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Electrical stimulation and swimming performance

FLORENCE PICHON, JEAN-CLAUDE CHATARD,
ALAIN MARTIN, and GILLES COMETTI

Groupe Analyse du Mouvement,
UFR STAPS,
Université de Bourgogne,
Dijon, FRANCE; and
Laboratoire de Physiologie,
GIP Exercice,
Faculté de Médecine de Saint-Etienne, FRANCE

ABSTRACT

PICHON, F., J-C. CHATARD, A. MARTIN, and G. COMETTI. Electrical stimulation and swimming performance. *Med. Sci. Sports Exerc.*, Vol. 27, No. 12, pp. 1671–1676, 1995. The purpose of the study was to examine the influence of a 3-wk period of electrostimulation training on the strength of the latissimus dorsi m. and the swimming performances of 14 competitive swimmers divided into 7 electrostimulated (EG) and 7 control swimmers (CG). The peak torques registered during the flexion-extension of the arm was determined with the help of an isokinetic dynamometer at different velocities (from $-60^{\circ}\cdot s^{-1}$ to $360^{\circ}\cdot s^{-1}$). Performances were measured over a 25-m pull buoy and a 50-m freestyle swim. For EG, a significant increase of the peak torques was measured in isometric, eccentric, and concentric conditions ($P < 0.05$). The swimming times declined significantly ($P < 0.01$) by 0.19 ± 0.14 s, for the 25-m pull-buoy, and by 0.38 ± 0.24 s, for the 50-m freestyle. For CG, no significant difference was found for any of the tests. For the whole group, the variations of the peak torques, measured in eccentric condition ($-60^{\circ}\cdot s^{-1}$) were related to the variations of the performances ($r = 0.77$; $P < 0.01$). These results showed that an electrostimulation program of the latissimus dorsi increased the strength and swimming performances of a group of competitive swimmers.

LATISSIMUS DORSI, ISOKINETIC DYNAMOMETER, STRENGTH TRAINING, STROKE RATE, STROKE LENGTH

Electrostimulation is a technique of muscle strengthening based on the electrical stimulation of intramuscular branches of motor nerves (16) which induces muscular contraction. In rehabilitation, numerous studies have demonstrated that electrostimulation programs reduce the delay of atrophy (8), temporary spasticity (19) and contracture (22). Electrostimulation was also demonstrated to improve the isometric strength of the quadriceps femoris muscle for patients recovering from knee ligament surgery or with chondromalacia patellae (17). More recently, electrical stimulation was used as a strengthening means in the training program of athletes. Isometric peak torque gains ranging from 0% (24) to 44% (27) were reported. Such widely spread data were demonstrated as a result of the diversity of the training protocols (number and duration of the sessions), the modes of stimulation (frequency, pulse duration), the differences in testing procedure as reviewed by Enoka (7) and Hainaut and Duchâteau (12), and the variety of the subjects studied (11). In the literature, only one study has referred to a homogeneous group of subjects engaged in one sport, i.e., weightlifting (6). No study has been carried out in swimming. Although muscle strength has been shown to be an important factor of success on short distances, related in swimming to the recruitment of fast twitch muscle fibers (4), very few studies have been conducted to determine whether the improvement in muscular strength gained from dry-land training resulted in faster swimming performances (4,28,30).

Thus, the purpose of the present study was to assess the influence of a 3-wk period of electrostimulation on the strength of the latissimus dorsi m. of a group of competitive swimmers compared to a control group. The latissimus dorsi m. was chosen because an electromyography study (3) has revealed the extensive involvement of this muscle in front crawl throughout the motor phase, lowering the arm and orienting the propulsive surfaces. It was also chosen because it can be easily electrostimulated as it is a superficial muscle. The influence of the electrostimulation program on the strength was measured before and after training with the help of an isokinetic dynamometer in isometric, eccentric, and concentric conditions. The influence on the swimming performance was studied on two sprint swims (a 25-m pull-buoy and a 50-m freestyle). During these swims, the stroke rate was measured and the stroke length calculated to assess

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whether strength and performance variations could be related to these two biomechanical parameters.

