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Original Article

A three-dimensional aspect of front crawl swimming in swimmers with different proficiency levels

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Abstract:
Problem Statement: Although three-dimensional evaluations of swimming have described aspects of a set of performance variables, studies that distinguish higher than lower swimmers' performance from a three-dimensional perspective are still necessary. **Approach:** analyses that provide an overview regarding variables that differentiate swimmer's proficiency are required. **Purpose:** The aim of this study was to compare the spatio-temporal characteristics of the arm stroke between higher and lower proficiency swimmers. **Methods:** Twenty-one swimmers (18.5 ± 3.78 years) allocated to a high and lower performance groups (G1 and G2, respectively) performed a 50m maximum front-crawl swimming, recorded by 4 underwater cameras. A cycle stroke was digitizing in specific kinematic analysis software, SIMI Reality Motion Systems. Swimming velocity, stroke rate (SR), stroke length (SL), intracycle velocity variation (IVV), stroke dimensions, hand velocity and coordination index were analyzed. Independent Student's test or Mann Whitney test (to non-parametric variables) was used to compare high and lower performance groups with $p<0.05$. **Results:** The results showed that high performance group was 11% faster than lower proficiency one, presented stroke length 11% larger, 26% stroke wider, 13% deeper and faster hand in the submerged and upsweep phase (11% and 14%, respectively). For the other hand, stroke rate, intracycle velocity variation and coordination index were not able to differentiate performance groups. **Conclusion:** Higher proficiency swimmers were distinguished by a set of variables (i.e. higher velocity, stroke length, width and depth of the stroke, with higher velocity in the upsweep and in the underwater hand displacement), which coaches need to focus on.
Key Words: **- Performance, kinematics, swimming, cycle stroke**

Introduction

Kinematic analysis has been widely used by researchers and coaches for a better swimming performance understanding (McCabe et al., 2011, López-Belmonte et al. 2023). As swimming velocity is the product of stroke length by the stroke rate, it has been widely used by coaches and swimmers to monitor swimming performance. The manipulation of stroke length and rate influences the maximum swimming velocity that can be achieved (Chollet et al., 1997). High-performance swimmers are characterized by the use of longer stroke length and lower stroke frequency, which result in greater swimming efficiency (Nikodelis et al., 2005). These variables are objective and easy to obtain, since they are measured in a two-dimensional plane and do not require waterproof devices.

The complexity of capturing underwater movements limits additional analysis from a multidimensional perspective including width, length and depth of the stroke during the submerged phase. Despite the fact that bi-dimensional parameters simplify the analysis, only a three-dimensional analysis allows a more realistic understanding of different stroke phases during the submerged phase. Although three-dimensional evaluations of swimming have described aspects of a set of performance variables (Figueiredo et al., 2013; McCabe et al., 2011), studies that distinguish higher than lower swimmers performance from a three dimensional perspective are still necessary. Thus, analyses that provide an overview regarding variables that differentiate swimmers proficiency are required. In fact, additionally to stroke length and rate monitoring, others kinematics variables influence performance and need attention, such as intracyclic velocity variations (Silva 2019), specific stroke dimension (Santos 2021), hand acceleration during the cycle stroke (Kudo et al., 2023, Samson et al., 2015) and coordination index (Schnitzler et al., 2021). Furthermore, these biomechanics aspects adaptations may vary according to the swimmers level of expertise. The present study aimed to compare the spatio-temporal characteristics of the front crawl arm stroke between higher and lower proficiency swimmers, in order to determine aspects that characterize more expressive swimming results. It was hypothesized was that higher proficiency swimmers would present higher swim parameters (velocity; stroke length; dimensional stroke parameters; percentage of time spent in the underwater phase; and overlapping of arms), except intracycle variation velocity and stroke frequency, which would be lower in high performance.

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Material & methods

Participants

Twenty-one sprint specialists (18.5 ± 3.78 years, males: 1.79 ± 0.07 m; 71.50 ± 9.43 kg and females: 1.62 ± 0.06 m; 58.62 ± 7.17 kg) participated in this study. The participants were allocated to a high-performance group (G1 - 11 swimmers) and low-proficiency group (G2 - 10 swimmers), determined by the point scoring, proposed by the International Swimming Federation. The swimmers inclusion criteria and point scoring calculation were described by the working group previously (K. B. Santos et al., 2020; K. B. d. Santos et al., 2020). The experimental procedures had the approval of the University Ethics Committee under the protocol number CAAE 30819514300000102 and informed consent document was provided by participants and /or parents or guardians.

