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ORIGINAL ARTICLE

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Adaptation of maximal aerobic and anaerobic tests for disabled swimmers

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Abstract The purpose of the present study was to submit disabled swimmers to two maximal swimming tests, and by comparing the physiological and performance responses of disabled and normal swimmers to determine if these adapted tests can be used to design training programmes for this particular class of swimmer. Two groups of disabled ($n = 8$ and 6) and two groups of normal competitive swimmers ($n = 9$ and 13) were respectively submitted to a functional maximal aerobic power test (FMAPT) and a maximal anaerobic lactic test (MANLT). For the disabled, the FMAPT included a slower initial speed and a slower increase in swimming speeds. In the maximal aerobic test, exercise duration, peak heart rate, and the maximal speed relative to the respective best time of a 100-m race [55.5 (SD 3.9) compared to 56.5 (SD 2.8)%] were not significantly different between the disabled and normal swimmers. Peak lactate concentration was, however, higher in the disabled swimmers [10.8 (SD 3.5) compared to 6.8 (SD 1.6) $\text{mmol} \cdot \text{l}^{-1}$]. In the MANLT, peak lactate concentration [14.3 (SD 4) compared to 16.8 (SD 1.9) $\text{mmol} \cdot \text{l}^{-1}$], and the maximal speed relative to the respective best time in a 100-m race [99.1 (SD 3.2) compared to 98.3 (SD 2.5)%] were not significantly different between the disabled and normal swimmers. These results would seem to indicate that functional maximal aerobic and anaerobic field tests could be

used to evaluate and design training programmes for disabled competitive swimmers.

Key words Disabilities · Swimming · Lactate · Heart rate · Recovery

Introduction

One of the aims of rehabilitation is to increase the individual's performance in the activities of daily life. It has been shown that the normal activities of daily life of disabled people with no additional physical training are not intense enough to maintain a satisfactory level of physical fitness (Eriksson et al. 1988; Moretto et al. 1992). As the body is almost weightless in water, swimming is one of the most appropriate sports for people with disabilities to perform to develop aerobic fitness (Cowell et al. 1986; Shephard 1988) and to reduce spasticity (Calliet 1980). It has been reported that bio-energetic exercise by disabled swimmers is uncommon and infrequent (Roi and Cerizza 1992; Chatard et al. 1992). Consequently, for a better understanding of the physiological responses of this special population during swimming training and competition, it becomes important to adopt function assessments conducted on normal subjects to the special needs of the handicapped. To evaluate the exercise intensity during maximal and supramaximal efforts, evaluation of physiological responses is as necessary for disabled swimmers as it is for normal swimmers. Therefore, the purpose of the present investigation was to submit a group of disabled swimmers to two maximal swimming tests, and by comparing the physiological and performance responses of disabled and normal swimmers, determine if these maximal tests could be used to design training programmes for this particular class of swimmer. This was achieved by submitting disabled and normal swimmers to a functional maximal aerobic power test (FMAPT; Lavoie et al. 1985) and a maximal anaerobic lactic test (MANLT; Pelayo 1985).

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Methods

Subjects

All the subjects voluntarily agreed to participate in the study. They provided written informed consent, and were submitted to a complete medical examination prior to the beginning of the experiment. All evaluations in the study were made under medical supervision.

Procedure

The FMAPT was evaluated in two different group of swimmers. The first group (CP1) consisted of 8 disabled swimmers who practiced 3–4 h · week⁻¹ and competed at national level [(6 men and 2 women, 20.9 (SD 3.4) years]. All the subjects presented cerebral palsy without mental retardation. They were classified using the Cerebral Palsy International Sports and Recreation Association (CPISRA) classification system and were either a class 4, 5 or 7 (Table 1). The diagnosis of CP1 subjects included 2 cases of spastic diplegia (syndrome of Little), five cases of spastic hemiplegia and 1 case of quadriplegia athetosis. The CP1 swimmers presented a spasticity located mainly in their lower limbs. The second group, acting as a control group (NSI), was formed of normal swimmers [6 men and 3 women, 19.4 (SD 1.6) years] who were training 10 h · week⁻¹. The FMAPT (Lavoie et al. 1985) consisted of a progression of 2 min stages at the athlete's best swimming style.

