INTRODUCTION

Research upon swimming started at the beginning of the 20th century. Keskinen (1991) listed 574 publications on biomechanics in swimming which were mainly concerned with the front crawl stroke.

The nineteen seventies were marked by a new development in swimming research methods. Before the seventies, the front crawl movement was considered from a view lateral to the swimmer’s body displacement. The swimmer’s hand was compared to an oar blade which pushed the water along a straight line in a front to backward direction (Brown & Counsilman, 1971). According to Vaday and Nemessuri (1971), the stroke was divided into four phases in a sagittal plane: input (glide), pull, push, output and recovery phases. This oar blade model was largely investigated by an electromyographical approach (EMG) (Clarys, 1983). Most of the results gave some examples of EMG envelopes in reference to the input, pull, push, output and recovery phases. More precisely, Piette and Clarys (1979) and Clarys (1983) attempted to identify the EMG peak activity with regard to the different phases. The comparison between previous studies was difficult because of the non-standardization of the division of the phases from kinematic parameters and the non-standardization of the EMG data acquisition and treatment process (Clarys & Cabri, 1993). Moreover a good synchronization between EMG and kinematic data

MUSCULAR ACTIVATIONS DURING REPETITIONS OF SCULLING MOVEMENTS UP TO EXHAUSTION IN SWIMMING

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ABSTRACT

The purpose of this study was to examine the influence of the repetition of sculling movements of the upper limb on muscular electrical activities during an exhaustive test in front crawl. Six upper limb muscles activities of nine swimmers were recorded, with telemetric EMG data acquisition system using active surface electrodes, during a 4 × 100 m front crawl test conducted to exhaustion. The pattern of the movement was analysed from views obtained by recordings of two underwater cameras. Four phases in the stroke were identified from the hand coordinates in the frontal plane (down-sweep, insweep, outsweep and recovery). Raw EMG were rectified, integrated (IEMG) and normalized for each subject and for each muscle with respect to the highest IEMG obtained during the strokes and the phases.

Results indicated that the repetition of the stroke up to exhaustion was not associated with an increase in IEMG for the total stroke and its phases excepted for the most activated muscle. The different sculling movements appeared to be clearly identify by the EMG approach whatever the trial. The contribution of the different muscles remained the same through the different repetitions up to exhaustion. The larger muscular recruitments were obtained during the insweep phase when important antagonist activities were observed.

It would be interesting to observe the EMG in a next 100 m repetition when the swimmer could not sustain the same velocity.

KEYWORDS: EMG, exhaustion, repetition, sculling movements, swimming, upper limb.
acquisitions was required to quantify the EMG through the different phases.

Brown and Counsilman (1971) used underwater filming to examine the aquatic path of the hand of good swimmers. They observed a non linear trajectory of the hand which followed a sculling movement in all 3 planes, specially in the frontal plane. The hand did not moved like an oar blade but like a propeller to create lift force. A new model of propulsion was proposed based on the application of Bernouilli’s principle (Counsilman, 1971). Schlehauf (1979) proposed a new division of the stroke into phases taking into account the three planes of the space. For Maglischo (1982), the aquatic part of the stroke was divided into three phases determined from key positions of the hand with reference to a frontal plane.

The stroke began with the initial press during which the hand moved downward and forward, the second phase was the inward scull during which the hand moved in a medial and backward direction. During the final phase or outward scull, the hand had a backward-upward movement directed away from the midline of the body. High performance swimmers appeared to be different in the emphasis given to each phase (Maglischo, 1982).

Since 1982, these three phases have been used as reference by coaches and researchers in swimming. This stroke division has been recently supported by an EMG approach (Clarys & Rouard, 1995; Rouard & Clarys, 1995; Rouard et al., 1995). Results pointed out larger muscular recruitments during the insweep phase. With regard to these previous findings, the purpose of this study was to examine the influence of the repetition of the stroke up to exhaustion on the muscular recruitments within the phases of the stroke crawl cycle.

METHODS

Nine good swimmers participated in this study. Their mean ± SD age, height and body mass were respectively 17.33 ± 2.59 y, 1.81 ± 0.09 m and 72.33 ± 11.5 kg. To limit the influence of the expertise level on the results, the subjects were homogeneous concerning their best performance on 100 m front crawl (mean 58.2 ± 2.5 s).

