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## EFFECTS OF TRAINING INCLUDING BIOMECHANICAL BIOFEEDBACK IN SWIMMERS WITH CEREBRAL PALSY

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### SUMMARY

The purpose of the study was to assess the feasibility and the effects of a weekly training programme including biofeedback swimming hand paddles on swimmer skill with cerebral palsy subjects (CPS). Eight top level CPS performed pre and post training assessment sessions which consisted of a 50m test, a functional maximal aerobic power test (FMAPT) and a maximal swim power test (MSPT). Pre and post FMAPT blood lactate concentrations ([La]) and maximal swim power (MSP) were assessed. The velocity (V), the stroke length (SL), the stroke rate (SR) and the stroke index (SI) were recorded in all testing conditions. Significant decreases in SR and post FMAPT [La] ( $P < 0.05$ ), and the increases in SL and SI ( $P < 0.05$ ) showed changes in stroking characteristics and swimming skills. The increases in swimming performances (noticed three weeks after training) and MSP indicated an improvement in swimming skills. The individual analysis showed that the degree of disability was not a discriminating factor in the improvement achieved. This study introduced an effective and feasible training method which seemed to have great effect, especially in younger and less skilled CPS.

## INTRODUCTION

Cerebral palsy (CP) is defined as a non-progressive lesion of the brain occurring before, at, or shortly after birth which interferes with the normal development of the immature brain. It results in an impairment of muscle coordination, along with a reduced capability to maintain postures and balance and to perform normal movement and skills. The movement capability is disturbed by muscle tone troubles, coordination and postural adjustment problems linked to spasticity or athetosis. The use of feedback (FB) to improve the motor control of disabled individuals has been well documented. Nevertheless, a review criticises these techniques when they are to be used for complex skills optimisations (Wehner et al, 1987). They show that FB based on the muscular electrical activity cannot supply all the information normally returned by the proprioception (balance, posture, etc). Biokinetic feedback was used for functional rehabilitation and to

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improve performance in physical activities with healthy athletes. This technique seems to be effective when the anticipated correction concerns a complex skill. The information returns the biokinetic parameters of the movement (pressure, speed, force, etc) in the perceptible form. An auditory "augmented feedback" was used to correct the foot pronation of dancers during barre exercises (Clarkson et al, 1986). Augmented feedback was applied to training in several cyclical activities. An "extrinsic augmented feedback" was used to improve motor efficiency in cyclists (Broker et al, 1993; Sanderson and Cavanagh, 1990) and showed the long term effects of augmented feedback. In other studies which focused on aquatic cyclical activities, the search of efficiency is more difficult because it is linked to the specificity of hydrodynamic pressures. Improvements in performance were observed in rowers by using "augmented performance feedback" based on the force and the angular speed of the oar (Gauthier, 1985). Biomechanical biofeedback (BBFB) allowed healthy swimmers to improve their stroking characteristics (Chollet et al, 1988, Chollet et al, 1992). The information was based on hydrodynamic pressures of the hand and on variations of swimming speed. Finally, some studies summarised the use of BBFB in the development of motor skills in individuals with cerebral palsy (ICP). An auditory BBFB which returned the pressure of the foot at the ground, was used to optimise gait (Seeger et al, 1981 and 1983). This information has allowed 4 young ICP with hemiplegia to correct the symmetry of their gait (temporal aspect of gait cycle). The same type of auditory BBFB allowed children with cerebral palsy to correct the load of the impaired limb (Fleiss et al, 1980). In swimmers with cerebral palsy (CPS), no study has reported the use of biomechanical biofeedback during training.

The purpose of this study was to analyse the effects of training including biofeedback swimming hand paddle device (Chollet et al, 1988) on swimming performances and skills and on stroking parameters in swimmers with cerebral palsy.

## METHODS

### *Subjects*

Eight swimmers with cerebral palsy (CPS) competing at national and international level participating in a one week training programme served as subjects for this investigation. All the subjects gave written consent to participate voluntarily in this study, and were submitted to a medical

examination prior to the beginning of the experiments. All evaluations in the study were carried out under medical supervision. The population was  $20 \pm 5.37$  years and trained 2 to 6 hours per week since  $6.9 \pm 4.5$  years. They have been chosen on a national basis by the coach who had trained them for 3 to 15 years. The selected subjects were affected with cerebral palsy but did not, however, suffer from any mental retardation or hearing impairments. They were classified using the Cerebral Palsy International Sports and Recreation Association (C.P.I.S.R.A.) classification (Table 1). The degree of disability ranged from C3 to C7 and the subjects were either class 3, 4, 6 or 7. The diagnosis of CPS subjects included 1 case of hemiplegia athetosis, 2 cases of spastic diplegia (syndrome of Little), 2 cases of spastic hemiplegia and 3 cases of quadriplegia athetosis. The main physical and performance characteristics of the subjects are presented in Table 1.

