Perceptual & Motor Skills: Exercise & Sport
2012, 115, 1, 300-308.

ASSESSMENT OF BEGINNERS' FRONT-CRAWL STROKE EFFICIENCY[1]

FABRÍCIO MADUREIRA

School of Physical Education and Sport
University of São Paulo

Faculty of Physical Education
Metropolitan University of Santos

FLAVIO HENRIQUE BASTOS,
UMBERTO CESAR CORRÊA

School of Physical Education and Sport
University of São Paulo

THIAGO ROGEL

School of Physical Education and Sport
University of São Paulo

Faculty of Physical Education
Metropolitan University of Santos

ANDREA MICHELE FREUDENHEIM

School of Physical Education and Sport
University of São Paulo

Summary.—Efficiency in front-crawl stroke has been inferred primarily by means of the analysis of arm actions, specifically, stroke frequency and stroke length. The objective of the present study was to investigate whether swimming efficiency could be better assessed in children still learning the front-crawl stroke by analyzing the movement pattern as a whole. Forty-two children enrolled in private swimming programs volunteered to participate in the study. The task consisted of swimming 30 m as fast as possible. Three experts analyzed the movement pattern of the participants using a checklist. Both stroke frequency and stroke length were calculated. The correlation coefficients between the time taken to swim and both the stroke frequency and stroke length were not significant, but the total and components of the checklist scores were. Results indicate that the swimming efficiency of children learning the front-crawl stroke can be better assessed by analyzing their whole movement pattern.

Swimming efficiently can be seen as covering a given distance in the smallest possible unit of time, which makes *speed* a key concept. Speed in swimming has been associated to stroke length and stroke rate (Craig, Skehan, Pawelczyk, & Boomer, 1985; Chollet, Pelayo, Delaplace, Toumy & Sidney, 1997; Barbosa, Bragada, Reis, Marinho, Carvalho, & Silva, 2010). Stroke rate refers to the total number of cycles performed by one arm during a given unit of time, and stroke length refers to the distance that the swimmer moves forward during each arm cycle. Those two measures, focusing on arm actions, have been used to indicate efficiency of both adult

[1]Address correspondence to Andrea Michele Freudenheim, Laboratório de Comportamento Motor, Av. Prof. Mello Moraes 65, São Paulo/SP, Brasil 05508-900 or e-mail (amfreud@usp.br).

DOI 10.2466/06.05.25.PMS.115.4.300-308 ISSN 0031-5125

(Seifert, Chollet & Rouard, 2007; Psycharakis, Cooke, Paradisis, O'Hara, & Phillips, 2008) and young swimmers (Poujade, Hautier, & Rouard, 2002; Kjendlie, Stallman, & Stray-Gundersen, 2004; Kjendlie, Ingjer, Stallman, & Stray-Gundersen, 2004; Jürimäe, Haljaste, Cicchella, Lätt, Purge, Leppik, *et al.*, 2007).

Although arm actions are obviously important to an efficient displacement in the water, since they generate 90% of the propulsion in front-crawl swimming (Deschodt, Arsac, & Rouard, 1999; Stager & Tanner, 2005), another decisive aspect is the hydrodynamic resistance, or drag, produced by the body. A beginner who still needs to refine his front-crawl swimming produces relatively inefficient body movements that generate more hydrodynamic resistance than an experienced swimmer (Kjendlie & Stallman, 2008). Specifically, when the skill has already been mastered and refined, it seems reasonable to suppose that analyzing arm actions may provide a good measure of swimming efficiency, since it is expected that movements are not hindering the displacement of the swimmer. The same assumption is probably not realistic in children still learning how to swim, emphasizing the necessity of broadening the scope of analysis. The goal of the present study was to investigate whether swimming efficiency could be better assessed among children still learning the front-crawl stroke by analyzing the movements produced by the whole body, compared to measuring arm actions exclusively.

In the view of the fact that to swim, one has to coordinate movements from different parts of his body, any movement that negatively influences the displacement of the swimmer can be considered an "error" (Maglischo, 2003; Stager & Tanner, 2005). An instrument to assess such errors should include movements from the whole body and consider both movements that increase hydrodynamic resistance and movements that are inefficient in generating propulsion. Hence, a checklist developed by Madureira, Gollegã, Rodrigues, Oliveira, Dubas, and Freudenheim (2008) was employed in the present study.