METHODS

Subjects

A group of 14 competitive swimmers was studied. All the subjects agreed to participate in the study on a voluntary basis and signed an informed consent form. Approval for the project was obtained from the University Committee on Human Research. Among the swimmers, 10 were competing at a national level and four at a regional level. They trained on average 8.5 ± 1.5 h (mean ± SD) per week. All the swimmers were sprinters, 50-m, or 100-m freestyle specialists. They were divided into two groups of seven electrostimulated (EG) and seven control swimmers (CG) to make two groups as homogeneous as possible for the swimming performances. During the experiment, the swimming training was the same for all the swimmers and was performed with the same coach (5 sessions per wk; 1.5 h per session; swimming distance 5000–6000 m with an aerobic dominant work).

Electrostimulation Training

It was carried out in the morning between 9 and 11 a.m. over a 3-wk period, 12 min per session, 3 sessions per week, following the recommendation of Sale and MacDougall (26). Swimmers lay on a bench with the arms stretched slightly forward to form an angle of about 140° with the torso (0° corresponding to complete arm flexion). Electrostimulation was performed with the help of a Stiwell® stimulator (Stiwell Medical Technologies, Villeneuve, Switzerland). Both latissimi dorsi m. could be stimulated simultaneously. The electrodes used for the electrostimulation were 2 mm thick, self-adhesive, elastomer type. Single-pole stimulation was used with two electrodes of different surface areas, one small 22 cm^2 (4 cm × 5.5 cm), and one large 66 cm^2 (12 cm × 5.5 cm). The negative electrodes, which have the property of depolarizing the membrane, were placed as close as possible to the motor zone of the muscles. Thus, they were placed two finger-widths from the tip of the shoulder blades. The positive electrodes were placed along the spine at a slight angle. To stimulate the paravertebral muscles, these electrodes were placed two finger-widths from the spinous processes. Pulse currents of 80-Hz frequency lasting 300 μs were used. The contraction time was 6 s and the rest time 20 s. The number of contractions per session was 27. All the swimmers used a myostatic® type dynamometer (Allegro, Sallanches, France). The subjects controlled the intensity of the muscle contraction themselves, which was planned to correspond on average to 60% of the maximal voluntary contraction. The aim of the electrostimulation was to reach 60% of the maximal voluntary contraction at the beginning of the stimulation and to maintain this contraction level during 6 s.

Measurement of Muscle Strength

The peak torque of the flexion-extension of the dominant arm, expressed in Newton-meters (Nm), was measured before and after training, using an isokinetic dynamometer, Biodex® (Biodex Corporation, Shirley, NY), which was validated by Taylor et al. (31). A 10-min period of standardized warm-up and familiarization with the measurement apparatus with several submaximal and maximal exertions employing eccentric and concentric actions was performed. During measurement, swimmers sat with the torso strapped at the shoulders and pelvis. The arm was held parallel to the Biodex lever arm. The motor spindle was lined up with the rotate center of the articular joint. The measurements were made using a velocity range of $-60°\cdot s^{-1}$, $0°\cdot s^{-1}$, $60°\cdot s^{-1}$, $120°\cdot s^{-1}$, $180°\cdot s^{-1}$, $240°\cdot s^{-1}$, $300°\cdot s^{-1}$, and $360°\cdot s^{-1}$ which were performed in a randomized order. The same experimental procedure was used for all the velocities. The subjects were asked to perform two maximal efforts at each angular velocity. Only the best performance was retained. A 4-min period of rest separated each test. It allowed the subjects to recover and to perform all the tests with the maximum effectiveness. In isometric action, the effort lasted 5 s and a 1-min period of rest separated the repetitions. The shoulder angular was 140° (0° corresponding at the complete extension).