#### *Training programme*

The training programme was organised following the winter training programme which commonly consisted of the development of aerobic capacity. The adherence to training was extremely high with a regular attendance for all subjects. The programme which included technical training based on biomechanical biofeedback was organised over a week. Each subject performed 7 training sessions. Two consecutive sessions were interspersed with a minimum of 7 hours rest. Each training session was divided into two periods (P1 and P2) and began after a warm-up period of 10 minutes (commonly  $125 \pm 50$  m in different swimming styles at spontaneously chosen moderate velocity). P1 consisted of a 15 minute technical programme without any device (except pull-buoy). It consisted of a series of 4 to 6 x 25m and 2 to 3 x 50m with 20s and 30s rests, respectively. The objective was to reduce the stroke rate and to maintain constant velocity. P2 consisted of a training session including biofeedback swimming hand paddles. This device consisted of hand paddles including a single waterproof force sensor situated in its centre. The sensor is connected to a battery and a sound generator placed near the swimmer's ears inside a swimming cap. The transducer worked on the basis of "all or nothing". When a pre-determined level of pressure was satisfied, the swimmer was immediately informed by the acoustic signal. If it had not been reached, a signal was not issued. The level of pressure had been pre-determined in relationship with the practice level of each subject. While the coach was unable to detect the signal, each individual was aware of his own pressure. The use of biofeedback hand paddles provided a real time evaluation of the stroke and an external biofeedback loop under the control

of the swimmers (Chollet et al, 1988). The series consisted of a repeated best style 50m with 1 min rest during 30 minutes. The objective was to reach the signal through the duration of the stroke cycles. The swimming velocity was not imposed. Each swimmer completed as many 50m as possible. According to the severity of the disability, a range of 10 to 15 trials have been observed for the C3 to C7 classed individuals.

#### *Testing procedures*

Using their best swimming style, each subject performed 3 swimming tests at the beginning and at the end of the training programme.

#### *50-m test*

In the first test, the subjects performed a 50m test with a start in the water in 25m pool to evaluate the swimming performance. The velocity (V) was measured over a distance of 10m from a videotape according to the following protocol. Two S-VHS video cameras running in synchronisation, set 10m apart along the central part of the pool and connected to a timer, enabled us to assess the value of V. This procedure was similar to that of Kennedy et al (1990) and Pelayo et al (1996b) and was chosen in order to eliminate the changes in speed at start and turn. The stroking characteristics were assessed in order to identify the strategy and the practice level for each subject. The stroke rate (SR) was measured three times across the length of the pool using a Seiko frequency meter (base 3) and was expressed in  $\text{cycle}\cdot\text{s}^{-1}$ . The stroke length (SL) was calculated from the V/SR ratio and was expressed in  $\text{m}\cdot\text{cycle}^{-1}$ . In order to appreciate the evolution of practice level, the stroke index (SI) was calculated for each subject because Costill et al (1985) showed that SI is one of the best predictors of swimming success. SI is the result of the product of V and SL and was expressed in  $\text{m}^2\cdot\text{cycle}^{-1}\cdot\text{s}^{-1}$ . A third video camera (25 Hz) was placed in the middle of the pool under the water. The frame to frame video analysis realised with a U-Matic video recorder enabled us to assess the propulsion time. It was measured between the beginning of the first sweep and the end of the push phase in the sagittal plan. The two phases were pin pointed from the orientations of both hand and arm propulsive area. The propulsion time was reported to the time of the cycle and recorded as propulsion time ratio (PT). PT was expressed in percent of cycle and enabled us to evaluate the swimming skills performed in each subject's best style.

#### *Maximal swim power test*

The second test consisted of the maximum swim power (MSP)

assessment. The swimmer performed a series of 15m sprints (start in water) under tethered conditions by using the Control Aqua Training device (C.A.T.S., by Fahnmann, Germany) allowing to determine the effect of adding resistance on the evolution of stroking parameters according to the speed. The test was a triangular one with incremental loads. The load was increased by 0.5 kg step by step. Each swimmer had two minutes rest between the steps. The MSP was the load of the step completed last. The velocity and the stroke rate were measured over a distance of 10 m from 5 up to 15m of the start using the aforementioned method. To ascertain the evolution of swimming parameters under tethered conditions, V, SL, SR and SI were calculated at different levels being  $45 \pm 5\%$  and  $75 \pm 5\%$  of the maximal swim power reached at the end of the training programme.

#### *Functional maximal aerobic power test*

In the third test, the subjects were submitted to the functional maximal aerobic power test (FMAPT) according to the protocol of Lavoie et al (Lavoie et al, 1985). FMAPT consisted of a progression of 2 min stages in the athlete's best swimming style. Speed was monitored by a submerged bank of lights (5m spaced) connected to a speed programmer (Balise temporelle, Baumann CEM S.A., Electronique Médicale, CH2114 Fleurier, France). To adapt the test to disabled swimmers, the speeds were increased every lap by  $0.025 \text{ m}\cdot\text{s}^{-1}$  according to the study of Pelayo et al (1995). The initial swimming speed (Table 3) was set to approximately 55% of the maximal speed of a 100m swim (best swimming style) for each subject so that the test would last approximately 15 min (Pelayo et al, 1995). The test was stopped when the swimmer could not follow the visual signal of the timing light system. During the second assessment (end of the training programme) the swimmer was stopped when they reached the last step of the previous FMAPT in order to have the same exercise duration and to reach the same last speed. Blood samples were taken from the fingertips into capillary tubes for lactate determination before the warm-up and at 3 min after the completion of the test while a passive recovery in the sitting position was imposed. Blood samples were analysed for lactate concentrations using Boehringer's bi-enzyme method (Noll and Bergmeyer, 1974). The stroking parameters (V, SL, SR and SI) were calculated during the last step using the method previously expressed.

