EFFECT OF GLIDE ON NEUROMUSCULAR ADAPTATION IN BREASTSTROKE SWIMMING: A CASE STUDY OF AN ELITE SWIMMER

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ABSTRACT: *The aim of this case study was to examine the upper and lower limbs muscular responses of one elite breaststroke swimmer at three different glide and speed conditions, to understand how strength and condition could be optimized during training.*

Surface electromyograms (sEMG) were collected in biceps brachii (BB), biceps femoris (BF), deltoid anterior (DA), gastrocnemius medialis (GM), pectoralis major (PM) rectus femoris (RF), tibialis anterior (TA), and tríceps brachii (TB) during 18 x 25 m breaststroke trials performed at three different glide(normal, maximal, minimal) and speed (70, 80 and 90% of maximal speed) conditions. Each trial required an individually imposed swimming speed corresponding to 70, 80 and 90% of the swimmer maximal speed and a specific glide condition: minimal glide, normal glide and maximal glide. In maximal glide, higher participation of TB and DA and TA, RF, and GM muscles. In normal glide, a significant higher participation of all the muscles occurred, except for GM. In minimal glide, a significant higher participation of all the muscles occurred, except for the PM. We have also found that swimming at 90% of maximal speed led to significant higher use of the BB and PM muscles, for the upper limbs and BF and TA muscles for the lower limbs. In conclusion, the swimmer recruited different muscles as increasing his swimming speed and when gliding differently than normally. It suggested that strength and condition should be trained for various swimming speeds associated to various conditions of glide to ensure behavioral adaptability in competition.

Keywords: *Swimming; Breaststroke; Glide effect; EMG*

1. INTRODUCTION

The breaststroke technique is one of the least economic of the four swimming techniques[1] and its relationship with the physical performance of the swimmers seems obvious as in no other swimming technique, effort is devoted not only to the production of propulsion, but also in overcoming the active drag during the recovery phases of upper and lower limbs[2]. Indeed, Gatta et al. [3] suggested that the average frontal area and the estimated active drag values are largest in breaststroke compared to the other techniques. This economy issue can lead to early fatigue in breaststroke swimming.

After limbs recovery, the glide and relaxation time occur within each cycle, however long glide duration may be inefficient due to the increase of the intra-cyclic speed variations [4].

These intra-cyclic speed variations decreased in sprint as the propulsive and recovery phases occur almost continuously (i.e. without gliding) or with an overlap [4]. However, breaststroke swimming remained the technique with the highest active drag due to a less economic underwater recovery of arms and legs [5,6]. Higher resistive recovery forces during recovery in conjunction with cyclical changes of trunk angle attack on incoming mass of water increase neuromuscular fatigue [7].

Some studies also suggested that style differences (e.g., flat, undulating) are more important in breaststroke than in other strokes by observing larger average of the coefficient of variation in frontal area, trunk inclination and dorsal camber in breaststroke [3, 8, 9].

Swimming at different speeds led in changes of trunk inclination and dorsal camber, arm-leg coordination [5, 10] and muscular responses [11, 12]. Seifert et al. [9] observed that for different imposed swim speeds, swimmers adapted the glide duration, in accordance with Chollet et al. [5] who differentiated between ‘glide’, ‘continuous’ and ‘superposition’ breaststroke techniques. However, when specific glide conditions are imposed (e.g., maximal or minimal glide), swimmers changed glide duration as well as arm propulsion, leg propulsion and arm to leg coordination during propulsive phase, showing that a complete reorganization of the technique occurred. Martens & Daly [13] suggested that during the propulsive phases of the arms, the swimmer changes body position from an optimal streamline during the glide to the least streamlined position during breathing. The glide refers to phases in swimming techniques during which the swimmer attempts to “maintain speed” without actions to propel the body in order to minimize resistive forces [14]. According to Newton’s second law of motion, there is an inevitable deceleration during a glide that depends on the resistive forces applied to his body, almost exclusively to its immersed part. The glide phases could be improved (trying to maintain speed) by minimizing the resistive forces and could also be optimized by adapting the relative duration to the entire stroke cycle.

