and physiological factors¹. Important biomechanical factors are those related to the kinetics (drag and propulsion forces) and kinematics of swimming. The latter includes the average stroke rate (SR), defined as the number of arm stroke cycles per unit of time, and the average stroke length (SL) in meter², in addition to characteristics related to swimming coordination and to the trajectories of the center of mass and segments in the water³. The product of SR and SL during pure swimming determines the average swimming velocity (SV), excluding propulsive contributions of starts and/or turns against the border of the pool.

Factors that can modify the relationship between SL and SR in front crawl are the breathing pattern used by the swimmers, which is expressed as the number of arm stroke cycles per breath, with one arm stroke cycle corresponding to two complete strokes⁴. The most common breathing pattern in front crawl is one breath every two strokes. Although almost all coaches⁵ agree that this is the best pattern for distances longer than 200 m, many coaches recommend restricted breathing patterns for distances up to 100 m. The dilemma faced by swimmers is that excessive restriction in their breathing (a decrease in breathing frequency) may reduce the supply of oxygen, increase CO₂ concentrations and contribute to the onset of fatigue, whereas an excessive breathing frequency can reduce velocity. It is therefore important to determine the most effective breathing pattern for each trial distance^{6,7}.

According to Seifert et al.⁶, a swimmer can swim faster if no breathing movement is performed. There are two reasons for this: (1) the opposite stroke would be more propulsive when no force is used to increase the body roll angle related to breathing, and (2) the increase in body roll angle for breathing could increase the resistance to forward progress. Counsilman⁸ suggested breathing every two strokes in longer competitive events, whereas in sprint races the best strategy should be determined for each swimmer in relation to his performance. However, it is common for sprint swimmers to hold their breath in 50-meter races.

With respect to the breathing pattern in front crawl, studies have aimed to (1) determine the existence of differences in kinematics of the trunk and upper extremities between preferred-side breathing and breath-holding swimming⁹⁻¹¹; (2) to measure and compare the percentage of time spent in expiration, inspiration and apnea during front crawl in swimmers of intermediate level¹²; (3) to analyze the effect of breathing and breath-holding on SR, SL, SV, stroke index, swimming coordination and symmetries or asymmetries in competitive swimmers^{6,13}, and (4) to examine how breathing actions influence 25-m velocity using two breathing strategies⁴. However, different factors that affect these strategies should be taken into

consideration: body position⁷, effects of energy metabolism^{7,12}, technical and performance level⁴, specialty of the swimmer⁹, and training¹⁰.

In contrast to other studies in this area, the present study investigating the effects of different breathing patterns on SR, SL and SV used parameters that can be easily measured by coaches and that do not require sophisticated instruments or tests which demand time-consuming treatments, so that coaches and swimmers can rapidly obtain responses for training application¹⁶. Considering the lack of consensus regarding the effects of breathing patterns on front crawl kinematics, the overall objective of this study was to determine the effects of different breathing patterns on the kinematics and performance of competitive college swimmers in 25-m races, a distance widely used in sprint training^{14,15}. The hypothesis was that lower breathing frequencies and preferred-side breathing permit a higher average velocity during pure swimming by altering the relationship between SR and SL, since both parameters⁵⁻⁹ represent the mechanical adjustments to the energy requirements of each swimming event, especially when performed at maximum intensity.

METHODOLOGICAL PROCEDURES

The sample consisted of 11 college swimmers, 10 men and one woman (height: 1.75 ± 0.04 m; arm span: 1.82 ± 0.03 m; body weight: 73.6 ± 7.5 kg; age: 23.3 ± 1.8 years), who participated in state and/or national and international competitions. The participants had 7.9 ± 2.9 years of experience (training and competition) and the mean best 50-m time in a 25-m pool was 28.0 ± 2.4 s (25.1 s for male swimmers and 32.4 s for the female swimmer). The participants underwent three to five training sessions per week, swimming 2,000 to 4,000 m per session.