The checklist considers both of the above-mentioned movement categories, giving them different weights to produce a score. Specifically, errors concerning hydrodynamic resistance and having the strongest negative effect on the displacement of the swimmer (Havriluk, 2007; Zamparo, Gatta, Pendergast, & Capelli, 2009) are scored 1.5 or 2, while errors concerning propulsion generation are scored 0.5 or 1. The checklist consists of the 98 most common errors in front-crawl swimming, identified by Maglischo (2003) and Thornton and Hannula (2001), and organized into 12 categories: (1) recovery and entrance errors, (2) release errors, (3) stroke synchronization errors, (4) breathing errors, (5) stroke/breathing synchronization errors, (6) down-sweep errors, (7) in-sweep errors, (8) upsweep errors, (9) body positioning errors, (10) lower limb errors, (11) lower limb/ breathing synchronization errors, and (12) lower limb/stroke synchronization errors.

Method

Participants

Forty-two children (14 boys, 28 girls), enrolled in private swimming programs in the city of Santos, Brazil (*M* age = 8.7 yr., *SD* = 1.2), volunteered to participate in the study. In order to have beginners with different proficiency levels and ensure that they were all able at least to swim using the movement pattern that characterizes the front-crawl swimming, an inclusion criterion was employed: having attended at least 50 formal swimming classes, with 50 min. duration each. Additionally, the age group (7 to 10 years old) was chosen to prevent pubertal biological effects (Malina & Bouchard, 2002).

The study was approved by the Ethics Committee of the School of Physical Education and Sport, University of São Paulo, and all participants provided written informed consent, signed by their parents or guardians. They were not aware of the purpose of the study.

Equipment and Task

An Olympic-sized swimming pool was used during data collection. Two Sony Digital Handy Camera Recorder, model TRV 340 (C1 and C2), one positioned near the surface and the other underwater, recorded movements for posterior analysis. The cameras were vertically aligned with each other and coupled to a trolley that allowed manually moving them on a track along the poolside, so that the experimenter could follow the participant during the task.

Participants were tested individually. The task was started with participants standing on the side of the swimming pool, 15 m from the end. They were instructed to swim back and forth a 15-m distance, as fast as possible, using the front-crawl stroke. Additionally, they were instructed to use a freestyle flip turn to swim back to the position where they started.

Procedures

Participants had anatomical points marked with nontoxic ink before starting the experiment. The presence of those marks was intended to help with visualization of the body segments in the videos. Seven points were marked: fifth metatarsus (hands), lateral epicondyle (forearms), greater tubercle of the humerus (arms), anterior superior iliac spine (hips), lesser trochanter of the femur (thighs), lateral epicondyle and lateral malleolus (legs), and fifth metatarsus (feet).

Each participant had their images analyzed by three experts, who applied the checklist developed by Madureira, *et al.* (2008). It is worth mentioning that, as the participants swam back and forth, both sides of their bodies were considered in the analysis.

Measures

The total time taken to swim 30 m was obtained by means of the number of frames, since the video cameras recorded 60 frames per second (60 Hz). The average stroke length was obtained by dividing the distance (30 m) by the number of strokes. The checklist score, obtained by the sum of its items, could range from 0 to 152, with 0 meaning that the experts found no error (i.e., movements generating efficient propulsion and adding no "extra" hydrodynamic resistance). The average of the scores, provided by the experts for each participant, was used for data analysis.

Data Analysis

Data analysis consisted fundamentally of Pearson product-moment correlations between the time taken to swim 30 m and the variables that were considered possible indicatives of efficiency: number of strokes, stroke length, and checklist score. Other correlations were calculated to verify which subsets (categories) of the checklist correlated with the time to swim 30 m.

Results

The mean time needed to complete the task (to swim back and forth) was 36.95 sec. ($SD = 8.50$). The mean number of strokes and stroke length were 33.7 ($SD = 11.7$) and 1.0 m ($SD = 0.5$), respectively. The correlation coefficients between the time taken to swim and the above mentioned variables related to arm actions were not significant (Table 1). The correlation coefficient between the time to swim and the checklist score was significant ($r = .63$, $p < .01$), indicating that, when it comes to children still learning the front-crawl stroke, analyzing actions of the whole body is more likely to provide a good measure of swimming efficiency than analyzing arm actions exclusively. When subsets of the checklist were considered individually, all of them showed significant correlation coefficients with the time to swim (Table 2).

TABLE 1

Pearson Correlation Coefficient Between the Time Taken to Swim and the Checklist Score, Number of Strokes, and Average Stroke Length

	Checklist	No. of Strokes	Stroke Length
Time	.63†	−.28	.36
95%*CI*	.42, .82	−.60, .06	−.01, .62

*$p < .05$. †$p < .01$.