#### *Statistical analyses*

The mean and standard deviation were computed for all the measured variables. The Wilcoxon test was used to compare paired data between the two assessments. The significance threshold was set at  $P < 0.05$  (\*) for all

TABLE 1: Main characteristics of the subjects.

Disability	Sex	Height (cm)	Span (cm)	Mass (kg)	Age (years)	SS	Dist. (m)	Time (s)	T/W	Yt	CPSRA classification groups	
											Time best time performed in competition	Dist distance
C7 <sub>1</sub> Spastic diplegia	M	170	181	63	23	C	400	485	3	5		
C7 <sub>2</sub> Quadriplegia athetosis	F	147	151	43	26	C	200	268	3	15		
C7 <sub>3</sub> Hemiplegia athetosis	M	152	150	60	13	BS	400	605	2	3		
C6 Spastic hemiplegia	F	144	150	48	18	BS	100	163	2	6		
C4 <sub>1</sub> Quadriplegia athetosis	M	152	173	45	28	C	200	277	6	13		
C4 <sub>2</sub> Spastic hemiplegia	M	170	180	50	20	C	50	658	3	4.5		
C4 <sub>3</sub> Spastic diplegia	M	153	163	42	14	BS	400	665	2	3		
C3 Quadriplegia athetosis	M	173	175	63	18	BS	100	191	2	6		
Mean (sd)		157 (11)	165 (13)	51.7 (9.8)	20 (5)				2.8 (1.4)	6.9 (4.5)		



comparisons. Linear regression was used for the statistical analysis of the relationship between the values recorded pre and post training programme. The data was reported for each subject and an individual analysis was then conducted and discussed because the population included swimmers with different degrees of cerebral palsy.

## RESULTS

### *50m test*

The data concerning V, SL and SR values, recorded pre and post training programme, were reported as abscissa and ordinate in Figure 1. The stroke index values and the propulsion time ratio were reported in Table 2 for each subject. The significant correlation between the data recorded pre and post training programme indicated that V, SL and SR changes were similar in proportion to their pre-test score, i.e. changes were consistent across subjects (Figure 1). The statistical analysis showed that V did not improve significantly ( $0.67 \pm 0.27$  vs  $0.69 \pm 0.26$  m.s<sup>-1</sup>). However, SL ( $1.07 \pm 0.34$  vs  $1.38 \pm 0.40$  m.cycle<sup>-1</sup>) and SI ( $0.77 \pm 0.48$  vs  $0.99 \pm 0.50$  m<sup>2</sup>.cycle<sup>-1</sup>.s<sup>-1</sup>) increased significantly ( $p < 0.05$ ). SR ( $0.62 \pm 0.15$  vs  $0.51 \pm 0.18$  cycle.s<sup>-1</sup>) decreased significantly ( $p < 0.05$ ) after a one week training programme. The propulsion time ratio increased significantly ( $P < 0.05$ ) from  $74.4 \pm 10.4$  to  $80.1 \pm 9.7$  %.

With regard to each subject, V and SL increased from 1% for C4<sub>1</sub> to 15% for C3 (except for C4<sub>2</sub> and C7<sub>2</sub>) and from 6% for C7<sub>1</sub> to 91% for C4<sub>3</sub>, respectively. V remained constant for C4<sub>2</sub> and decreased by 5% for C7<sub>2</sub>. Therefore, SI increased for all subjects from 8% for C7<sub>1</sub> to 99% for C4<sub>3</sub>. SR decreased for all subjects from 5% for C7<sub>1</sub> to 43% for C4<sub>3</sub>. The propulsion time ratio increased from 3.7% for C<sub>3</sub> to 12.5% for C4<sub>1</sub> except for C4<sub>2</sub> (a decrease of 6.5% was noticed).

### *Functional maximal aerobic power test*

At the last completed step, the imposed velocity was the same for both FMAPT (i.e. the test was interrupted during the second FMAPT at the step reached during the first FMAPT). The data concerning SL and SR values, recorded pre and post training, were reported as abscissa and ordinate in Figure 2. SI and the blood lactate concentrations ([La]) were reported in Table 2 and Table 3, respectively. The significant correlation between the data recorded pre and post training programme indicated that SL and SR changes were relatively homogeneous (Figure 2). SL and SI

FIGURE 1: Relationship between the pre and post training stroking characteristics values during Functional Maximal Aerobic Power Test. The pre and post training programme values are reported as abscissa and ordinate, respectively. The dotted and full lines represent the identity and regression lines, respectively.