Speeds were imposed by a sub-aquatic bank of lights connected to a speed programmer and were increased every lap by 0.05 m · s⁻¹ for NSI and by only 0.025 m · s⁻¹ for the CP1 swimmers (Pelayo et al. 1992). The initial swimming speeds for the test were 0.4 and 0.95 m · s⁻¹ for the cerebral palsy and normal swimmers, respectively. These initial speeds were calculated to correspond to approximately 55% of the maximal speed of a 100-m swim (best swimming style) for each class of swimmer. These initial speeds were calculated so that the test would last approximately 15 min for each class of swimmer. The heart rate (HR) and blood lactate concentrations ($[la^-]_b$) were first determined after a period of rest in the sitting position before the warm-up.

During the test, the arm-stroke index was calculated according to Lavoie et al. (1985). This index consisted of the number of arm strokes during a distance of 125 m divided by the swimming velocity in meters per second. Arm strokes for each of the 125 m were recorded by an observer and the total of these arm strokes was used in the calculation of the index. The HR was continuously recorded by a HFM Sport Tester (PE 3000) and venous blood samples were taken at the completion of the test and every 3 min until the end of the experiment (at 21 min) during passive recovery. Immediately after the completion of the test, the swimmers were asked to get out of the water and sit for the entire duration of the recovery period. Blood samples were analysed for $[la^-]_b$ using Boehringer's bi-enzyme method (Noll 1974).

The MNALT was evaluated in two different groups of swimmers. The first group (CP2) consisted of 6 cerebral palsy swimmers [2 men and 4 women, 24.3 (SD 6.2) years] without mental retardation who were training and competing at both national and international levels. They were classified 3 or 7 (CPISRA) and the diagnosis included 1 case of hemiplegia athetosis and 5 cases of spastic diplegia. The second group (NS2) was formed of 13 normal swimmers [9 men and 4 women, 18.1 (SD 1.9) years] who were performing at both national and international levels. The test used in the second experiment challenged the anaerobic system (see Chatard et al. 1986; Sawka et al. 1978) and was conducted according to the protocol of Pelayo (1985). This test is supposed to reproduce the real competitive effort of a swimmer in a 200-m event without the psychological constraints of the competition. The test started after a standardised warm-up consisting of two series of 6 and 4-min swims at low speed,

intercalated by a series of 3 × 50 m swims at progressively increasing speed with a 30-s rest. At 5–10 min after the warm-up, the swimmers swam four times 50 m at full speed with a rest of 10 s so that the total swimming time was shorter than the competitive time of a regular 200-m. The HR was measured at the end of the test for the disabled swimmers only. Blood was sampled into capillary tubes for $[la^-]_b$ determination at 3 and 12-min postexercise with passive recovery in a sitting position for the two groups and these were analysed using the same method as previously cited (Noll 1974).

Statistical analyses

Statistical analyses were performed using a two-way analyses of variance (ANOVA) with a nonrepeated measures design to compare $[la^-]_b$ and HR responses between NSI compared to CP1. Student's *t*-tests were used to compare $[la^-]_b$ for NS2 compared to CP2. The Mann and Whitney test was used to compare the physical characteristics between NS1 compared to CP1 and NS2 compared to CP2. A 95% level of confidence was accepted for all comparisons.

Results

The main characteristics of the four groups studied are presented in Table 1. The normal swimmers were significantly taller and heavier than the disabled ones. The means for the velocity measured during a 100-m race, the weekly training hours and the years of training were higher for both groups of normal swimmers compared to the two groups of disabled ones.