The change in glide duration is correlated to stroking parameters (stroke rate and stroke length) [5]. However, Invernizzi et al. [15] stated that, in breaststroke, the same distance can be covered at similar speeds with different stroke rate (SR) and thus, that breaststrokers can use different styles to achieve their goals. These authors analyzed the effect of SR style (low or high-SR) on upper and lower limbs strength in national-level swimmers and showed that low-SR had significant lower chin-up results and up and down trunk movement than swimmers with high-SR. In sum, changes in glide are linked to swimming speed, stroke rate strategy and have an impact on kinematics (arm and leg stroke phase duration, arm to leg coordination, intra-cyclic speed variations); however, less information are available regarding the influence of glide on muscular activity.

At high skill level, some important upper limbs muscles are recruited in breaststroke swimming, namely: the biceps brachii (BB), triceps brachii (TB), latissimus dorsi (LD) [12,16], deltoid anterior (DA)[16] , LD and pectoralis major (PM)[11] for the arm pull-phase, deltoid posterior[12] for the shoulder elevation during the arm pull, LD and PM[11] for the pull-through phases, and supraspinatus, infraspinatus, middle deltoid, and serratus anterior[11] during the recovery phase. With regard to the lower limbs the rectus femoris (RF), biceps femoris (BF), gastrocnemius medialis (GM) and tibialis anterior (TA) were the most recruited regarding the breaststroke kick [17]. Concerning the lower limbs, Yoshizawa et al. [12] reported that RF, TA, vastus medialis (VM), and BF had a role in the pelvis stabilization during the kick, that VM and RF stabilize the knee joint and that BF is involved in the recovery phase of the kick. In another point of view, Guignard et al. [18] described that the RF muscle was responsible for the hip flexion, the GM for the knee joint and TA for the ankle joint. Although these previous studies provided useful knowledge concerning the muscular activity in breaststroke, this body of literature remained insufficient to understand the effect of glide on the muscular organization of limbs in order to support the work of researchers, coaches and swimmers. Therefore, the aims of this study was to examine the upper and lower limbs muscular responses of one elite breaststroke swimmer at three different glide and speed conditions, to understand how strength and condition could be optimized during training.

Through a case study, we sought to highlight how the swimmer adapts his muscular participation when he is instructed to swim at different glide and speed conditions, because it might reflect his behavioral ability to face to various constraints during competition.

We hypothesized that (i) the swimmer muscular participation is destabilized and requested adaptations when gliding differently than normally, (ii) the higher swimming speed leads to a minimal glide condition and higher muscular participation.

2. METHODS

2.1 Study design and subjects

This was a case of study performed on elite level male breaststroke swimmer (23 y; 180.5 m of body height; 80 kg; personal best time long course 100m breaststroke: 1:03.06) volunteered for this study. The subject was informed about the procedure and signed a consent approved by the local ethics committee. The experiment was performed in a 25-m indoor swimming pool at a water temperature of 28.5°C and 85% of humidity. After a standard warm-up of 800-m front crawl, and a specific warm-up of 200-m breaststroke at a medium level of effort, the swimmer performed 18 x 25-m breaststroke trials at different speeds and glide conditions with five minutes rest between trials. Each trial required an individually imposed swim speed corresponding to 70, 80 and 90% of his own maximal speed assessed during a previous all-out 25-m trial. The swimmer was also required to swim a specific glide condition: minimal glide, normal glide (i.e. preferential glide) and maximal glide.

The stroke rate was controlled for each trial. No underwater propulsion was permitted after the push-off that began each trial.

2.2 Data Collection

The Stroke Rate (SR/stroke.min^{-1}) was controlled for each trial (Seiko S141 stopwatch.).

SR is expressed in number of complete cycles per minute (stroke.min^{-1}). The three cycles that the experimenter timed were from 10 m after the push-off. SR was also *a posteriori* assessed by the use of video recordings of the trials. Kinovea software (v.0.8.23) was used and the time to perform each cycle was computed. Mean and standard deviation of SR of all the cycles (except the two first and the two lasts) were assessed.