C3 to C7 CPISRA classification groups

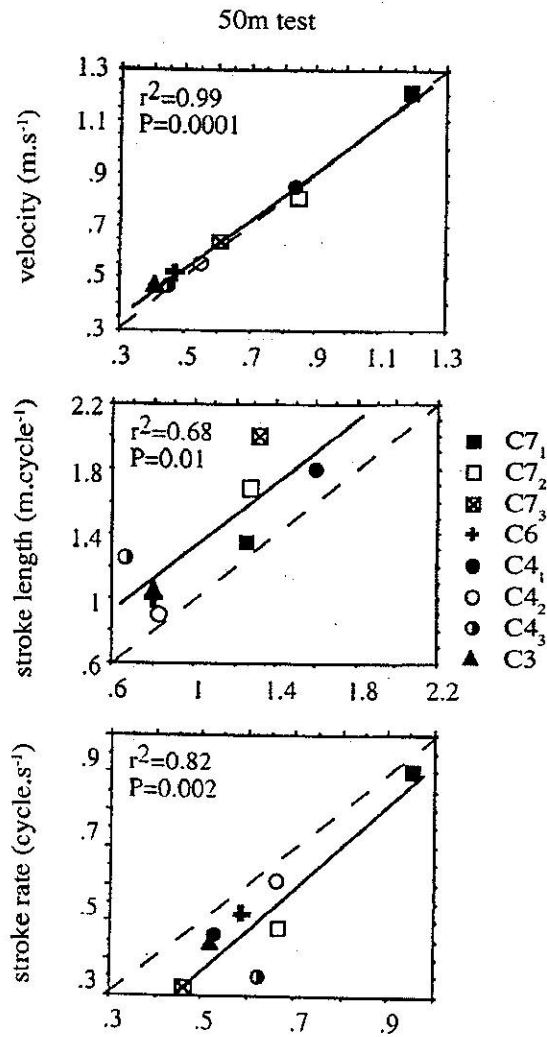


TABLE 2: Individual propulsion time ratio (PT) and stroke index (SI) values recorded during pre and post training 50m test. Maximal swim power test (MSPT 35% and 75% of MSP) and functional maximal aerobic power test (FMAPT).  
 C3 to C7 CPISRA classification groups  
 C7<sub>1</sub> first subject classed C7

	50m test				FMAPT		MSPT			
	PT		SI		SI		SI		SI	
	(% of cycle)		(m <sup>2</sup> .cycle <sup>-1</sup> .s <sup>-1</sup> )		(last step)		35% MSP		75% MSP	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
C7 <sub>1</sub>	65.2	73.1	1.50	1.62	1.10	1.10	0.50	1.30	0.50	0.68
C7 <sub>2</sub>	61.6	68.0	1.09	1.36	0.66	0.68	0.24	0.48	0.14	0.14
C7 <sub>3</sub>	83.1	89.1	0.81	1.28	0.64	0.92	0.32	0.44	0.18	0.28
C6	85.1	92.6	0.38	0.52	0.48	0.56	0.30	0.36	0.14	0.26
C4 <sub>1</sub>	59.8	72.3	1.34	1.53	0.60	0.60	0.58	0.58	0.28	0.34
C4 <sub>2</sub>	78.9	72.4	0.46	0.50	0.33	0.45	0.34	0.46	0.16	0.21
C4 <sub>3</sub>	81.7	90.0	0.30	0.59	0.30	0.33	0.07	0.10	0.06	0.09
C3	79.6	83.3	0.33	0.50	0.27	0.28	0.14	0.19	0.08	0.13
mean	74.4	80.1*	0.77	0.99*	0.55	0.62*	0.31	0.49*	0.19	0.27*
(sd)	(10.4)	(9.7)	(0.48)	(0.50)	(0.27)	(0.28)	(0.17)	(0.36)	(0.14)	(0.19)

\* Difference between pre and post training values statistically significant ( $P < 0.05$ )

TABLE 3: Individual blood lactate concentrations [La] measured during the Functional Maximal Aerobic Power Test (FMAPT) and maximal swim power (MSP) values reached during the Maximal Swim Power Test (MSPT).

Vi *velocity of the initial step*  
 Sc *number of steps completed*  
 [La]rest *blood lactate concentrations at rest*  
 [La]3 min *blood lactate concentrations at 3 min after the completion of the last step*

	Vi (m.s <sup>-1</sup> )	Sc	FMAPT				MSPT	
			Pre		Post		Pre	Post
			[La] Rest (mmol.l <sup>-1</sup> )	[La] 3 min (mmol.l <sup>-1</sup> )	[La] Rest (mmol.l <sup>-1</sup> )	[La] 3 min (mmol.l <sup>-1</sup> )	MSP (kg)	MSP (kg)
C7 <sub>1</sub>	0.53	7	1.40	13.46	2.22	11.70	6.0	7.5
C7 <sub>2</sub>	0.40	7	2.29	8.06	2.35	6.42	3.0	3.5
C7 <sub>3</sub>	0.36	7	1.80	10.20	2.31	5.98	2.0	2.5
C6	0.31	5	1.98	10.10	1.74	7.72	2.5	2.5
C4 <sub>1</sub>	0.36	5	1.83	10.20	1.76	8.26	3.0	4.0
C4 <sub>2</sub>	0.25	5	2.36	9.20	1.43	9.74	2.0	3.0
C4 <sub>3</sub>	0.31	5	2.10	7.30	2.44	5.10	2.0	2.0
C3	0.25	5	1.32	4.40	1.26	4.22	4.0	5.0
mean	0.35	5.75	1.88	9.12	1.94	7.39*	3.1	3.7*
(sd)	(0.09)	(1.04)	(0.38)	(2.64)	(0.45)	(2.48)	(1.4)	(1.8)

\* Difference between pre and post training values statistically significant ( $p < 0.05$ )

increased significantly after the training programme from  $1.07 \pm 0.29$  to  $1.21 \pm 0.34$  m.cycle<sup>-1</sup> and from  $0.55 \pm 0.27$  to  $0.62 \pm 0.28$  m<sup>2</sup>.cycle<sup>-1</sup>.s<sup>-1</sup>, respectively. SR decreased significantly ( $P < 0.05$ ) from  $0.47 \pm 0.08$  to  $0.42 \pm 0.09$  cycle.s<sup>-1</sup>.

