EFFECT OF SWIM PADDLES ON THE INTRA-CYCLIC VELOCITY VARIATIONS AND ON THE ARM COORDINATION OF FRONT CRAWL STROKE

Michel **Sidney**[1,2], Sylvain **Paillette**[1], Jean-Michel Hespel', Didier **Chollet**[2,3], and Patrick **Pelayo**[1,2]
[1] LEHM, Faculte des Sciences du Sport et de **l'Education** Physique, Universite **Lille 2,** France, [2] CREN, centre Nauticaa, Lievin, France
[3] Faculte des Sciences du Sport, Rouen, France

This study analysed the effect of swimming with hand paddles on arm coordination and velocity pattern. Eight competitive swimmers performed two maximal aerobic tests. The maximal aerobic velocity was significantly higher when swimming with paddles but stroke rate, maximal heart rate and blood lactate values did not differ. The index of coordination (IdC) determined according to Chollet et al. (2000) and the intra-cyclic velocity variations were measured in two 25 m tests, one with and one without swim paddles, at a fixed stroke rate. When swimming with paddles, IdC and the duration of the propulsive phase increased significantly ($p<0.05$) and the velocity signal frequency spectrum showed fewer harmonics ($p<0.01$). These results enabled a better understanding of the technical consequences of the swimming paddles versus free swimming.

KEY **WORDS:** swimming, hand paddles, motor coordination, intra-cyclic velocity

INTRODUCTION: Several authors have shown that the use of paddles influences the propulsion of the swimmer. Indeed, Schleihauf (1979) demonstrated that the propulsive force acting on the hand is proportional to its surface and speed. Toussaint et al. (1991) showed that the propelling efficiency of the strokes with paddles was higher (7.8%) than that of the stroke without paddles. The work per arm cycle increases while work per unit distance covered during the cycle decreases in strokes with paddles. Besides, the amplitude increases and the stroke frequency decreases, for a given speed. Monteil and Rouard (1990) found that the use and the size of the paddles did not modify the temporal parameters of the stroke and the muscular recruitment. The results of Ogita and Tabata (1993) and Ogita et al. (1999) did not show that faster swimming with hand paddles induced a differential metabolic response and it was expected that the use of paddles involves a higher propelling efficiency. Thus, biomechanical investigations are needed to clarify how paddle swimming can improve the swimming performance more specifically. Hence, the aim of this study was to detect the modifications of the motor pattern through the intra-cyclic velocity variations and on the swimming coordination when using paddles at a fixed stroke rate.

METHODS: Eight national level swimmers (aged 20.0 ± 1.5) volunteered to enter the study. They were submitted to a complete medical examination prior to the beginning of the experiment. Written informed consent was obtained from each participant. Each swimmer performed two maximal aerobic tests and two 25m swim tests.
Experimental Procedures. In order to verify that stroke rate did not differ at maximal aerobic velocity (MAV), each subject performed two tests (Lavoie et al., 1985), once using the paddles and once free. Then, each swimmer performed two 25 m swim tests in randomized order at an imposed stroke rate determined in the maximal aerobic pretests: once using the hand paddles and once free. During the 25 m swim tests, they were connected to a speed sensor. The conventional Tyr paddles used during training were used in the experiments. The mean surface area of the paddle was 360 cm^2. All subjects had previously trained with these paddles. In all measurements, they used the same pull buoy to support their legs. Also, during swimming, the subjects had their ankles fastened together to prevent them performing the leg kick.

Maximal Aerobic Tests. Stroke rate was measured every 25 m using a Seiko stopwatch (base 3). The stroke rate (SR) recorded during the last completed stage corresponded to the stroke rate at maximal aerobic speed. Maximal heart rate (HRmax, in $beats.min^{-1}$) was recorded using a heart rate monitor (Polar Accurex+, Finland). The capillary blood lactate concentration ([La], in $mmol.l^{-1}$) was measured three minutes after the end of the test, by taking blood samples from fingertips. Samples were analyzed by a spectrophotometric method (Dr. Lange apparatus).