TABLE 2

CORRELATION BETWEEN THE TIME TAKEN TO SWIM 30 M AND CHECKLIST SUBSETS / CATEGORIES INVOLVING ERRORS

Errors	RE	R	SS	B	SBS	DS	IS	US	BP	K	KBS	KSS
Time	.64†	.50†	.53†	.38*	.62†	.44*	.41*	.42*	.43*	.39*	.54†	.54†
95%*CI*	.47, .81	.31, .70	.22, .77	.09, .69	.29, .83	.12, .67	.17, .61	.18, .64	.13, .78	.00, .65	.25, .73	.32, .76

Note.—Recovery and entrance (RE); Release (R); Stroke synchronization (SS); Breathing (B); Stroke and breathing synchronization (SBS); Down-sweep (DS); and In-sweep (IS); Upsweep (US); Body positioning (BP); Kicking (K); Kick and breathing synchronization (KBS); Kick and stroke synchronization (KSS).*$p < .05$. †$p < .01$.

DISCUSSION

Swimming efficiency has been associated with low stroke frequency and high stroke length (Craig, *et al.*, 1985; Smith, Norris, & Hogg, 2002; Psycharakis, *et al*., 2008; Alberty, Sidney, Pelayo, & Toussaint, 2009). This relationship has been confirmed at different swimming speeds (Craig & Pendergast, 1979; Keskinem & Komi, 1993; Toussaint, Carol, Kranenborg, & Truijens, 2006), swimming strokes (Chollet, Chalies, & Chatard, 2000; Chollet, Seifert, Boulesteix, & Carter, 2006; Chollet, Seifert, & Carter, 2008), and competition distances (Arellano, Brown, Cappaert, & Nelson, 1994; Seifert, Boulesteix, Chollet, & Vilas-Boas, 2008). However, evidence of this relationship was found exclusive in highly experienced swimmers (athletes), suggesting that the same would not be true for beginners. Thus, the present study aimed to investigate the hypothesis that children's swimming efficiency would not be adequately assessed by analyzing arm actions exclusively and that the movement pattern as a whole should be considered instead.

The results confirmed this prediction. Specifically, while a significant correlation coefficient was found between performance (time to swim) and the checklist score, no significant correlation was found between performance and both mean number of strokes and stroke length. Therefore, the results reported here indicate that measures normally used to assess the efficiency of experienced swimmers seem to be inappropriate for children still learning how to swim. Additionally, the results indicate that the checklist score, resulting from the analysis of the movement pattern as a whole, is more adequate to infer the efficiency of these children's front crawl stroke. One possible explanation for this result refers to the skill level of the children participating in this study.

While skilled behavior can be characterized by its fluency and efficiency, beginners' motor behavior is known for being uncoordinated and inconsistent (Tani, 2000, 2005). It is worth mentioning that most of the research about front-crawl stroke involved elite swimmers. Known for their skilled behavior, the main factors responsible for distinguishing those swimmers from each other are the physiological ones, such as strength and aerobic capacity (Palayo, Alberty, Sydney, Potdevin, & Dekerle, 2007; Formosa, Mason, & Burkett, 2011; Schnitzler, Brazier, Button, Seifert, & Chollet, 2011; Stirn, Jarm, Kapuso, & Strojnik, 2011). For instance, swimmers that can produce propulsive forces for longer periods of time have lower stroke rate, indicating more efficient movements (Seifert, Toussaint, Alberty, Schnitzler, & Chollet, 2010). Additionally, some authors (e.g., Alberty, Potdevin, Dekerle, Pelayo, Gorce, & Sydney, 2008) have shown that although adjustments in the motor behavior (e.g., movement pattern) of elite athletes are similar, they depend on the swimmer's fatigue state and, thus, are related to physiological limits. Conversely, the results reported here indicate that movement coordination and control are more relevant for assessing beginners' swimming efficiency than physiological aspects. Specifically, the checklist used in this study includes the analysis of angles, trajectories, position and interactions between body parts. Thus, it is reasonable to suppose that the results given by the checklist could be less affected by the physiological characteristics of the swimmers than are stroke frequency and length.

One could have expected that only subcomponents related to arm strokes, as sweep down and sweep up, would correlate with the performance, since those actions are identified as most relevant to the displacement of the swimmer (Seifert, Toussaint, Alberty, Schnitzler, & Chollet, 2010; Formosa, Mason, & Burkett, 2011). Several studies investigating the front-crawl stroke have focused on arm movements, although they had different objectives (e.g., Chollet, *et al.*, 2000; Freudenheim, Basso, Xavier Filho, Silva, Madureira, & Manoel, 2005). Nevertheless, a significant correlation coefficient was found between performance and all the checklist items. For example, due to little direct involvement of the legs in the swimmer's propulsion (Stager & Tanner, 2005) one could expect no correlation between performance and the checklist items related to their actions. However, their effect on body flotation and on keeping the displacement up between the propulsive phases of the strokes (McCullough, Kraemer, Volek, Solomon-Hill, Hatfield, Vingren, *et al.*, 2009; Sanders, & Psycharakis, 2009) seem to be as important as arm actions for beginners' swimming efficiency.