With regard to individual values, C7<sub>2</sub> increased SR and decreased SL by 3%. SL and SR remained constant for C4<sub>1</sub> and C7<sub>1</sub>. SL increased for the other CPS by 7% for C<sub>3</sub> to 43% for C7<sub>3</sub>. SR decreased for the other CPS by 8% for C<sub>3</sub> to 30% for C7<sub>3</sub>. SI remained constant for C4<sub>1</sub> and C7<sub>1</sub>, decreased by 3% for C7<sub>2</sub>, and increased for the other subjects from 4% for C<sub>3</sub> to 44% for C7<sub>3</sub>. Blood lactate concentrations ([La]) reported at rest remained constant between pre and post training programme ( $1.88 \pm 0.38$  vs  $1.94 \pm 0.45$ ). Three minutes post exercise lactate values decreased significantly from  $9.12 \pm 2.64$  mmol.l<sup>-1</sup> before the training programme to  $7.39 \pm 2.48$  mmol.l<sup>-1</sup> after the training programme (Table 3). [La] increased by 6% for C4<sub>2</sub>. All other cases showed a decreased of [La] from 4% for C<sub>3</sub> to 41% for C7<sub>3</sub>.

#### *Maximal swim power test*

Individual maximal swim power (MSP) corresponding to the load reached at the step completed last were reported in Table 3. Stroking characteristics recorded at 35% and 75% of the MSP were reported in Figure 3 and Figure 4, respectively. SI values were reported in Table 2. The maximal swim power increased significantly ( $P < 0.05$ ) from  $3.06 \pm 1.37$  kg up to  $3.75 \pm 1.79$  kg after the training programme. At 35% of MSP, V ( $0.43 \pm 0.13$  vs  $0.54 \pm 0.25$  m.s<sup>-1</sup>), SL ( $0.67 \pm 0.22$  vs  $0.82 \pm 0.28$  m.cycle<sup>-1</sup>) and SR ( $0.65 \pm 0.09$  vs  $0.67 \pm 0.18$  cycle.s<sup>-1</sup>) did not significantly change. However, SI increased significantly from  $0.31 \pm 0.17$  to  $0.49 \pm 0.36$  m<sup>2</sup>.cycle<sup>-1</sup>.s<sup>-1</sup>. At 75% of MSP, V ( $0.35 \pm 0.14$  vs  $0.40 \pm 0.17$  m.s<sup>-1</sup>), SL ( $0.50 \pm 0.16$  vs  $0.62 \pm 0.21$  m.cycle<sup>-1</sup>) and SI ( $0.19 \pm 0.14$  vs  $0.27 \pm 0.19$  m<sup>2</sup>.cycle<sup>-1</sup>.s<sup>-1</sup>) increased significantly, but SR ( $0.70 \pm 0.10$  vs  $0.66 \pm 0.18$  cycle.s<sup>-1</sup>) remained constant.

With regard to individual values, the maximal swim power remained constant for C4<sub>3</sub> and C6. For all other swimmers, the MSP increased by 17% for C7<sub>2</sub> to 50% for C4<sub>2</sub>. At 35% of MSP, the significant correlation between the data recorded before and after the training programme indicated that V and SL changes were relatively homogeneous. A great discrepancy explained that SR changes were not correlated (Figure 3). V improved from 9% for C4<sub>3</sub> to 87% for C7<sub>1</sub> except for C7<sub>3</sub> who decreased by 15%. SL decreased for C4<sub>1</sub> (by 17%) but increased for all other swimmers ranging

FIGURE 2: Relationship between the pre and post training stroking characteristics values during 50m test. The pre and post training programme values are reported as abscissa and ordinate, respectively. The dotted and full lines represent the identity and regression lines, respectively.  
 C3 to C7 CPISRA classification groups