Swimming Performances

The swimming performances were measured in a 25-m swimming pool, after a 15-min warm-up (600–800 m, principally in freestyle). Each swimmer participated in two maximal swims. The first was a 25-m swim with the arms only and a pull-buoy held between the thighs and a belt fastened to the ankles avoided the use of the legs during swimming (25-m PB). The second swim was a 50-m whole stroke freestyle (50-m FS). The two swims were performed starting in the water, without diving. Timing began as the swimmer's feet left the wall on an underwater pushoff and was stopped when the swimmer's fingers touched the wall. A 10-min passive rest period separated the two tests. The performances were timed by two official timers who regularly timed swimming competitions. The 50-m FS swim was videotaped at normal camera speed to measure the stroke rate of all the swimmers. The stroke rate was measured with a frequency meter on three complete stroke cycles in the middle of the pool. The stroke length was calculated by dividing the mean velocity of the whole swim by the stroke rate.

TABLE 1. Main characteristics of the seven electrostimulated and the seven control swimmers.

	Age (yr)	Height (cm)	Weight (kg)	50-m Best Time (s)	Training Duration (h·wk^{-1})	Practice Level
Electrostimulated group						
GN	21	180	63	24.97	10	National
JT	22	184	76	24.4	10	National
LE	26	173	72	25.91	8	National
RG	26	182	76	26.41	6	Regional
SY	23	175	66	25.43	8	National
BO	23	175	75	25.18	7.5	National
PS	21	187	82	24.81	10	National
Mean	23	179	73	25.30	8.5	
SD	2.1	5.3	6.5	0.68	1.55	
Control group						
PP	22	184	76	26.02	8	National
BE	23	172	73	27.59	7.5	Regional
FE	23	175	74	26.03	10	National
CE	22	176	69	29.91	8	Regional
BV	21	189	92	24.82	10	National
MD	28	175	70	29.81	6	Regional
BJL	23	176	72	24.47	10	National
Mean	23	178	75	26.95	8.5	
SD	2.3	6.0	7.8	2.23	1.55	
Total						
Mean	23	179	74	26.07	8.5	
SD	2.1	5.5	7.0	1.69	1.55	

No significant difference was found between the two groups.

TABLE 2. Results of the performance times, stroke rate (SR), stroke length (SL) pre- and posttraining for the seven electrostimulated (EG) and the seven control (CG) swimmers.

		Pretraining				Posttraining			
		25-PB (s)	50-FS (s)	SR (cycle·min^{-1})	SL (m·cycle^{-1})	25-PB (s)	50-FS (s)	SR (cycle·min^{-1})	SL (m·cycle^{-1})
EG	Mean	14.34	26.19	55.1	2.10	14.15*	25.82*	54.2	2.15*
	SD	0.39	0.7	2.6	0.16	0.46	0.6	2.7	0.14
CG	Mean	15.21	27.98	51.4	2.10	15.28	27.82	52.3	2.08
	SD	1.6	2.5	4.6	0.11	1.5	2.6	5.1	0.11

*Significantly different from pretraining values.
25-PB = 25-m swam with a pull boy; 50-FS = 50-m whole stroke freestyle.

Statistical Analysis

Means and standard deviations were calculated for all the variables. Analyses of variance (ANOVA) were used to compare (i) the main characteristics, performances, muscular strength, stroke length, and stroke rate of the two groups (EG and CG), (ii) the individual differences of these variables between pre and post training. In each group, Student's *t*-test for paired samples was used to compare the effects of the electrostimulation program on strength, performances, and biomechanical parameters. For the whole group, correlation coefficients were calculated between the variations of the peak torques and the variations of performances. Stat View 512+ (Abacus Concepts Inc.®, Berkeley, CA, 1992) and Cricket Graph programs were used. In all the statistical analyses, the 0.05 level of significance was adopted.