25 m Swim Tests. During the 25 m swim tests, velocity was measured with a speed sensor. The swimmer was connected to an unstretchable cable driving an electromagnetic angular velocity tachometer. It provided a linear velocity measurement of the cable which can be held over the length of pool (25 m). The sampling rate was set at 60 Hz.

The stroke phases and modes of arm coordination were analyzed underwater with two video cameras set at rapid shutter speed (111000 s). One camera filmed the swimmer from a frontal view, the other in profile. They were connected to a double-entry audiovisual mixer, a chronometer, a monitoring screen and a video recorder that mixed the pictures.

Subjects were asked to hold their breath for a distance of 10 m (from 15 m to 25 m), in order to avoid modifications in coordination due to breathing. An acoustic water-resistant metronome placed in the swimmer's swim cap was used to keep the stroke rate constant. Only the two 25 m swims done at the imposed stroke rate were analysed.

Data Analysis. In order to reduce the noise component of the velocity signal, a low-pass filter was used with 9 Hz cut off frequency. For each test, average speed (Vm), relative average maximal speed (ratio between Vmax, the mean value of the maximal peaks of each cycle, and Vm) and relative average minimal speed (ratio between Vmin, the mean value of the minimal peaks of each cycle and Vm) were calculated. The filtered signal was analyzed in terms of its frequency content. It was reconstituted from a given number of harmonics. This number depends on the standardized variation (error rate) existing between the initial signal and the reconstituted signal. The selected rate was fixed at 2.5%. From the video analysis, arm coordination was quantified using the Index of Coordination (IdC) of Chollet et al. (2000). This index characterizes coordination patterns by measuring the lag time between propulsive phases of each arm. Each movement of the arm was broken down into four distinct phases, defined by Chollet et al. (2000) (phase A: entry and catch of the hand into the water; phase B: pull; phase C: push; phase D: recovery). From this breakdown into distinct phases, the mean duration of each phase was calculated, over a series of two arm strokes. The mean duration of a complete arm movement, defined as the sum of the four distinct phases (A + B + C + D), was calculated. Each phase was then expressed as a percentage of the duration of a total arm stroke.

Statistical Analysis. Means and standard deviations were calculated for all measured parameters. A paired Student's t-test was used to evaluate the differences between bare hands and hand paddle strokes. Correlations were made between IdC and the other variables for each stroke procedure. The threshold for significance was set at the 0.05 level of confidence.

RESULTS: For the maximal aerobic tests, a significant difference ($p<0.05$) was noticed between MAV values with and without paddles (1.38 ± 0.09 vs. 1.32 ± 0.12 $m.s^{-1}$). HRmax and [La] mean values did not differ significantly under the two stroke conditions (183.4 ± 11.6 vs. 182.9 ± 12.5 $beats.min^{-1}$ and 6.0 ± 1.7 vs. 6.17 ± 2.3 $mmol.l^{-1}$). SR values recorded during the last completed stage did not differ significantly under the two stroke conditions (35.2 ± 4.4 vs. 36.2 ± 4.6 $cycles.min^{-1}$).

For the 25m swim tests, Vm was significantly higher in strokes with paddles than without ($p<0.05$). Relative average maximal speed values were significantly lower in strokes with paddles than in one without (Table 1). Relative average minimal speed values did not differ significantly ($p<0.05$). The mean IdC was negative and was in correspondence to catch up coordination. The Idc increased significantly ($p<0.01$) with the use of the paddles from -5 ± 4 to –1 ± 4%. The relative duration of the phase C (push phase) increased significantly ($p<0.01$) with the swim velocity and the use of hand paddles (Table 1). The amount of the total propulsive phase (B+C) increased significantly ($p<0.05$) from 46 ±3 to 48 ±3% and the amount of the total non-propulsive phase (A+D) decreased significantly ($p<0.05$) from 54 ± 3 to 52 ± 3%. The number of harmonics needed to reconstitute the signal (error of 2.5%) was significantly lower ($p<0.01$) in strokes with paddles (4.75 ± 2.49) than without paddles (6.38 ± 2.62). IdC measured with bare hands was inversely proportional to the duration of phase A ($r = -0.64$, $p<0.05$) and positively correlated with the duration of phase C ($r = 0.64$, $p<0.05$). IdC measured with hand paddles was negatively correlated to the duration of phase A ($r = -0.76$, $p<0.01$). It increased in parallel with the duration of phase C ($r = 0.60$, $p<0.05$). There was no significant correlation with Vm, stroke rate and the number of harmonics needed to reconstitute the signal.