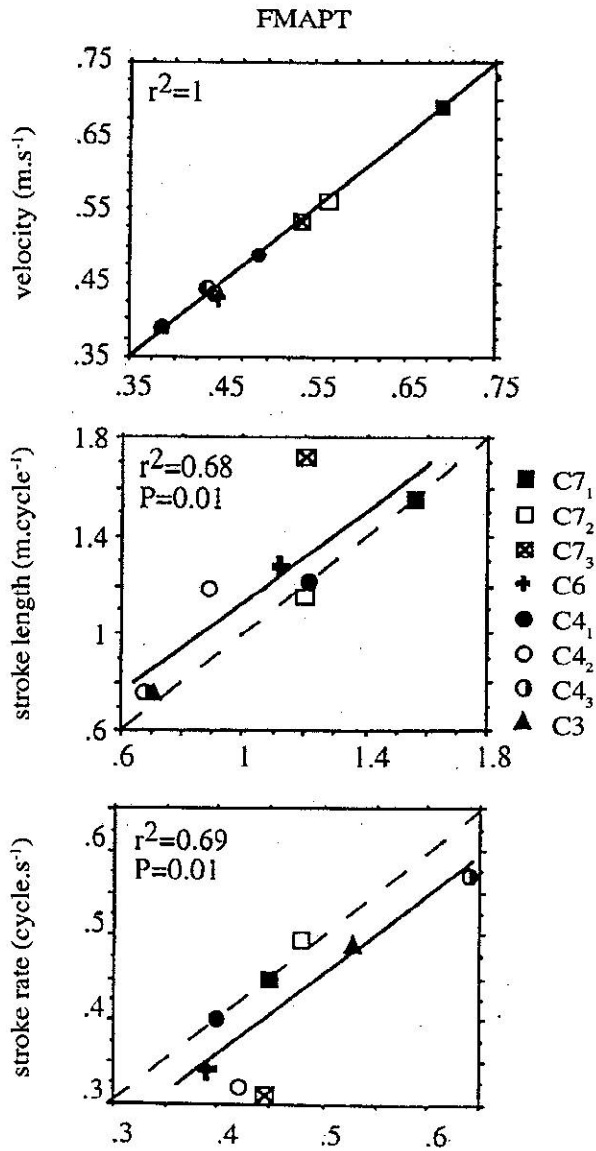


FIGURE 3: Relationship between the pre and post training stroking characteristics values during the Maximal Swim Power Test at 35% MSP. The pre and post training programme values are reported as abscissa and ordinate, respectively. The dotted and full lines represent the identity and regression lines, respectively.  
 C3 to C7 CPISRA classification groups

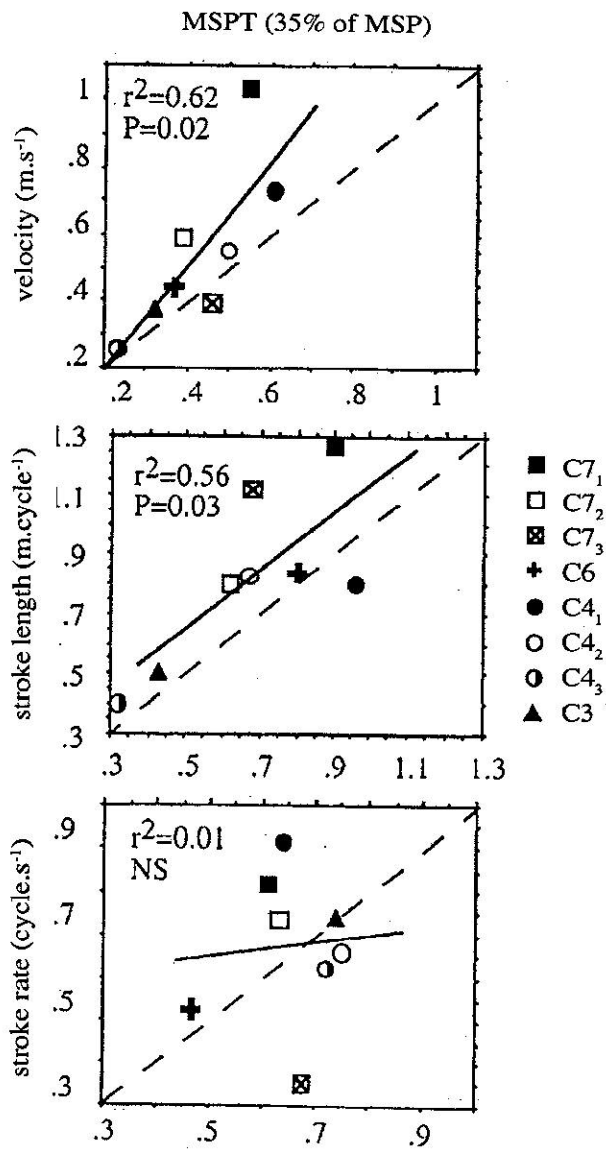
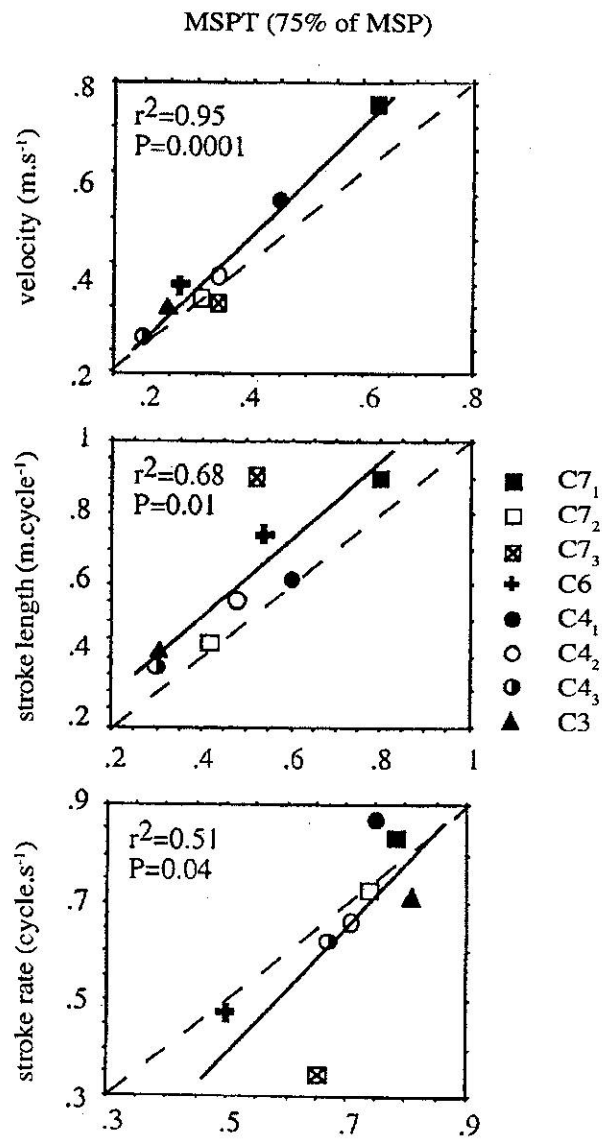