Instruments and procedures

Anthropometric measurements (weight, height and arm span) were taken prior to testing. After uninstructed warm-up, swimmers were instructed to perform 50m maximum front crawl swimming. Data collection was recorded by four underwater cameras (Gopro Hero 4), focused on a previously calibrated volume, synchronized by a pulse of light at 60 Hz frequency acquisition.

The markers were positioned in the dominant side of the distal phalanx of the 3rd metacarpal and major trochanter of the femur. A complete stroke cycle divided in four phases (i.e., glide + downsweep; insweep, upsweep and recovery) was analyzed by the digitizing markers in specific kinematic analysis software (SIMI Reality Motion Systems). From the cycle stroke, the following variables were analyzed:

- Swimming velocity
- Stroke rate (SR)
- Stroke length (SL)
- Intracyclic velocity variation (IVV)
- Stroke width
- Stroke depth
- Underwater stroke amplitude
- Percentage of time in the submerged phase (Tsub)
- Coordination index (IdC)
- Mean velocity of the hand in the underwater phase
- Mean velocity of the hand in each submerged stroke phase

Further information regarding set up, experimental procedures and variables descriptions are detailed in Santos et al. works (K. B. Santos et al., 2020; K. B. d. Santos et al., 2020, Dos Santos et al., 2017).

Statistical analysis

Shapiro-Wilk and Levene testes were applied to verify normality and homogeneity of the data. Independent Student's t-test was used to compare parametric variables. Non-parametric analysis (Mann Whitney) was preferred when normality and homogeneity were not confirmed. The effect size was calculated considering the ratio between the means difference and its standard deviations. Statistical analysis was performed using Statistic version 7 software, with significance at $p < 0.05$.

Results

The groups G1 and G2 did not present significant anthropometric differences (height: 1.75 ± 0.09 and 1.68 ± 0.11m, arm span: 1.81 ± 0.10 and 1.73 ± 0.15m, 18 ± 10.93 and 64.30 ± 9.77 kg, $p > 0.05$). The group of swimmers with the highest point scoring swam approximately 11% faster than the group of lesser proficiency. In addition, they presented stroke length 11% larger, 26% wider and 13% deeper. Furthermore, upsweep and underwater phase were faster among the most proficient swimmers (10 and 13% respectively), while intracycle velocity variation and coordination index did not differ between groups. The comparison of the parameters of the swim is indicated in table 1.

Table 1 – Comparison of swimming parameters between groups of higher (G1) and lower (G2) point scoring.

	G1	**G2**	**p**	***d***
Velocity ($m.s^{-1}$)	1.60 ± 0.15	1.42 ± 0.18	0.004	1.11
Stroke length (m)	1.91 ± 0.21	1.71 ± 0.26	0.041	0.87
Storke rate ($cycles.min^{-1}$)	49.24 ± 4.05	48.00 ± 5.01	0.751	0.28
Stroke amplitude (m)	0.70 ± 0.15	0.68 ± 0.12	0.724	0.15
Stroke width (m)	0.39 ± 0.12	0.29 ± 0.10	0.048	0.93
Stroke depth (m)	0.70 ± 0.16	0.61 ± 0.09	0.017	0.71
Time in the submerged phase (%)	68.71 ± 4.29	69.84 ± 4.05	0.526	0.28
Coordination index	0.82 ± 5.42	0.27 ± 4.02	0.407	0.38
Downsweep velocity ($m.s^{-1}$)	2.03 ± 0.50	1.70 ± 0.32	0.289	0.81
Insweep velocity ($m.s^{-1}$)	2.31 ± 0.29	1.97 ± 0.30	0.060	1.18
Upsweep velocity ($m.s^{-1}$)	2.57 ± 0.44	2.30 ± 0.20	0.035	0.81
Submerged hand velocity ($m.s^{-1}$)	2.38 ± 0.29	2.06 ± 0.22	0.009	1.27
Intracyclic velocity variation	0.21 ± 0.08	0.22 ± 0.08	0.821	0.14

Discussion

This study compared three-dimensional kinematic aspects in swimmers of greater and lesser proficiency. The most proficient group displayed the highest swimming velocity. This was expected, since the division was performed through the point scoring, which considers performance time. The stroke length was higher in swimmers with better proficiency, which reinforces the findings of the literature (Nasirzade et al., 2015; Schnitzler et al., 2011). In fact, the greater stroke length for a given velocity represents a more efficient/economical swim (Chollet et al., 1997; Nikodelis et al., 2005). However, stroke frequency did not differ between groups. While the stroke length is used to obtain a higher velocity, the frequency can present different strategies. In this view, this variable does not seem to distinguish clearly the best and worst performing groups and may not be the best predictor of swimming. Thus, swimming velocity seems to be more susceptible to the stroke length than to its frequency (Satkunskiene et al., 2005).