In summary, the results reported here indicate that the swimming efficiency of children still learning the front-crawl stroke can be better assessed by analyzing their whole movement pattern, compared to analyzing only their arm actions, specifically, their stroke frequency, and stroke length. Future studies could investigate at which proficiency level the variables "stroke length" and "stroke frequency" begin to be good assessments of front-crawl stroke efficiency, as observed in athletes.

REFERENCES

ALBERTY, M., POTDEVIN, F., DEKERLE, J., PELAYO, P., GORCE, P., & SIDNEY M. (2008) Changes in swimming technique during time to exhaustion at freely chosen and controlled stroke rates. *Journal of Sport Sciences,* 26(11), 1191-1200.

ALBERTY, M., SIDNEY, M., PELAYO P., & TOUSSAINT, H. M. (2009) Stroking characteristics during time to exhaustion tests. *Medicine & Science in Sports & Exercise*, 41(3), 637-644.

ARELLANO, R., BROWN, P., CAPPAERT, J., & NELSON, R. C. (1994) Analysis of 50-m, 100-m, and 200-m freestyle swimmers at the 1992 Olympic games. *Journal of Applied Biomechanics*, 10, 189-199.

BARBOSA, T. M., BRAGADA, J. A., REIS, V. M., MARINHO, D. A., CARVALHO, C., & SILVA, A. J. (2010) Energetics and biomechanics as determining factors of swimming performance: updating the state of the art. *Journal of Science and Medicine in Sport,* 13(2), 262-269.

CHOLLET, D., CHALIES, S., & CHATARD, J. C. (2000) A new index of coordination for the crawl: description and usefulness. *International Journal of Sports Medicine,* 21(1), 54-59.

CHOLLET, D., PELAYO, P., DELAPLACE, C., TOUMY, 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.

CHOLLET, D., SEIFERT, L., BOULESTEIX, L., & CARTER, M. (2006) Arm to leg coordination in elite butterfly swimmers. *International Journal of Sports Medicine,* 27(4), 322-329.

CHOLLET, D., SEIFERT, L. M., & CARTER, M. (2008) Arm coordination in elite backstroke swimmers. *Journal of Sport Sciences,* 26(7), 675-682.

CRAIG, A. B., & PENDERGAST, D. R. (1979) Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. *Medicine & Science in Sports & Exercise*, 11, 278-283.

CRAIG, A. B., SKEHAN, P. L., PAWELCZYK, J. A., & BOOMER, W. L. (1985) Velocity, stroke rate, and distance per stroke during elite swimming competition. *Medicine & Science in Sports & Exercise,* 17(6), 625-634.

DESCHODT, V. J., ARSAC, L. M., & ROUARD, A. H. (1999) Relative contribution of arms and legs in humans to propulsion in 25-m sprint front-crawl swimming. *European Journal of Applied Physiology and Occupational Physiology,* 80, 192-199.

FORMOSA, D. P., MASON, B., & BURKETT, B. (2011) The force-time profile of elite front crawl swimmers. *Journal of Sport Sciences,* 29(8), 811-819.

FREUDENHEIM, A. M., BASSO, L., XAVIER FILHO, E., SILVA, C. G., MADUREIRA, F., & MANOEL, E. J. (2005) Organização temporal da braçada do nado crawl: iniciantes "versus" avançados. *Revista Brasileira de Ciência e Movimento,* 15(2), 75-84.

HAVRILUK, R. (2007) Variability in measurement of swimming forces: a meta-analysis of passive and active drag. *Research Quarterly for Exercise & Sport*, 8(2), 32-39.

JÜRIMÄE, J., HALJASTE, K., CICCHELLA, A., LÄTT, E., PURGE, P., LEPPIK, A., & JÜRIMÄE, T. (2007) Analysis of swimming performance from physical, physiological, and biomechanical parameters in young swimmers. *Pediatric Exercise Science*, 19(1), 70-81.

KESKINEN, K. L., & KOMI, P. V. (1993) Stroking characteristics of front crawl swimming during exercise. *Journal of Applied Biomechanics*, 9, 219-226.