RESULTS

Main Characteristics of the Swimmers

The main characteristics of the two groups of swimmers are summarized in Table 1. Before training, no significant differences were found for the main characteristics, the swimming times (25-m PB and 50-m FS), muscular strength, stroke rate, and stroke length of the two groups (Table 2). Although EG swimmers swam on average faster than CG (25.3 ± 0.68 s vs 26.95 ± 2.23 s) they had lower peak torques at the onset of the experiment.

Effect of Electrostimulation on Muscle Strength

For EG, peak torques measured during the flexion-extension of the arm (Fig. 1A), increased significantly in isometric (+21%), eccentric (+24,1% at −60°·s^{-1}) and concentric conditions (+10.3% at 180°·s^{-1}; +14.4% at 300°·s^{-1}; and +14.7% at 360°·s^{-1}). For CG, no significant difference was observed (Fig. 1B). Within the two groups, the individual differences of the peak torques measured after the training period where statistically significant at −60°·s^{-1}, 0°·s^{-1}, 180°·s^{-1}, 240°·s^{-1}, 300°·s^{-1}, and 360°·s^{-1}. Although EG swimmers had on average higher peak torques than CG, the difference for the two groups was not statistically significant.

Effect of Electrostimulation on Swimming Performances

For EG, the swimming times declined significantly by 0.19 ± 0.14 s (14.15 ± 0.46 s vs 14.34 ± 0.39 s) for the 25-m PB and by 0.38 ± 0.24 s (25.82 ± 0.58 s vs

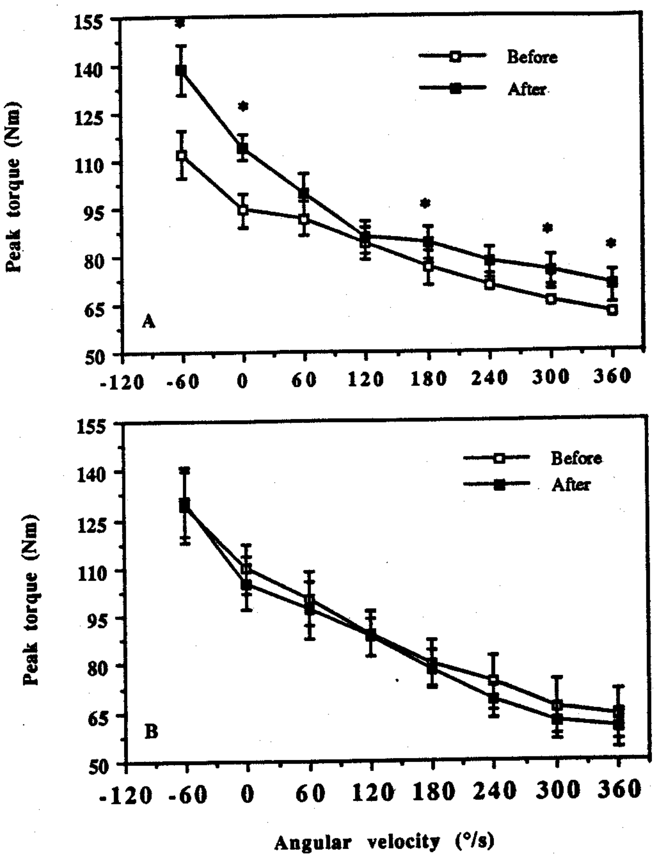

Figure 1—Relationship between the peak torque and the angular velocity before and after training for the electrostimulated group (A) and the control group (B); * denotes significance ($P < 0.05$). Values are means and standard error of estimate.

26.19 ± 0.70 s) for the 50-m FS. For CG, no significant differences were measured for the 25-m PB and the 50-m FS (Table 2). Within the two groups, the variations of the performances, expressed in percentage of the initial performances, were significant for the 25-m PB but not for the 50-m FS. For EG, the stroke length increased significantly by 0.05 m·cycle^{-1}, while for CG no statistical difference was measured (Table 2). For the stroke rate, no statistical differences were measured for EG and CG. Within the two groups, the individual differences of the stroke length and stroke rate measured after the training period where statistically significant.