It was expected that lower performance swimmers presented lower underwater amplitude (displacement on the x axis), however this assumption was not confirmed. Despite the similarity in the distance covered by the stroke in the underwater phase, the longer time spent in the underwater stroke by the lower performance group, indicates a lower hand velocity, which results in a lower swimming velocity. The width stroke showed by the lower performance group was slightly higher than reported by Payton et al. (1999) (0.29 versus 0.27 m respectively), while the depth was considerably lower (0.61 versus 0.79m). On the other hand, the stroke width and depth of the highest performance group (0.39 ± 0.12 and 0.70 ± 0.16 m) are in line with the results observed by McCabe et al. (2011) (39 ± 0.01 m and 66 ± 0.01 m).

Width and depth can be influenced by aspects such as: swimmers level, elbow angle, arm size and body roll. The similarity of the anthropometric profile presented by the groups (stature and arm span) discards the length of the segment as the main responsible for the differences found. On the other hand, the technical ability of swimmers seems to be related to such variables, since the more proficient swimmers presented deeper and wider strokes. Maybe shallower and narrower strokes generate an unfavorable lever around the upper segments or negatively influence the angle of attack and movement direction that contribute to swimming propulsion by lift theory and may also increase drag forces by the turbulence generated in the water close to the body. However, it can not be assumed that, wider and deeper strokes result in a better swimming performance, since increased levers may hinder the generation of propulsive forces and generate deviations in the vector of the swimmer's movement. Widths around 0.39m with depths close to 0.70m appeared to be more advantageous among swimmers evaluated. Further studies are required to confirm these speculations.

The groups presented similar Tsub ($p > 0.05$) and are in agreement with Gourgousli and collaborators (70,67%) (Gourgoulis et al., 2010). Consuming longer time in the underwater phase in relation to the recovery phase seems to be convenient as the propulsion occurs during mainly in insweep and upsweep phases (Maglischo, 2003). However, the duration of the underwater phase was not sufficient to discriminate the swimmers levels of the present study.

Both groups had an average coordination index of opposition ($-1\% > IdC < 1\%$). This data is in agreement with those by Seifert et al. (2007) for medium and low velocity swimmers and of different levels swimmers reported by Chollet et al. (2000). In addition, the values are higher than those reported by Silva et al. (Silva et al., 2019) to young swimmers in sprint performance and Alberty et al. (Alberty et al., 2009) in exhaustion tests. However, comparison with other studies must be viewed with caution, due methodological differences to obtain the IdC. The hypothesis that the group with the highest performance would present a higher index of coordination was not confirmed.

Similarly, Silva et al. (2019) did not found difference between IdC and swimmers level or sex. In addition, the standard deviations of the means indicate that it was not all the swimmers who presented an opposition index, but rather that within the groups the three models of coordination were observed. The hand experienced successive velocity increments in each of the underwater phases (see Table 1), which is in agreement with the literature that describes the stroke with non-linear incremental velocity (Maglischo, 2003). When compared the phases velocity separately in the groups, the insweep and upsweep were faster in the higher performance group. This indicates that increases in performance can be obtained by increments in the velocity of the hand in these phases. In fact, the insweep and upsweep correspond to the main propulsive actions of the swimming. In addition, hand acceleration at the end of the stroke is fundamental for high swimming performance (Samson et al., 2015).

Intracycle variation of velocity of the hip did not differ between groups, so the hypothesis that the swimmers with the highest point scoring would show less variation in the velocity of their hip displacement was not confirmed. Maybe, the difference in performance showed between groups in the present study, were not enough to express such a difference. The results found in the present study are in line with the findings reported by Psycharakis et al. (Psycharakis et al., 2010) for intracycle variation of the center of mass velocity (0.22). The estimation of this variable through a fixed point in the hip is indicated as a simple and fast response alternative (Fernandes et al., 2012). However, comparisons should be cautioned since a fixed point in the body of the swimmer may not correspond in full with the dynamics of the displacement of its center of mass.

Conclusions

This article provides an overview for coaches regarding variables that distinguish higher performance in swimmers. Higher velocity, stroke length, width and depth of the stroke, with higher velocity in the upsweep and in the underwater hand displacement, have been shown to be the variables that distinguish the most proficient swimmers. Thus, the development of these variables in swimming training should be highlighted. However, stroke rate, intracycle velocity variation and coordination index were not able to differentiate performance between swimmers' group. Studies that include joint segment angles and observe lower limb movements in the leg actions are encouraged.

Conflicts of interest - the authors declare no conflicts of interest regarding this article.

References:

Alberty, M., Sidney, M., Pelayo, P., & Toussaint, H. (2009). Stroking characteristics during time to exhaustion tests. *Medicine & Science in Sports & Exercise, 41*(3), 637.