KJENDLIE, P. L., INGJER, F., STALLMAN, R. K., & STRAY-GUNDERSEN, J. (2004) Factors affecting swimming economy in children and adults. *European Journal of Applied Physiology,* 93(1-2), 65-74.

Kjendlie, P. L., & Stallman, R. K. (2008) Drag characteristics of competitive swimming children and adults. *Journal of Applied Biomechanics*, 24(1), 35-42.

Kjendlie, P. L., Stallman, R. K., & Stray-Gundersen, J. (2004) Passive and active floating torque during swimming. *European Journal of Applied Physiology*, 93(1-2), 75-81.

Madureira, F., Gollegã, D. G., Rodrigues, H. F., Oliveira, T. A. C., Dubas, J. P., & Freudenheim, A. M. (2008) Validação de um instrumento para avaliação qualitativa do nado "Crawl." *Brazilian Journal of Physical Education and Sport*, 22(4), 273-284.

Maglischo, E. W. (2003) *Swimming fastest*. Champaign, IL: Human Kinetics.

Malina, R. M., & Bouchard, C. (2002) Atividade física do atleta jovem: do crescimento à maturação. São Paulo: Roca.

McCullough, A. S., Kraemer, W. J., Volek, J. S., Solomon-Hill, G. F., Jr., Hatfield, D. L., Vingren, J. L., Ho, J. Y., Fragala, M. S., Thomas, G. A., Häkkinen, K., & Maresh, C. M. (2009) Factors affecting flutter kicking speed in women who are competitive and recreational swimmers. *Journal of Strength & Conditioning Research*, 23(7), 2130-2136.

Palayo, P., Alberty, M., Sidney, M., Potdevin, F., & Dekerle J. (2007) Aerobic potential, stroke parameters, and coordination in swimming front-crawl performance. *International Journal of Sports Physiology and Performance*, 2(4), 347-359.

Poujade, B., Hautier, C. A., & Rouard, A. (2002) Determinants of the energy cost of front-crawl swimming in children. *European Journal of Applied Physiology*, 87(1), 1-6.

Psycharakis, S. G., Cooke, C. B., Paradisis, G. P., O'Hara, J., & Phillips, G. (2008) Analysis of selected kinematic and physiological performance determinants during incremental testing in elite swimmers. *Journal of Strength & Conditioning Research*, 22(3), 951-957.

Sanders, R. H., & Psycharakis, S. G. (2009) Rolling rhythms in front crawl swimming with six-beat kick. *Journal of Biomechanics*, 42(3), 273-279.

Schnitzler, C., Brazier, T., Button, C., Seifert, L., & Chollet, D. (2011) Effect of velocity and added resistance on selected coordination and force parameters in front crawl. *Journal of Strength & Conditioning Research*, 25(10), 2681-2690.

Seifert, L., Boulesteix, D., Chollet, D., & Villas-Boas, J. P. (2008) Differences in spatial-temporal parameters and arm-leg coordination in butterfly stroke as a function of race pace, skill and gender. *Human Movement Science*, 27(1), 96-111.

Seifert, L., Chollet, D., & Rouard, A. (2007) Swimming constraints and arm coordination. *Human Movement Science*, 26(1), 68-86.

Seifert, L., Toussaint, H. M., Alberty, M., Schnitzler, C., & Chollet, D. (2010) Arm coordination, power, and swim efficiency in national and regional front crawl swimmers. *Human Movement Science*, 29, 426-439.

Smith, D. J., Norris, S. R., & Hogg, J. M. (2002) Performance evaluation of swimmers: scientific tools. *Sports Medicine*, 32(9), 539-554.

Stager, M. J., & Tanner, A. D. (2005) *Handbook on sports medicine and science: swimming.* London: Blackwell Science.

Stirn, I., Jarm, T., Kapus, V., & Strojnik, V. (2011) Evaluation of muscle fatigue during 100-m front crawl. *European Journal of Applied Physiology*, 111(1), 101-113.

Tani, G. (2000) [Adaptative process in motor learning: the role of variability]. [*Brazilian Journal of Physical Education and Sport*], 3, 55-61. [in Portuguese]

Tani, G. (2005) *Comportamento motor: aprendizagem e desenvolvimento.* Rio de Janeiro: Guanabara Koogan.

THORNTON, N., & HANNULA, D. (2001) *The swim coaching bible.* Champaign, IL: Human Kinetics.

ZAMPARO, P., GATTA, G., PENDERGAST, D., & CAPELLI, C. (2009) Active and passive drag: the role of trunk incline. *European Journal of Applied and Physiology,* 106(2), 195-205.

Accepted July 3, 2012.