For the whole group, no significant correlation coefficients were found between the peak torque measurements and the swimming performances before or after training. However, the variations of the peak torques, measured in eccentric condition (−60°·s^{-1}), and the variations of the performances were related together (r = 0.77; Fig. 2).

DISCUSSION

The main point of the present study was to indicate that electrostimulation of the latissimus dorsi m. enhanced muscular strength, performances, and stroke length of a group of competitive swimmers compared with a control group.

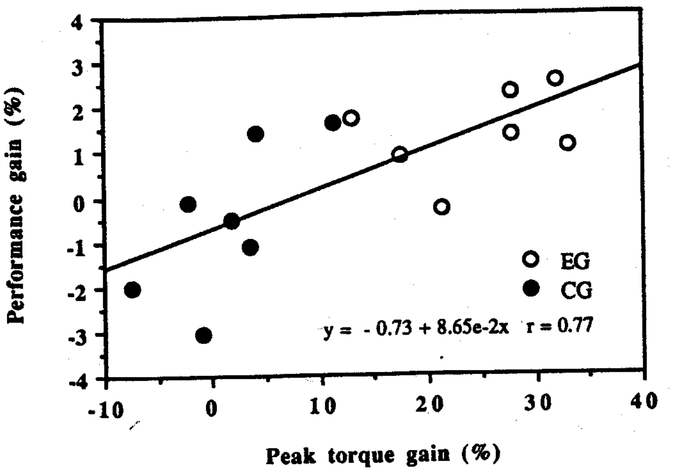

Figure 2—Relationship between the gains of performance, expressed in percentage of the initial performance, for a 50-m whole stroke swum in freestyle and the percentage of gain of the peak torque, for the electrostimulated (EG) and the control groups (CG).

In isometric, concentric, and eccentric conditions, the relationship between the peak torque measured in the present study and the angular velocities agreed with those reported in the literature (15,34). The peak torque decreased as soon as the rate of shortening velocity increased and the values of the peak torque were greater in eccentric conditions than in concentric and isometric conditions.

In isometric conditions, the peak torque gain measured in the present study (+21%) was similar to those reported in the literature, as reviewed by Selkowitz (27) and Hainaut and Duchâteau (12). Although, the muscular actions performed during isometric test and training session were different. The isometric gain observed in the present study may not be specific and could be also due to the learning of the specific coordination of the movement (25), which was performed at the same articular angle during testing and training.

For some authors, the gain observed in eccentric and concentric conditions and found in the present study, is a subject of controversy. As a matter of fact, Hartsell (13) found that electrostimulation under static conditions should not affect dynamic strength, whereas a more recent study of Martin et al. (21) has reported the contrary. In the present study, the strength gain observed in eccentric and concentric conditions at higher angular velocity (up to 180°·s^{-1}) could be partly explained by a preferential adaptation of the fast twitch fibers, which could be preferentially recruited during electrostimulation (7). Indeed, in eccentric condition, during submaximal exercise, the fast twich fibers were demonstrated to be preferentially recruited (23). Moreover, Friden et al. (9) had shown that during eccentric training, the fast twitch fibers are preferentially damaged. Although the testing conditions differed from the submaximal exercise used in the study of Nardone et al. (23) and of Friden et al. (9), these data suggest that during eccentric contraction, the fast motor units were the probable determinant for the strength development. In concentric conditions, over a 180°·s^{-1}, Thorstensson et al. (32) and Froese and Houston (10) have reported that the percentage of fast twitch fibers was an important factor for the development of the maximal generated force. In such conditions, the composition of muscle fibers can even be predicted (32,33).