Chollet, D., Delaplace, C., Pelayo, P., Tourny, C., & Sidney, M. (1997). Stroking characteristic variations in the 100-m freestyle for male swimmers of differing skill. *Perceptual and Motor Skills, 85*(1), 167-177.

Dos Santos, K. B., Lara, J. P., & Rodacki, A. L. (2017). Reproducibility, repeatability and accuracy analysis of three-dimensional kinematics of the front crawl stroke trajectories in impaired swimmers. *Journal of Physical Education and Sport*, 17(1), 367-370.

Fernandes, R., Ribeiro, J., Figueiredo, P., Seifert, L., & Vilas-Boas, J. (2012). Kinematics of the hip and body center of mass in front crawl. *Journal of Human Kinetics, 33*, 15-23.

Figueiredo, P., Sanders, R., Gorski, T., Vilas-Boas, J., & Fernandes, R. (2013). Kinematic and electromyographic changes during 200 m front crawl at race pace. *International Journal of Sports Medicine, 34*(01), 49-55.

Gourgoulis, V., Antoniou, P., Aggeloussis, N., Mavridis, G., Kasimatis, P., Vezos, N., Mavromatis, G. (2010). Kinematic characteristics of the stroke and orientation of the hand during front crawl resisted swimming. *Journal of sports sciences, 28*(11), 1165-1173.

Kudo, S., Matsuda, Y., Sakurai, Y., & Ikuta, Y. (2023). Rapid Change in the Direction of Hand Movement to Increase Hand Propulsion During Front Crawl Swimming. *Journal of Applied Biomechanics*, 1(aop), 1-9.

López-Belmonte, Ó., Ruiz-Navarro, J. J., Gay, A., Cuenca-Fernández, F., Mujika, I., & Arellano, R. (2023). Analysis of pacing and kinematics in 3000 m freestyle in elite level swimmers. Sports Biomechanics, 1-17.

Maglischo, E. W. (2003). *Swimming Fastest*: Human Kinetics.

McCabe, C. B., Psycharakis, S., & Sanders, R. (2011). Kinematic differences between front crawl sprint and distance swimmers at sprint pace. *Journal of Sports Sciences, 29*(2), 115-123.

Nasirzade, A., Sadeghi, A., Sobhkhiz, A., Mohammadian, K., Nikouei, A., Baghaiyan, M., & Fattahi, A. (2015). Multivariate analysis of 200-m front crawl swimming performance in young male swimmers. *Acta of Bioengineering and Biomechanics, 17*(3).

Nikodelis, T., Kollias, I., & Hatzitaki, V. (2005). Bilateral inter-arm coordination in freestyle swimming: Effect of skill level and swimming speed. *Journal of Sports Sciences, 23*(7), 737-745.

Psycharakis, S., Naemi, R., Connaboy, C., McCabe, C., & Sanders, R. (2010). Three-dimensional analysis of intracycle velocity fluctuations in frontcrawl swimming. *Scandinavian Journal of Medicine & Science in Sports, 20*(1), 128-135.

Samson, M., Monnet, T., Bernard, A., Lacouture, P., & David, L. (2015). Kinematic hand parameters in front crawl at different paces of swimming. *Journal of Biomechanics, 48*(14), 3743-3750.

Santos, K. B., Bento, P. C., Payton, C., & Rodacki, A. L. (2020). Symmetry in the front crawl stroke of different skill level of able-bodied and disabled swimmers. *PloS One, 15*(3), 1-10.

Santos, K. B. d., Bento, P. C. B., Payton, C., & Rodacki, A. L. F. (2020). Kinematic parameters after repeated swimming efforts in higher and lower proficiency swimmers and para-swimmers. *Research Quarterly for Exercise and Sport*, 1-9.

Satkunskiene, D., Schega, L., Kunze, K., Birzinyte, K., & Daly, D. (2005). Coordination in arm movements during crawl stroke in elite swimmers with a loco-motor disability. *Human Movement Science, 24*(1), 54-65.

Schnitzler, C., Seifert, L., & Chollet, D. (2011). Arm coordination and performance level in the 400-m front crawl. *Research Quarterly for Exercise and Sport, 82*(1), 1-8.

Schnitzler, C., Seifert, L., Button, C. (2021) Adaptability in swimming pattern: How propulsive action is modified as a function of speed and skill. *Frontiers in Sports and Active Living, 3*(1), 1-12.

Silva, A. F., Figueiredo, P., Ribeiro, J., Alves, F., Vilas-Boas, J. P., Seifert, L., & Fernandes, R. J. (2019). Integrated analysis of young swimmers' sprint performance. *Motor control, 23*(3), 354-364.