All procedures of this study were approved by the Ethics Committee of the Federal University of Rio Grande do Sul (Universidade Federal do Rio Grande do Sul) and were conducted in accordance with Resolution 466/2012 of the National Health Council. The participants received detailed information about the study procedures and signed the free informed consent form.

Experimental procedures

After a warm-up of 600 m freestyle at low intensity, each subject performed seven repetitions of 25 m front crawl at maximum intensity in a 25-m pool. The water temperature ranged from 28° to 30°C. There was a minimum interval of 2 min between repetitions¹⁴. One trial was performed in the breath-holding condition and the remaining six trials were performed using variable breathing frequencies (one breath every two, four and six strokes) and sides (preferred side – 2, 4 and 6PS; opposite side – 2, 4 and 6OS). The order of the trials was determined by drawing lots. The time of each trial was recorded with a stopwatch (Casio) by two experienced examiners. To minimize errors resulting from manual timing, time was

only recorded to a tenth of a second, not hundredths of a second. When the times recorded by the two examiners differed in the tenths, the higher value was considered. The beginning of each trial was indicated by voice command and the end by the touch of the swimmer's hand at the opposite border. All trials were performed inside the pool, without the use of a starting block, in order to prevent the effect of starts on kinematics and to obtain a sufficient swimming distance for data collection.

The kinematic data of each 25-m trial were obtained using the Dvideo Videogrammetry System in two dimensions, with the front crawl being performed by the swimmer in the sagittal plane. Reflective markers (adhesive tape) were placed around the right wrist of each swimmer (radial and ulnar styloid processes used as references) and on the silicone swimming cap (above the right ear). The images were collected at a non-interlaced frequency of 50 Hz. Lane 5 of a 25-m pool with six lanes was used for this protocol. A digital camera (JVC) was positioned at the lateral border of the pool, with the center of the lane in a parallel plane to the plane of the camera at a distance of approximately 11.7 m. The camera was at a height of approximately 2.35 m from the water surface. These distances permitted a field of view of approximately 7.5 m from the plane of the swimmer's displacement in relation to the mark-up of the bottom of the pool corresponding to lane 5. Stroke rate, SL and SV could thus be obtained. Prior to recording of the trials, the image of a 2-m calibration ruler was recorded at the center and at the two ends of the field of view. A mean variation of 4.2% from the 2 m between the ends and the center of the image was observed.

For each 25-m trial, the SR was recorded from the entry of the right hand in the water until the next entry (corresponding to one cycle). The SR was calculated as the ratio between the number of cycles performed and the time necessary to perform them within the 7.5 m. Swimming velocity was obtained as the ratio between the distance covered in the horizontal plane from the swimmer's head and the time necessary for displacement within the 7.5 m. The SL was calculated as the ratio between SV and SR for each trial. Swimming performance was defined as the time necessary to swim the 25 m.

Statistical analysis

For analysis of the data, the normality (Shapiro-Wilk test) and sphericity of the data (Mauchly test) were tested. Next, means, standard deviations and standard errors were calculated for all variables. For comparison of SR, SL and SV between the different breathing frequencies and breathing sides, two-factor analysis of variance for repeated measures was applied in a 3X2 model (breathing frequency and breathing side). The interaction between factors was tested and main effects were determined using an LSD post-hoc test. The Student t-test for paired data was used to compare the values between the breath-holding and breathing conditions. The effect size was calculated for all comparisons (Cohen's d for t-tests and η^2 for ANOVA). Statistical analyses were performed using the SPSS 15.0 program for a $\alpha < 0.05$.

RESULTS

The mean and standard errors of time (s), SR (Hz), SV ($\text{m}\cdot\text{s}^{-1}$) and SL (m) are shown in Table 1.

Table 1. Mean \pm standard error of time (s), swimming velocity (SV, $\text{m}\cdot\text{s}^{-1}$), stroke length (SL, m) and stroke rate (SR, Hz) obtained for the different breathing patterns and breathing sides ($n = 11$).