Surface EMG signals from the bíceps brachii (BB), biceps femoris (BF), deltoid anterior (DA), gastrocnemius medialis (GM), pectoralis major (PM), rectus femoris (RF), tibialis anterior (TA), and tríceps brachii (TB) were recorded at 1000 Hz, according to International Society of Electrophysiology and Kinesiology placement recommendations. These muscles were selected according with their importance in breaststroke [11, 12, 16, 18].

Bipolar electrodes were used (10 mm diameter discs and diameter of 57 mm with snap connector of 3.9 mm diameter, Plux, Lisbon, Portugal) with an inter-electrode distance of 20 mm were waterproofed. Additionally, to immobilize the cables, the swimmer wore a full-body swimming suit (Fastskin Speedo®, USA).

All EMG was conducted with MATLAB (Mathworks Inc., Natick, USA) for determining the muscle activity by the neighborhood points, where the energy was 30% of muscle activation maximum peak within a stroke. These were calculated by segmenting the muscle input signal energy [19].

A Butterworth filter was used, but as muscle energy is very noisy and presents several peaks, activity boundaires were established an selected by finding the neighborhood point where the energy is 30% of the determined maximum peaks. For each muscle, it was defined its active phase as the part of the EMG signal for which the energy was at least 30% of the local maximum energy value, for particular muscle activation. The raw EMG segments belonging to the active phases were extracted and used in calculation of the active phase duration. The non-active phase was defined as the time interval between the two consecutives active phases.

The temporal evolution of the active and inactive phases average durations during stroke were calculated for each muscle for all swimming time. Linear regression curve were fitted to the data and the durations of the fitted curves at the time of the beginning and end of swimming bout were compared.

For matched-paired data (pre and post measurements), based on differences, in a non-normal differences distribution, procedure of Wilcoxon Signed-Rank, Kruskall-Wallis H and t-Student paired test were applied. The assumptions were checked for each case. Statistical significance level was set at $P \leq 0.05$.

3. RESULTS

The SR increases from 70% to 90% of maximal velocity, and there were differences in SR between the three specific glide and speeds (Figure 1).

For active phase, at 70% the TB muscle presented higher in the end (0.99 s), followed by the TA (0.98 s). At 80% the TB presented higher in the end (1.43 s), and the TB (1.15 s). For inactive phase, at 70% and 90% the RF and

TA presented differences between beginning and end (*p* = 0.008; *p* = 0.026 and *p* = 0.015; *p* =0.026). For PM, DA and BF at 90% the behavior of the swimmer was different (*p*= 0.026; *p*=0.026; *p*=0.023).

The active and inactive phases showed differences at 90% for BB (*p* = 0.036), BF (*p* = 0.017), PM (*p* = 0.05) and TA (*p* = 0.011).

The duration of active phase (Table 1) below was for TB higher in the end (3.37 s) with respect to the beginning at 90% in the minimal glide. The longest duration of active phase was in TB in the end of the swimming for the 90% and minimal glide (3.37 s) and the shortest for the BB in beginning for the 70% and maximal glide (0.12 s).

The glide effect showed at 90% of maximal velocity differences between different glides (*p*=0.018). Those were noticed between normal and minimal glide, with a mean difference of -0.203 (*p*=0.030). For active and inactive phase the same glide condition presented differences on TA (*p* = 0.039).

For all muscles and in maximal glide, the inactive phase showed a decrease in the end at 70% and 80% and an increase in the end at 90% (Table 2)below..

Considering glide conditions and velocity's, at 70% the mean differences were reflected in BB, BF and TB, between maximal and minimal glide (BB: *p*=0.046; BF: *p*=0.031; TB: *p*=0.014), and normal and minimal glide (BB: *p*=0.045; TB: *p*=0.028). The BB, BF, DA and TB, showed statistical differences in normal and minimal glide (BB: *p*=0.017; BF: *p*=0.03; DA: *p*=0.046; TB: *p*=0.035). The BB presented variations at 90%, between normal and minimal glide (*p* =0.035).

4. DISCUSSION

The aim of this study was to examine the upper and lower limbs muscular responses at three different glide and swimming speed conditions in breaststroke.

The main finding concerning the glide effect was that when swimmer swum with normal glide, higher participation of all the muscles, except GM, may be linked because the leg kick is the largest propulsive force and because the GM was responsible for the knee joint movement during the recovery phase of legs [18].