Thus, peak torque gains at high velocities observed in the present study could benefit from nervous adaptation, which could result in an increased recruitment of the fast twitch fibers. This assumption is indirectly supported by the results of Enoka (7), who suggested that electrostimulation could recruit preferentially the Type II muscle fibers. Indeed, when the muscle is artificially activated, as with electrostimulation, the improvement of motor units is known to be different from that underlying natural activation. This claim is supported by Cabric and Appell (1), whose sources favor an inversely proportional order of recruitment of motor units. The results show a greater strength gain for the larger motor units which are faster and have a higher threshold compared with the smaller, slower motor units. Several factors may be involved. The first is the diameter of the motor axons. The excitation threshold of an axon is inversely proportional to its diameter (29). Large motor neurons therefore have a low threshold of excitability. Thus, large diameter axons are activated more rapidly than small diameter ones, unlike in voluntary contraction. The second factor is the distance between the stimulating electrode and the axon. Large motor units diameter are often located superficially in the muscle and therefore lie closer to the electrode (20).

For the whole group of swimmers, the attempt to relate arm strength to performance was unsuccessful. It was probably due to the testing procedure used in the present study. As a matter of fact, the contribution of strength to the swimming performance has been clearly demonstrated by Johnson et al. (18). These authors related different kinds of arm strength measurements to the performance of a 22.86-m swim. The highest correlation was found when the arm peak power was measured during swimming ($r = 0.87$ for 29 swimmers) and the lowest when power ($r = 0.74$) or strength ($r = 0.55$) was measured in dry-land conditions. Thus, to be significant, strength testing must be specific to the movement patterns used in swimming explaining, therefore, the lack of a significant relationship between the peak torques and the performances found in the present study.

Although muscle strength has been shown to be an important factor of success over short distances, the contribution of strength training to performance has not been clearly explained. Some studies have been conducted to determine whether the improvement in muscular strength gained from dry-land training resulted in faster swimming performances (4,28,30). Costill et al. (4) showed that after a strength training program five competitive swimmers increased their mean power by 28% while their sprint performance over a 22.86-m swim improved by 3.6% (11.3 s vs 11.8 s). Sharp et al. (28) confirmed this relationship on four competitive swimmers. The study of Tanaka et al. (30) differs. They showed that both swim training and combined swim and dry-land resistance training groups had significant but similar power gains as measured on a biokinetic swim bench. Moreover no significant differences were found between the groups in any of the swim power and swimming performance tests. In the present study, the seven swimmers of the electrostimulated group increased their peak power on average by 10%–24% and their performance by 1.3% and 1.4%. For the whole group, the variations of the peak torques were significantly related to the variations of the performances but only in eccentric condition (−60°·s^{-1}). This relation could be explained on the one hand by the fact that during eccentric contractions, fast twitch fibers were an important determinant for the strength development. On the other hand, by the fact that, in sprint, swimming performance require explosive force and fast twitch fibers.

In the present study, the gains in performances of the electrostimulated swimmers were associated with an increase of the stroke length. Many studies (2,4,5,14) have demonstrated the importance of the stroke length in swimming. Hay and Guimaraes (14) have shown that the improvement of the velocity over the course of a season were almost exclusively due to corresponding improvements of stroke length. Craig et al. (5) have indicated that the decline of the velocity during a race was completely accounted for by the decreasing stroke length. The improvements in velocity between the 1976 and 1984 Olympic Games were attributable to increased stroke length and a decline stroke rate in 16 of 20 events. The authors suggested that stroke length variations were probably related to the ability to develop the force necessary to overcome resistance to forward movement (5).

In summary, this study indicates that an electrostimulation program of the latissimus dorsi increased the arm strength measured in isometric, eccentric, and concentric conditions and the swimming performances of a group of competitive swimmers compared to a control group. Thus, electrostimulation appears to be not only a rehabilitation means but also a possible useful means to develop specific arm strength in swimming.

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Address for correspondence: Florence Pichon, Groupe Analyse du Mouvement, Université de Bourgogne, BP 138, 21004 Dijon cedex, France.

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