	2PS	4PS	6PS	2OS	4OS	6OS	B
Time (s)	15.09 ^{a*} ± 1.2	14.98 [*] ± 1.5	14.90 ^a ± 1.5	15.21 ^{a*} ± 1.2	14.94 [*] ± 1.0	14.59 ^a ± 1.2	14.41 [*] ± 1.2
SV ($\text{m}\cdot\text{s}^{-1}$)	1.61 [*] ± 0.18	1.64 ± 0.21	1.63 ± 0.20	1.57 [*] ± 0.18	1.59 [*] ± 0.16	1.63 ± 0.18	1.66 [*] ± 0.19
SL (m)	1.94 ^{a*} ± 0.34	1.88 [*] ± 0.38	1.91 [*] ± 0.40	1.95 ^{a*} ± 0.35	1.79 ± 0.33	1.76 ^b ± 0.32	1.72 [*] ± 0.38
SR (Hz)	0.84 ^{a*} ± 0.11	0.89 [*] ± 0.10	0.89 [*] ± 0.14	0.82 ^{a*} ± 0.11	0.90 [*] ± 0.10	0.95 ± 0.14	0.99 ^{a*} ± 0.15

2PS: breathing every two strokes to the preferred side; 4PS: breathing every four strokes to the preferred side; 6PS: breathing every six strokes to the preferred side; 2OS: breathing every two strokes to the opposite side; 4OS: breathing every four strokes to the opposite side; 6OS: breathing every four strokes to the opposite side; B: breath-holding. Superscript letters and asterisks indicate differences for $p < 0.05$. Time: * = differences between B and 2PS, 2OS, 4OS; a = differences between 2x1 (irrespective of side) and 6x1 (irrespective of side); SV: * = differences between B and 2PS, 2OS, 4OS; SL: * = differences between B and 2PS, 4PS, 6PS, 2OS, 4OS; a = differences between 2x1 (irrespective of side) and 6x1 (only on the opposite side); SR: * = differences between B and 2PS, 4PS, 6PS, 2OS, 4OS; a = differences between 2x1 (irrespective of side) and all other frequencies.

There was no significant interaction effect between breathing side and breathing frequency on the variables analyzed. The breathing side (PS or OS) exerted no effect on 25-m time ($F(1, 9) = 3.304$; $p = 0.102$; $\eta^2 = 0.074$). On the other hand, breathing frequency was able to change the 25-m time ($F(2, 18) = 4.763$; $p = 0.022$; $\eta^2 = 0.191$), but the effect size was small. The 25-m time at maximum intensity was shorter when breathing every six strokes compared to two-stroke breathing. No difference was observed between four- and six-stroke breathing or between four- and two-stroke breathing. The breath-holding condition resulted in better times when compared to the 2PS, 2OS and 4OS trials ($p < 0.05$; effect size ranging from 0.10 to 0.27).

Swimming velocity (excluding the impulse from the wall) was not affected by breathing side ($F(1,7) = 0.064$; $p = 0.8$; $\eta^2 = 0.074$) or breathing frequency ($F(2,14) = 2.05$; $p = 0.165$; $\eta^2 = 0.097$). Comparison of SV between each trial and the breath-holding trial showed higher values for the latter compared to 2PS, 4PS, 6PS and 2OS ($p < 0.05$; effect size ranging from 0.07 to 0.23).

The breathing side did not interfere with SL ($F(1,7) = 2.984$; $p = 0.128$; $\eta^2 = 0.121$). With respect to breathing pattern, higher SL values were only obtained for the two-stroke pattern compared to the six-stroke pattern ($F(2,14) = 12.969$; $p = 0.009$; $\eta^2 = 0.159$). Stroke length was always shorter in the breath-holding condition ($p < 0.05$; effect size ranging from 0.29 to 0.65), except when compared to 4OS and 6OS, but the difference was not significant.