Each subject was requested to swim 4 × 100 m in front crawl at the same swimming velocity. Taking into account the weight and the discomfort due to the acquisition system carried by the swimmer, the speed of each 100 m was 85% of the swimmer’s best performance on 100 m front crawl. A 45 s rest period was allowed between each swim. At the end of the last trial, the swimmer was unable to realize another 100 m at the same speed because of the exhaustion condition. The total test corresponded to about 250 repetitions of a stroke cycle. The test was a typical hard anaerobic training exercise in which swimmers must sustained the same velocity over different repetitions (Instructional Series, 1988). This exercise allowed to examine the influence of the movement repetition up to exhaustion, on muscular recruitments in swimming, according to one of the definitions of fatigue proposed by Edwards (1981): “Increased EMG activity for given performance”.

Data collection: Front and lateral views of the swimmer’s aquatic movement were obtained with two synchronised underwater camcorders (Sony EVO 9100, 30 Hz). A field of 8.40 m was filmed at the end of each 100 m.

The activities of the left M. biceps brachii, the M. triceps brachii, the M. flexor carpi ulnaris (flex. car.), the M. brachioradialis (brachio.), the M. latissimus dorsi (lat. dorsi) and the M. deltoideus anterior (delto. ant.) were recorded by surface electromyography. These muscles were chosen according to previous studies for their main function in the swimming propulsion (Clarys, 1983). This choice allowed to study the influence of the stroke repetition up to exhaustion on the contribution of the upper limb and trunk muscles in the front crawl propulsion and to evaluate the agonist and antagonist activities during the stroke phases.

The EMG data were collected with a telemetric transmission system (Billat et al., 1991). The electrical potentials were captured with Ag-AgCl Beeckman type electrodes (Ø 11 mm) including preamplifier (gain 1000). These sensors were fixed, after the classic cleaning procedures of the skin, at the midpoint of the contracted muscle belly with adhesive bandage.

Each amplified signal was connected to a voltage-frequency converter and coded with a subcarrier frequency higher than the muscle frequency (15 to 500 Hz). Two kHz intervals between each subcarrier frequency gave a better interband rejection. The six coded signals were summed and the resultant modulated a radio frequency transmitter with a frequency of 72 MHz. Its power was 200 MW and its size minimized to 6 × 3 × 1.5 cm. This frequency permitted the use of a half-meter flexible plastic antenna. This system was not multiplexed and had the advantage of transmitting simultaneously the information from 6 muscles. The receiving device, located on the side of the pool, was
set at 72.455 MHz. It had a maximal range of 800 m. The received signal was stored on the HiFi soundtrack of the lateral underwater video camcorder to synchronise EMG’s acquisition with kinematic data collection.

**Data treatment:** For the two views, the stroke cycle was digitized frame by frame. The coordinates (x, y, z) of the left shoulder, elbow, wrist and fingertip were obtained from “Kinematic Analysis” software (Schleihau, 1995). The stroke was divided into four phases using the coordinates of the fingertip on the lateral axis relative to an absolute (pool-fixed) reference: (i) the downswing: from the hand entry to the maximum external position of the hand, (ii) the inswing: from the maximum external to the maximum internal positions of the hand, (iii) the outswing: from the maximum internal position of the hand to the hand exit (outward scull) and (iv) the recovery: from the hand exit to the hand input (Fig. 1).

According to the International Society of Electrophysiology and Kinesiology (ISEK) guidelines (Winter et al., 1980), the raw EMG signals of each muscle and of each 100 m swim were full wave rectified and low pass filtered (cut off frequency 6 Hz) with a sample frequency of 1000 Hz to obtain the linear envelope. The linear envelope was integrated for the cycle (from input back to input), for each phase (downswing, inswing, outswing, recovery) and for the four swims. As the phases did not present similar durations, the IEMG’s were divided by the time of each phase (IEMG/tP). For each subject and each muscle, we obtained 20 values of IEMG/tP (1 for the total stroke and 4 for the phases for the 4 × 100 m). To normalize the results, we took the maximum value from the 20 IEMG/tP values, and expressed the others in percentage of this maximum value.

Mean and standard deviation were calculated for each stroke and each phase for all the studied parameters. According to the number of subjects (n = 9), the Wilcoxon test (P < 0.05) was used to compare the different 100 m and the different phases.

**RESULTS**

The time over the 4 consecutive 100 m swims were respectively 68.15 ± 4.54, 71.02 ± 2.87, 71.86 ± 3.90 and 71.95 ± 4.20 s. A Wilcoxon test indicated that the first 100 m swim was significantly faster (P < 0.037) and that the 2nd, 3rd and 4th 100 m swim were executed at the same velocity. Swimmers respected the test conditions, i.e. sustaining the same velocity up to exhaustion.