FIGURE 4: Relationship between the pre and post training stroking characteristics values during the Maximal Swim Power Test at 75% of MSP. The pre and post training programme values are reported as abscissa and ordinate, respectively. The dotted and full lines represent the identity and regression lines, respectively.  
 C3 to C7 CPISRA classification groups





from 5% for C6 to 65% for C7<sub>3</sub>. SR did not change for C3 and decreased from 12%, 14% and 48% for C4<sub>2</sub>, C4<sub>3</sub> and C7<sub>3</sub>, respectively. In other cases, SR increased by 13% for C6 to 44% for C4<sub>1</sub>. SI increased for all the subjects except for C4<sub>1</sub> which did not change. The range of SI improvement was 20% for C6 to 160% for C7<sub>1</sub>. At 75% of MSP, the significant correlation between the data recorded pre and post training programme indicated that V, SL and SR changes were relatively homogeneous (Figure 4). V decreased by 9% for C7<sub>3</sub> and increased for the other swimmers from 3% for C7<sub>2</sub> to 30% for C6. SL increased for all the subjects from 3% for C4<sub>1</sub> to 73% for C7<sub>3</sub>. SR increased by 6% and 16% for C7<sub>1</sub> and C4<sub>1</sub>, respectively. For all other swimmers, SR decreased from 2% for C7<sub>2</sub> to 47% for C7<sub>3</sub>. SI increased from 21% for C4<sub>1</sub> to 86% for C6, except for C7<sub>2</sub> who did not improve.

## DISCUSSION

According to the coaches' advice, the improvements observed seem to be important with regard to the short time of the training programme and have not been noticed for a long time. The swimmers performed the tests easily at the end of the training programme and no improvement in disability along the stages have been noticed. The technical programme including biomechanical biofeedback to train swimmers with cerebral palsy seems to be of great effect and its feasibility must be reported. However, without a control group, the next results must be interpreted cautiously.

The swimming performances (V on 50m test) remained constant after the one week training programme. However, the tiredness induced by this type of short, intensive stage may have caused improvements in swimming performance. To support this point, the improvement in performances appeared three weeks after the training programme. During a competition, five of the eight subjects (C7<sub>1</sub>, C7<sub>3</sub>, C6, C4<sub>3</sub> and C3) increased their performances in their best swimming style and preferred distance by 5%, 7%, 8%, 10% and 12%, respectively. These swimmers performed the best improvement in 50m test at the end of the training programme.

With regard to the other tendencies which appeared after the training programme, we noticed improvements in maximal swim power (MSP) as well as velocity at 35% and 75% of the MSP. Several arguments may explain this point. The first one was an increase in muscular strength. However, Holland and Steadward (1989) needed 10 training weeks (2

sessions per week) to increase the strength of the arm from 5% to 30% in athletes with cerebral palsy. With regard to the short training time (7 training sessions in one week), an increase of the muscular strength can not be the single factor to explain the improvement of MSP ranging from 17% to 50%. The second argument was a biomechanical technique change linked to the training programme and to the use of biofeedback swimming hand paddles. The increase of stroke length, velocity and stroke index at 35% and 75% of MSP can support the latest argument. A change of swimming strategy and a technique change could explain the improvement of performances and stroking characteristics, during the swimming test under tethered conditions (Table 2). During the 50m test, the propulsion time ratio increased significantly by over 6% and was an other index of changes in swimming strategy and biomechanical technique.

As aforementioned, V remained constant for the 50m test. However, a tendency of SR reduction for the 50m test and FMAPT has been noticed. For MSPT at 75%, we noticed a tendency of SR decrease, but V increased. SL increase has been equally noticed for the same tests. The increase (or constancy) of V added to an increase of SL implicated the increase of SI. While training skilled swimmers with biofeedback hand paddles, an improvement in stroking characteristics (especially the stroke length) was noticed, but not in swimming performances (Chollet et al, 1992). Our results were in accordance with this study. The improvements in stroking characteristics observed in the three tests seems to be very important for a weekly training programme. An improvement of 8%-16% of SI was observed during a training season with top level healthy swimmers (Mc Murray et al, 1990). For the swimmers with cerebral palsy of the present study, SI improved in all testing conditions. SI showed an increase ranging from 4% to 44% for FMAPT, from 8% to 99% for the 50m test, from 20% to 160% for MSPT at 35% and from 21% to 86% for MSPT at 75%. Costill et al (1985) reported that SI is a sensitive indicator of swimming success and the best predictor of  $\text{VO}_2\text{max}$  ( $r=0.97$ ) in top level healthy swimmers. For C7<sub>2</sub>, SI and post FMAPT blood lactate concentrations [La] decreased by 3% and 20%, respectively. C4<sub>2</sub> increased SI and post FMAPT [La] by 36% and 6%, respectively. Except for these cases, the improvement in the swimming skill for FMAPT seems to be confirmed by the decrease of the post FMAPT [La] values from 4% to 41%. When C7<sub>2</sub> and C4<sub>2</sub> were discarded, the increase of SI and the decrease of post FMAPT [La] were significantly correlated ( $r^2=0.7$ ,  $P<0.05$ ). Post FMAPT [La] reached before the training programme ( $9.12 \pm 2.64 \text{ mmol.l}^{-1}$ ) were close to those of the same kind of disabled population ( $10.8 \pm 3.5 \text{ mmol.l}^{-1}$ ) and confirmed