The SR was not affected by breathing side ($F(1,8) = 2.169$; $p = 0.179$; $\eta^2 = 0.073$). In contrast, breathing frequency interfered with SR ($F(2,16)$

= 5.594; $p = 0.014$; $\eta^2 = 0.314$), which was lower for the two-stroke pattern compared to the other breathing patterns. No difference was observed between the two-stroke and four-stroke conditions. When SR was compared between each trial and the breath-holding trial, higher values were observed for the latter compared to 2PS, 4PS, 6PS, 2OS and 4OS ($p < 0.05$; effect size ranging from 0.32 to 0.54).

DISCUSSION

The objective of the present study was to determine the effects of different breathing patterns (frequency and breathing side) on front crawl kinematics and 25-m performance in competitive college swimmers. Differences were evaluated between breathing to the preferred or opposite side every two, four or six strokes, in addition to comparisons with breath-holding swimming.

Performance, which was evaluated based on 25-m time in the present study, was not affected by breathing side (preferred or opposite), whereas breathing frequency exerted an effect, but the effect size was small. The breath-holding condition resulted in better 25-m times compared to trials performed at higher breathing frequencies. Performance at maximum intensity was better (shorter time) when breathing every four and six strokes compared to breathing every two strokes. No difference was observed between breathing every four and six strokes. These data agree with the findings of Castro et al.⁹, who observed an increase in SR and SV in breath-holding front crawl swimming. In contrast, Payton et al.⁴ found no significant influence of breathing action on performance. Furthermore, Seifert et al.¹⁷ showed that breathing to the preferred side rather than to the opposite side was more related to asymmetric arm coordination during a 100-m front crawl race. In the study of Dos Santos et al.¹⁸, coordination asymmetry remained unchanged in all force and impulse parameters analyzed, irrespective of the swimmer's breathing preference (preferred or opposite side), indicating that the preferential breathing side does not prevent the occurrence of asymmetries in front crawl. In the present study, the variables analyzed only permitted inference of front crawl kinematics, but not of possible asymmetries.

According to Craig and Pendergast², the ability to achieve a high SV is directly related to an increase in SL. In the present study involving college athletes, this strategy was used when the swimmers breathed every two strokes; however, to maintain the same velocity breathing every four or six strokes, the swimmers increased SR and decreased SL. This finding may be due to the increased time necessary to perform two complete strokes when breathing is performed.

Toussaint and Beek¹⁹ suggested SL to be an important indicator of propelling efficiency, demonstrating the quality of the technique used in swimming, which may be used to evaluate the progress in "technical ability". In the present study, no difference in SL was observed between breathing to the preferred and opposite sides. The same result was obtained

for SR, i.e., this parameter was not affected by breathing side. However, breathing less often, the participants were able to increase SL, indicating a better technique in these situations. These data agree with the findings of Pedersen and Kjendlie¹⁰ who observed an increase in SL when the swimmers took no breath.

According to Vilas-Boas and Fernandes¹, for a swimmer to continuously move in water, he/she needs to be able to produce, at every moment, a propulsive force (p) that is at least equal to the hydrodynamic drag force (D) acting opposite to the direction of movement. Thus, the mass of the swimmer is subject, during the interval of time that this happens, to a negative impulse which will induce negative movement acceleration and, ultimately, implies the immobilization of the subject. The fact that the drag is directly proportional to the projected body area would explain the better kinematic values in the breath-holding and lower breathing frequency conditions due to the smaller number of body (breathing) movements that tend to increase drag.