Previous studies pointed out an increase in IEMG with sustained Maximal Voluntary Contraction (MVC) (Kuroda et al., 1970) and with succession of contractions made under anaerobic conditions (Edwards et al., 1977). In regards to these findings, would this constant swimming speed over the 4 × 100 m front crawl be associated with an increase of the IEMG?

Whatever the 100 m, the main active muscles during the stroke remained the M. flexor carpi ulnaris and the M. latissimus dorsi (Fig. 2).
The muscular recruitments, for the total stroke, over the four 100 m were different from one muscle to another. For example, the M. brachioradialis presented similar IEMG during the four 100 m although the M. flexor carpi ulnaris was characterized by an increase of the IEMG from the first to the fourth 100 m. Excepted for this muscle, no increase of the IEMG of the total stroke was observed through the four repetitions.

In regard to these results for the total stroke, the IEMG during the different phases of the stroke over the four 100 m were analysed.

During the first phase (downsweep), low IEMG values were observed excepted for the M. flexor carpi ulnaris and the M. latissimus dorsi (Fig. 3). The hand moved down, backward and outside with a slight flexion of the elbow (Maglischo, 1982). Agonist muscles (M. biceps brachii, M. brachioradialis) presented similar level of recruitment than antagonists (M. triceps brachii).

During this phase, the elbow flexor muscles (M. biceps and M. brachioradialis) presented higher IEMG for the first faster 100 m swim than for the three other ($P_{\text{biceps}} = 0.0588$ and $P_{\text{brachioradialis}} = 0.0663$).

During the insweep phase, the hand trajectory was inside, back and up with a strong flexion of the elbow (Maglischo, 1982). Compared to the other phases, the insweep phase was characterized by the higher activities for all the studied muscles, ranging from 40% to

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**Fig. 2.** Mean (S.D.) of the normalized IEMG of six arm shoulder muscles during the stroke for the 4 × 100 m trials in front crawl ($n = 9$). * significant increase $P < 0.05$.

**Fig. 3.** Mean (S.D.) of the IEMG of six arm shoulder muscles during the downsweep phase of the stroke cycle for the 4 × 100 m trials in front crawl ($n = 9$). * significant decrease $P < 0.05$. 

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more than 80% of IEMG (Fig. 4). The M. biceps brachii and the M. brachioradialis presented higher recruitments than the other studied muscles. The IEMG of the antagonist muscle (M. triceps brachii) increased from the first to the third 100 m with a decrease for the last 100 m (respectively $P = 0.0674$). Similar evolution was observed for the M. deltoideus anterior ($P = 0.0691$).

During the outweep phase where the hand moved out and back with an extension of the elbow (Maglischo, 1982), high muscular activities were observed for the M. triceps brachii and the M. latissimus dorsi with low intensities for their antagonist (M. biceps brachii and M. brachioradialis) (Fig. 5).

The outweep phase showed an increase of IEMG for the extensor muscle (M. triceps brachii) over the four 100 m ($P$ between the 1st and the 4th 100 m = 0.0634). Similar results were observed for the M. flexor carpi ulnaris.

The recovery phase indicated the main activity for the M. latissimus dorsi with an important activity of the M. deltoideus anterior and the M. flexor carpi ulnaris (Fig. 6).

![Graph showing IEMG of muscles during the insweep phase of the stroke cycle for the 4 × 100 m trials in front crawl.](image1)

**Fig. 4.** MEAN (S.D.) OF THE IEMG OF SIX ARM SHOULDER MUSCLES DURING THE INSWEEP PHASE OF THE STROKE CYCLE FOR THE 4 × 100 M TRIALS IN FRONT CRAWL ($n = 9$). * significant increase $P < 0.05$.

![Graph showing IEMG of muscles during the outweep phase of the stroke cycle for the 4 × 100 m trials in front crawl.](image2)

**Fig. 5.** MEAN (S.D.) OF THE IEMG OF SIX ARM SHOULDER MUSCLES DURING THE OUTSWEEP PHASE OF THE STROKE CYCLE FOR THE 4 × 100 M TRIALS IN FRONT CRAWL ($n = 9$). * significant increase $P < 0.05$. 

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A.H. ROUARD ET AL. 659
No increase of muscular activation was observed during this aerial phase over the four 100 m.