the feasibility of a functional maximal aerobic power test in swimmers with cerebral palsy. The same values, recorded after the training programme, decreased significantly ( $P < 0.05$ ) to  $7.39 \pm 2.48 \text{ mmol.l}^{-1}$  and were close to those of healthy swimmers ( $6.8 \pm 1.6 \text{ mmol.l}^{-1}$ ). An increase of stroke length (4.24%) with a decrease of blood lactate concentration (19%) was observed in top level healthy swimmers after a period of 6 months of aerobic training (Wakayoshi et al, 1993). Aerobic training, however, accounted for more than 90% of total swim training and the volume ranged from 3000m to 8000m daily, with approximately 8 training sessions per week. The simultaneous decrease of [La] and increase of SI appeared to be important with regard to the short time of training. An improvement in the swimming economy linked to an improvement in the swimming skill could explain these results which do not improve after a technical swimming programme including biomechanical biofeedback.

With regard to the severity of the disability, no differences have been noticed in the improvements achieved. As already noticed Chatard et al (1992), the degree of disability strongly influenced the performances. The less affected swimmers performed the higher velocity on FMAPT and 50m test. The increase of V depends on the simultaneous possibilities of maintaining SL and increasing SR (Pelayo et al, 1996b). According to Pelayo et al (1996a), we notice that SL seem to be a discriminating factor in relation with the degree of disability. Nevertheless, SR values of swimmers with cerebral palsy ( $34.1 \pm 10 \text{ cycle.min}^{-1}$ ), reported in this study on the 50m test, were lower than those noticed in disabled ( $49.96 \pm 3.4 \text{ cycle.min}^{-1}$ ) and normal ( $49.05 \pm 1.06 \text{ cycle.min}^{-1}$ ) swimmers during 100m freestyle (Pelayo et al, 1996a). With regard to the different disabilities, the lower SR values observed appeared as a characteristic of swimmers with cerebral palsy.

With regard to the number of years of training, some differences appeared. During FMAPT, C4<sub>1</sub> and C7<sub>2</sub> who trained for 13 and 15 years, respectively, did not improve SL. C7<sub>2</sub> increased SR and decreased SI by 3%. For C4<sub>1</sub>, SR and SI remained constant. However, the post test blood lactate concentration decreased by 20% and 19%, respectively. On the contrary, the younger swimmers, trained for 3 years, improved significantly in varied test conditions. C4<sub>3</sub> and C7<sub>3</sub> showed the greatest improvements for the 50m test. They increased SL by 91% and 52%, SI by 99% and 59% and decreased SR by 43% and 31%, respectively. At FMAPT, they performed the higher reduction of post test blood lactate concentrations with decreases by 30% and 41%, respectively. The training programme

proposed seems to be more effecting with younger and less skilled swimmers.

## CONCLUSION

The training programme including biomechanical biofeedback (BBFB) based on hydrodynamic forces of the hand seems to allow the CPS to develop more economic and more efficient swimming techniques. Amongst factors facilitating learning, we have to take into account the motivation due to the particular device used and the intensity of the programme (7 sessions in the week) compared to the usual training (3 to 6 sessions per week). All changes observed seem to be linked to an improvement in the swimming skill in relation to the training programme including BBFB. These modifications may include disorders due to cerebral palsy. The effects of training with BBFB in individuals with cerebral palsy (ICP) could be linked to the fact that the information returned supplied a proprioception disturbed by the disability. Concerning ICP, the effects of the feedback (FB) during motor learning were attributed to the plasticity of the nervous system. By completing a proprioception disturbed by the disability, the FB effected the development of parallel connection of neuronal bonds acting as a substitute for the damaged one. When informed correctly of the results of its action, the subject improved its performances (Mulder, 1985). Enhanced swimming skill over such a short conditioning period may be partially explained by a change in the muscular coordination and motor behaviour. Without a control group, we cannot conclude that BBFB is an efficient process to train swimmers with cerebral palsy. However, this study introduces an effecting method and reports the feasibility of training including BBFB in CPS. This method seems to have great effect and the aim of this study merits continuation as information based on the speed or the stroke rate are other possibilities of augmented feedback. Further studies should be conducted to discern on one hand the sensitivity of swimming parameters to feedback, and on the other hand, the accuracy of the different feedback anticipated for the training of swimmers with cerebral palsy.

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