Breathing plays a dual role during swimming: a physiological role related to body activity and the need for gas exchanges, and a mechanical role by directly influencing the buoyancy of the subject^{7,20}. This further indicates that not breathing, holding the air inside the lungs, would increase the athlete's buoyancy by temporarily reducing body density, increasing the athlete's performance in low-frequency breathing patterns and in the breath-holding condition. However, the higher the subject's SV, the greater the need for oxygen consumption of the organism and production of CO_2 ^{7,12,20}. Since the swimming distances were short (25 m) in the present study, this was not a determining factor; however, in official competitions, even sprint races (50 and 100 m), the swimmer will perform constant respiratory exchanges. On the other hand, the distance used in the present study (25 m) restricts extrapolation of the results obtained to competitive distances, which is a known limitation of the methods used. However, even in these cases would it be interesting to breathe at a lower frequency. According to unpublished observations of Pedersen and Kjendlie¹⁰, in a Norwegian 50-m freestyle competition, all eight male swimmers breathed one, two or three times during the last three stroke cycles in the race. However, no significant difference in velocity was observed, which was $0.01 \text{ m}\cdot\text{s}^{-1}$, corresponding to a loss of time of 0.03 s in the last 10 m of the race. This loss in performance meant the difference between the first and second place in the race. These findings suggest that swimmers benefit from learning a better breathing technique and breath control. The present results regarding the breath-holding condition agree with the findings of Seifert et al.⁶ who demonstrated the need of restricting the breathing frequency at distances of 25 and 50 m, since the increase in velocity thus obtained would be greater than the harmful physiological effects of the lack of breathing.

In front crawl swimming, to assume the best body position and to minimize drag, the swimmer is instructed to maintain the head aligned with the longitudinal axis while performing propulsive swimming movements⁷.

Thus, the breathing movement only consists of the face reaching the surface and the athlete performing an inspiration. Regardless of the distance of the competition, the breathing action is directly related to metabolic demands, either supplying oxygen to active muscles or to eliminate metabolic waste products (CO_2) derived directly from the energy metabolism or blood lactate buffering¹². Furthermore, Cardelli et al.⁷ showed that the increase in breathing frequency during a race is associated with greater requirement of anaerobic metabolism, which leads to a compensatory increase in SR, rendering the swim less efficient. Payton et al.⁴ concluded that swimmers perform the breathing action during front crawl without altering SR or the timing of the underwater phases. In that study, the swimmers also performed the breathing action without any decrease in SL and maintained similar mediolateral amplitudes and stroke width, although rolling further when breathing than when not. In contrast, with respect to rolling, a characteristic of swimming with alternating arms such as front and back crawl, Psycharakis and Sanders²¹ observed greater shoulder roll to the left side than to the right side in swimmers who preferred breathing to the right side, suggesting that factors related to laterality (breathing side) can influence shoulder roll symmetry.

Castro et al.⁹ identified an increase in SV in sprint swimmers during breath-holding swimming. This finding is probably related to the specific tactics of 50-m freestyle races when the swimmer does not perform breathing movements or performs few movements. This strategy may influence the swimming technique and final performance. Furthermore, Pedersen and Kjendlie¹⁰ reported a significant decrease in SV when breathing every two strokes, i.e., SV was higher when fewer respiratory cycles were used. According to these authors, swimmers should breathe as little as possible in 50-m freestyle sprints and no more than every six strokes in 100-m freestyle races.

CONCLUSIONS

The breathing side does not interfere with kinematic variables in the case of athletes with an already established technique. Breath-holding results in better times when compared to swimming at increased breathing frequencies, in addition to increasing average SV. The lower the breathing frequency, the higher the SR and the shorter the SL.

Coaches should emphasize breath control during both training sessions and competitions. The use of a given breathing pattern in a trial or training series should take into consideration individual differences in technique and physiological responses. A more detailed analysis of this topic, combining biomechanical and physiological responses, is necessary for future studies.

Acknowledgements

We thank the swimmers for participating in the tests and our colleagues for helping with the data collection. We also thank CNPq and CAPES for the fellowships granted.