DISCUSSION

The repetition of the stroke up to exhaustion in a test of 4 × 100 m front crawl was not associated with an increase of IEMG excepted for the M. flexor carpi ulnaris. To maintain a given swimming velocity, the swimmer did not recruit more motor units or did not improve the motor units synchronization to produce the stroke cycle. At the end of the 4 × 100 m, no typical muscular “fatigue” was observed as described in previous studies on simple movements (Bigland-Ritchie, 1981; Nyland, 1993). These authors found an increase of the IEMG at the beginning of the muscular fatigue “early local muscular fatigue” and a decrease of IEMG after a sustained fatigue condition “late fatigue”. Because of the testing procedures (4 × 100 m at the same swimming velocity), we could assume that the exhaustion condition would not be reached. It could be interesting to study the IEMG in a next 100 m when the swimmer would not able to sustain the same swimming velocity.

In the previous studies, changes in IEMG were associated with changes in force production. Edwards (1981), Bigland-Ritchie and Woods (1984), Gibson and Edwards (1985) described the local muscular fatigue as the inability of a muscle or a group of muscles to sustain the required force or power output. In the case of the swimming, the stroking technique was a complex movement in which the length, the velocity and the load of the involved muscles changed continuously during the movement. As a result, it was difficult to control these parameters during the test. Monteil (1992) realised a test of 400 m at maximal velocity in a flume (or swimming treadmill). The test stopped when the swimmer was unable to maintain the same velocity because of the flume conditions. A decrease of the forces produced by the hand was observed at the end of the test. We presented similar testing conditions: maximal effort on 4 × 100 m, same swimming velocity over the 4 × 100 m and exhaustion condition at the end of the test. As a result, we could suggest that the non-increase of the IEMG over the 4 × 100 m could be associated to a decrease of the forces produced by the upper limb. To complete this study, additional investigations will be necessary to evaluate force production and energy supply.

The repetition of the stroke up to exhaustion did not affect the contribution of each muscle during the stroke cycle. The greater activities observed for the M. flexor carpi ulnaris and the M. latisimus dorsi confirmed previous studies (Clarys, 1983). The M. flexor carpi ulnaris and presumably, all forearm flexors, acted to stabilize the wrist during all the aquatic part of the stroke. The “fatigue” condition did not influence the muscular patterns during the different phases of the stroke. Whatever the 100 m, the main muscular recruitments were obtained during the insweep phase confirming initial results (Clarys & Rouard, 1995; Rouard et al., 1995). The great muscular involvement of the insweep phase was similar to that observed in previous studies on other biomechanic parameters. Svec (1982) suggested the importance of the insweep phase related
to the hand pressure as Monteil (1992) and Deschodt (1996) underlined the importance of the duration and the amplitude of the hand trajectory during this sculling movement. On the other side, Schleihaufl (1979) did not observe hand peak forces during the insweep phase. For all the swimmers, maximal force and maximal hand velocity occurred during the final outswep phase. As a result, the maximal muscular effort seemed to occur before the maximal force production. This interval could be due to the electromechanical delay (Basmajian, 1978).

For each phase, the evolution of IEMG through the four 100 m was different from one muscle to another. We only observed an increase of IEMG for the prime mover muscles during the outswep phase (M. triceps brachii and M. flexor carpi ulnaris). In a complex movement such as swimming, the function and the load appeared to be specific to each muscle and changed within the stroke cycle. As a result, we were unable to evaluate the force produced by each muscle during each phase and to use the ratio force/IEMG as indicator of the “fatigue” (Edwards, 1981).

The activity of the antagonist muscles during the insweep phase (M. triceps brachii) increased with the “fatigue” condition. The purpose of this antagonist activity was to maintain joint stability and to supplement the prime movers action.

The muscular intensities of the M. triceps and the M. latissimus dorsi during the final outswep phase were not associated to high antagonist activities of the M. biceps brachii confirming previous findings (Rouard & Clarys, 1995). These results seem to be in accordance with Asmussen (1953) and Andrews (1985) observations who concluded that eccentric work creates higher forces than concentric actions.

In conclusion, the repetition of the stroke up to exhaustion in 4 × 100 m front crawl test was not associated with an increase of IEMG excepted for the M. flexor carpi ulnaris. No IEMG signs of “typical muscular fatigue” was observed in this kind of training exercise. It could be interesting to observe the IEMG in a next 100 m when the swimmer would not be able to swim at the same velocity.

Muscular patterns through the different phases were not influenced by the exhaustion condition. Whatever the 100 m, the greater muscular electrical activities were observed during the insweep phase supported by an important antagonist activities.

This study constituted a first approach in the evaluation of the exhaustion in complex swimming movement during training process. New investigations will be necessary to control other parameters such as force production and energy supply.

REFERENCES


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