Table **1** Mean **(±SD)** Values of the Relative Duration of the Different Stroke Phases

	Vm ($m.s^{-1}$)	Vmax/Vm (%)	Vmin/Vm (%)	IdC (%)	A (%)	B (%)	C (%)	D (%)
Without paddles	1.04 kO.II	121 f4	81 f4	-5 f4	32 f 5	21 23	25 f3	22 f2
Hand paddles	1.16 ±0.08 *	116 ±7 *	83 ±3	–1 ±4	30 ±4	21 ±3	27 ±3 *	21 f3

'significantly different between the stroke with and without paddles ($p<0.05$)

DISCUSSION: Maximal Aerobic Tests. The results of the two maximal aerobic tests showed that when hand paddles were used, the swimmer was able to swim significantly faster (+4.3 %) for the same maximal intensity of exercise with a same stroke rate. Several investigations have shown similar muscle activity with the use of the paddles (Bollens & Clarys, 1984; Monteil & Rouard, 1994). These results are in accordance with those of Ogita et al. (1999) who found that the ability to swim faster with hand paddles might mainly be attributed to other than metabolic factors, i.e. a higher propelling efficiency. Since the propelling efficiency is an important determinant of swimming performance (Toussaint et al., 1988), it is probably not surprising that previous studies (Toussaint et al., 1983 ; Sidney et al., 1988) have shown that top level swimmers had a significantly larger hand surface than less skilled swimmers.

25 m Swim Tests. When swimming without paddles, the coordination conformed to the front catch up model characterized by the presence of a non-propulsive lag time in the arm strokes. IdC increased with the use of hand paddles and with the swimming velocity. In this case, the coordination tends to the opposition model characterized by uninterrupted propulsion between the two arms. The swimmers reduced the non-propulsive phases (A + D) and relatively increased the propulsive phases of pull and push (B + C). These findings agreed with the observations of Keskinen and Komi (1993). They showed that in 10 high-level swimmers. the duration of the catch phase decreased with velocity whereas simultaneously the pull and push phases increased. Stoner and Luedtke (1979) have already shown that more time was spent in the underwater phase of the front crawl when the subjects used hand paddles. With these adaptations, swimmers are able to take advantage of longer periods of propulsive force action.

Swimming speed depends on the effects of propulsive forces that increase speed, and resistive forces that tend to slow the swimmer. Swimmers rely on forces produced by the water in response to their actions. Counsilman (1968) has shown that the swimmer does not need to move the hand in only a backward direction in order to move forwards. Inward and outward movements may also contribute to force in the forward direction due to lift forces produced (Schleihauf, 1979). In the 25 m test with paddles, the harmonic number of the velocity signal decreased significantly and the C phase of pulling was longer. With the use of hand paddles, the propelling surface is increased and the swimmer can push off against a larger mass of water and longer during the phase C (push). Lower intra-cycle velocity fluctuations as shown the significantly lower Vmax/Vm with the use of hand paddles (Table 1) could be likely in relation to the using predominantly drag forces in the push phase.

CONCLUSION: The study of the swimming paddles versus free swimming in front crawl at a fixed stroke rate pointed out that arm coordination and motor pattern were modified while swimmers used paddles. These results have to be taken into account by coaches in order to better understand the technical effects of training with hand paddles.

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