REFERENCES

1. Vilas-Boas JP, Fernandes R. Arrasto hidrodinâmico activo e potência mecânica máxima em nadadores pré-juniores de Portugal. *Rev Port Ciên Esp* 2001;1(3):14-21.
2. Craig AB, Pendergast DR. Relationships of stroke rate, distance per stroke and velocity in competitive swimming. *Med Sci Sports* 1979;11(3):278-83.
3. Figueiredo P, Pendergast DR, Vilas-Boas JP, Fernandes RJ. Interplay of biomechanical, energetic, coordinative, and muscular factors in a 200-m front crawl swim. *Bio Med Res Int* 2013;1(1):1-12.
4. Payton CJ, Bartlett RM, Baltzopoulos V, Coombs R. Upper extremity kinematics and body roll during preferred-side breathing and breath-holding front crawl swimming. *J Sports Sci* 1999;17(9):689-96.
5. Maglischo EW. *Swimming Fastest. The essential reference on technique, training, and program design.* Champaign: Human Kinetics. 2003.
6. Seifert L, Chehensse A, Chollet CT, Lemaitre F, Chollet D. Effect of breathing pattern on arm coordination symmetry in front crawl. *J Streng and Cond Res* 2008;22(5):1670-6.
7. Cardelli C, Lerda R, Chollet D. Analysis of breathing in the crawl as a function of skill and stroke characteristics. *Perc Mot Skills* 2000;90(3):979-87.
8. Counsilman JE. *La Natacion. Ciencia y Técnica para la Preparación de Campeones.* Barcelona: Editorial Hispano Europea SA. 7th ed. 1995.
9. Castro FAS, Guimarães ACS, Moré FC, Lammerhirt HM, Marques AC. Cinemática do nado "crawl" sob diferentes intensidades e condições de respiração de nadadores e triatletas. *Rev Bras Educ Fís Esporte* 2005;19(3):223-32.
10. Pedersen T, Kjendlie P. The effect of the breathing action on velocity in front crawl sprinting. *Rev Port Ciên Esp* 2006;6(2):75-77.
11. Castro FAS, Vilas-Boas JP, Guimarães ACS. Effects of swimming intensity and breathing in front crawl body roll angles for swimmers and triathletes. *Rev Bras Biomecânica* 2006;7(13):85-90.
12. Costill DL, Kovaleski J, Porter D, Kirwan J, Fielding R, King D. Energy expenditure during front crawl swimming: predicting success in middle-distance events. *Int J Sports Med* 1985;6(5):266-70.
13. Matos CC, Castro FAS. Variabilidade do lactato sanguíneo em resposta a nados de aquecimento e de máxima intensidade. *Rev Bras Ciênc Mov* 2013;21(1):98-106.
14. Toubekis AG, Adam GV, Douda HT, Antoniou PD, Douroundos II, Tokmakidis SP. Repeated sprint swimming performance after low- or high-intensity active and passive recoveries. *J Strength Cond Res* 2011;25(1):109-16.
15. Toubekis AG, Douda HT, Tokmakidis SP. Influence of different rest intervals during active or passive recovery on repeated sprint swimming performance. *Eur J Appl Physiol* 2005; 93(5):694-700.
16. Franken M, Carpes FP, Diefenthaler F, Castro FAS. Relação entre cinemática e antropometria de nadadores recreacionais e universitários. *Motriz* 2008; 14(3):329-36.
17. Seifert L, Chollet D, Allard P. Arm coordination symmetry and breathing effect in front crawl. *Hum Mov Sci* 2005;24(2):234-5.
18. Dos Santos KB, Pereira G, Papoti M, Bento PCB, Rodacki A. Propulsive force asymmetry during tethered-swimming. *Int J Sports Med* 2013;34(7):606-11.
19. Toussaint HM, Beek PJ. Biomechanics of competitive front crawl swimming. *Sports Med* 1992;13(1):8-24.
20. Lomax M, Castle S. Inspiratory muscle fatigue significantly affects breathing frequency, stroke rate, and stroke length during 200-M front-crawl swimming. *J Strength Cond Res* 2011;25(10):2691-5.
21. Psycharakis SG, Sanders RH. Shoulder and hip roll changes during 200-m front crawl swimming. *Med Sci Sports Exerc* 2008;40(12):2121-9.

Corresponding author

Marcos Franken
UFRGS, Escola de Educação Física
Rua Felizardo, 750, Jardim Botânico
90690-200. Porto Alegre, RS, Brasil
E-mail: marcos_franken@yahoo.
com.br