Conversely, the maximal glide were characterized by higher participation of TB and DA, that can be related to a higher streamline body position, supported by higher elbow extension[10] of TA, RF and, GM. Last, in minimal glide condition, all the muscles showed higher participation, except PM, this could be due to a compensatory strategy to maintain swimming speed in the end [16].

The main finding concerning the swimming speed effect, was that at 90% of the maximal speed, the swimmer mostly used the upper limbs (BB), called "arms propulsor" style, whereas 70% of the maximal speed he favored the lower limbs (RF) called "leg propulsors" style. We observed that at 90% of the maximal speed the muscular participation decrease, with the change from maximal to normal glide [5,10]. Indeed, at 70% of maximal speed, the swimmer recruited mostly the TB, DA, BB and TA, RF, and BF. At 80% of the maximal speed the TB, PM, and TA, RF, and GM were mostly recruited. Finally, at 90% of the maximal speed the DA, TB and TA, GM were mostly recruited,, suggesting that, whenever the swimmer swims at 90%, he begun to use more the BB, PM and BF, TA.

Yoshizawa *et al.*[12] reported muscular differences in lower limbs (GM, TA, BF and RF), and in upper limbs (TB), and for deltoid muscles linked to different recovery. When the swimmer was instructed to use different glide conditions, we observed more behavioral adaptations at 70 and 90% of the maximal speed than at 80% of the maximal speed. At 70% of the maximal speed, the muscular participation showed differences in BB, BF and TB, between maximal and minimal glide, with an increase in BF, and decrease in BB and TB. This could mean that he did a muscular adaptation as he changed the glide condition at the lowest speed, performing a transition from "arm propulsors" (maximal glide) to "leg propulsor" (minimal glide). At 90% he showed an increase in BB, when he modifies glide between normal and minimal, supporting the importance of the "arm propulsors", and a consequence of increase the speed and SR, the decrease of SL, and also changes in arm-leg coordination [20].

5. PRACTICAL APPLICATIONS

This study emphasized how this elite swimmer was able to switch between "arm propulsor" and "leg propulsor" in order to adjust is glide. The main practical application is to train strength and condition of the swimmers, in order to help the swimmer to adapt various durations of glide and respective neuromuscular recruitment and coordination. In other words, our study contributes to inform coaches and swimmers to get more efficient muscle recruitment, save energy, and develop the core body strength as a pre-condition for efficient transfer of propelling forces generated by limbs.

Instructing swimmers to use maximal and minimal glide appeared as a fruitful way to assess their behavioral adaptability, because, these conditions caused whole behavioral reorganization that could be useful during competition.

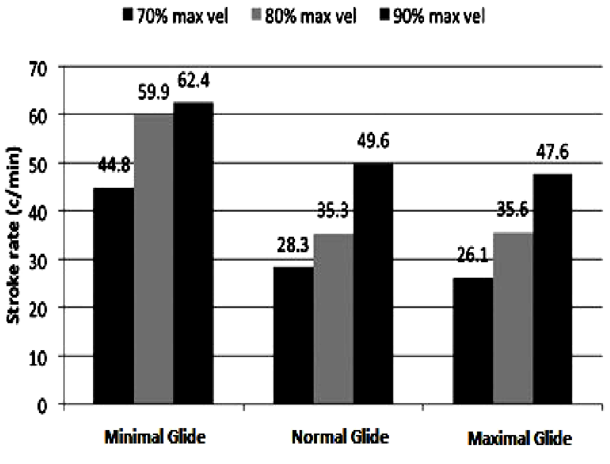

Fig. 1. Mean of the stroke rate (SR, stroke min^{-1}) for the three specific glide conditions (minimal glide, normal glide and maximal glide) and the imposed swim speeds (70, 80 and 90% of maximal speed)

Table 1. Mean active phase value for Beg (beginning) and End four all eight muscles (BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii), for the three specific glide conditions (maximal glide, normal glide and minimal glide) and the imposed swim speeds (70, 80 and 90% of maximal speed)

	Active phase (s)															
	BB		BF		DA		GM		PM		RF		TA		TB	
	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End
Maximal Glide																
70%	0.12	0.65	0.37	0.38	0.97	1.05	0.31	0.79	0.26	0.35	0.9	0.66	0.83	1.1	0.43	1.04
80%	0.57	0.56	0.75	0.61	0.54	0.56	0.43	0.99	0.64	0.64	0.68	0.72	0.69	0.81	0.94	1.42
90%	0.63	0.54	0.64	0.62	1.01	0.75	1.24	1.06	0.65	0.67	0.68	0.67	0.71	0.7	0.98	1.31
Normal Glide																
70%	0.61	0.96	0.41	0.34	0.63	0.61	0.79	0.48	0.27	0.28	0.83	0.22	0.97	0.98	0.24	1.47
80%	0.62	0.58	0.53	0.58	0.35	0.56	0.44	0.47	0.68	0.64	0.73	0.85	0.47	0.41	0.75	1.47
90%	0.55	0.59	0.62	0.72	0.76	0.62	0.28	0.42	0.61	0.67	0.76	0.62	0.66	0.84	1.58	0.72
Minimal Glide																
70%	0.74	0.74	0.75	0.74	0.51	0.41	0.38	0.44	0.55	0.58	0.75	0.79	0.74	0.87	0.38	0.46
80%	0.63	0.59	0.64	0.57	0.58	0.54	0.57	1.99	0.57	0.58	0.68	0.73	0.74	0.66	0.83	1.41
90% *	0.56	0.57	0.53	0.53	0.38	0.69	0.34	0.89	0.52	0.55	0.56	0.57	0.59	0.64	2.10	3.37

Notes: With *, statistically significant at 5 % (-2.371; 0.018); BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii

Table 2. Mean inactive phase value for Beg (beginning) and End four all eight muscles (BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii), for the three specific glide conditions (maximal glide, normal glide and minimal glide) and the imposed swim speeds (70, 80 and 90% of maximal speed).

	Inactive phase (s)															
	BB		BF		DA		GM		PM		RF		TA		TB	
	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End
Maximal Glide																
70% *	0.55	0.26	1.87	1.86	1.12	0.64	1.28	0.84	1.28	0.55	0.74	0.94	1.43	1.03	0.44	0.38
80%	0.86	0.65	0.72	0.71	0.91	0.91	0.76	0.84	0.58	1.02	0.51	1.03	0.64	0.61	0.43	0.34
90%	0.61	0.62	0.56	0.67	0.44	0.69	0.29	0.63	0.86	0.41	0.56	0.61	0.53	0.57	0.41	0.27
Normal Glide																
70%	0.44	0.36	1.35	1.79	0.83	0.44	1.14	0.73	0.96	0.97	0.63	1.24	1.22	1.06	0.46	0.68
80%	1.06	1.02	1.18	0.93	1.11	0.88	1.35	0.94	1.31	1.01	0.78	0.88	0.98	1.38	0.76	0.81
90%	0.64	0.74	0.62	0.67	0.58	0.77	0.78	0.69	0.77	0.58	0.28	1.02	0.4	0.65	0.39	0.32
Minimal Glide																
70% **	0.97	0.95	0.95	0.85	0.84	0.95	0.98	1.29	0.9	1.38	0.66	1.62	0.88	0.79	1.07	1.16
80%	0.44	0.48	0.49	0.53	0.47	0.58	0.51	0.47	0.38	0.87	0.52	0.31	0.38	0.59	0.44	0.25
90%	0.35	0.45	0.44	0.73	0.46	0.41	0.56	0.42	0.84	0.46	0.41	0.53	0.25	0.48	0.22	0.29

Notes: With * and **, statistically significant at 5 % (3.800; 0.002 and -2.500; 0.025); BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii

6. CONCLUSIONS

Our findings suggested that the swimmer recruited different muscles when swimming speed was increased and regarding different glide conditions. Thus, swimmers should carefully choose how they glide so it does not change their established muscular recruitment. The examination of the muscular adaptability by manipulating constraints such as glide duration is a promising way to understand (i) how swimmers may adapt their swimming skills in competition, and (ii) how to train their strength and condition.

COMPETING INTERESTS

None of the authors declare competing financial interests.

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