The duration of the maximal aerobic test was 14.2 (SD 1.4) and 16.4 (SD 2.2) min for the CP1 and NS1 swimmers, respectively ($P > 0.05$). The maximal aerobic swimming speeds reached by the disabled and normal swimmers during the FMAPT test were 0.66 (SD 0.16) m · s⁻¹ and 1.37 (SD 0.07) m · s⁻¹, respectively ($P < 0.01$). The arm-stroke indexes calculated during the test were 236 (SD 125) and 74.8 (SD 4.3) for the disabled and normal swimmers, respectively. The HR and $[la^-]_b$ values at rest, immediately after the FMAPT test, and during recovery for both groups of swimmers are presented in Table 2. During this test the disabled swimmers reached a peak HR and $[la^-]_b$ of 182.5 (SD 8.5) beats · min⁻¹ and 10.8 (SD 3.5) mmol · l⁻¹, respectively. The same responses for the normal swimmers were 178.5 (SD 12.5) beats · min⁻¹ and 6.8 (SD 1.59) mmol · l⁻¹, respectively. A small but significant ($P < 0.05$) group effect was found for HR with the disabled swimmers having higher values during recovery (Table 2). Peak $[la^-]_b$ was significantly higher ($P < 0.05$) in the disabled than in the normal swimmers. Throughout recovery, $[la^-]_b$ was significantly higher ($P < 0.01$) in the disabled than in the normal swimmers (Table 2). The slopes of the recovery curves were the same for both NS1 and CP1 ($[la^-]_{b,NS1} = 7.07 - 0.21x$, $r = 0.96$; $[la^-]_{b,CP1} = 11.76 - 0.28x$, $r = 0.99$; $x =$ time in minutes).

The swimming speeds reached during the anaerobic test were 0.91 (SD 0.10) m · s⁻¹ and 1.81 (SD 0.03) m · s⁻¹

Table 1 Main characteristics of the subjects. v_{100} Maximal velocity during a 100-m swim, T_r duration of training, $CPISRA$ Cerebral Palsy International Sports and Recreation Association, $NS1$, $NS2$ normal swimmers groups 1 and 2, $CP1$, $CP2$ cerebral palsy swimmers groups 1 and 2

	Normal swimmers												Disabled swimmers											
	NS1						NS2						CP1						CP2					
	6 Men		3 Women		9 Men		4 Women		6 Men		2 Women		n = 8		6 Men		2 Women		n = 6		2 Men		4 Women	
Height (cm)	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Mass (kg)	177	8	181	5	167	5	178	9	170	6	161	8*	164	7	151	1	166	9 ^a	176	9	160	6		
Age (years)	68.3	9	73.9	5.8	57.3	3.2	69.9	7.9	58.1	3	54.4	6.4*	55.2	4.2	44	2	55.8	10 ^a	65.5	12.5	51	5.6		
v_{100} (m s ⁻¹)	1.68	0.06	1.75	0.04	1.56	0.03	1.77	0.17	1.60	0.08	0.72	0.13*	0.74	0.11	0.69	0.09	0.90	0.12 ^a	1.01	0.08	0.82	0.11		
T_r (h · wk ⁻¹)	9.9	1.3	9.8	1.5	10.1	0.8	14	2	14	2.1	3.3	1.4*	3	1.3	4.3	1.2	5.8	2 ^a	4.6	1.6	4.7	2.7		
Yt (years)	11	1.8	12	1.4	9.6	0.9	8.9	3	9.5	2.3	9.8	3.1	10.3	2.9	10	2	10.1	2.7	7	2.6	11.2	2.6		
CPISRA											C4-C7		C4-C7		C4-C7		C3-C7		C3				C3-C7	

* Difference between $NS1$ and $CP1$ statistically significant ($P < 0.05$); ^a Difference between $NS2$ and $CP2$ statistically significant ($P < 0.05$)

Table 2 Heart rate (HR) and blood lactate concentration ($[la^-]_b$) during passive recovery after the Functional Maximal Aerobic Power Test for normal ($NS1$) and cerebral palsy ($CP1$) swimmers

	Rest	Max	30 s		1 min		1 min 30 s		3 min		6 min		9 min		12 min		15 min		18 min		21 min	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$NS1$ HR (beats · min ⁻¹)	69.7	12.3	178.5	19.9	131.4	28.4	116.7	21.9	106	14.4	93.2	10.7	91.2	8.9	90.5	9.8	89.1	9.2	85.2	8.9	82.4	9.3
($n=9$) $[la^-]_b$ (mmol · l ⁻¹)	1.5	0.3					6.8	1.59	5.8	1.57	4.9	1.47	4.3	1.31	3.7	1.19	3.2	1.03	3	0.96		
$CP1$ HR (beats · min ⁻¹)	84.1	7.3*	182.5	8.5	163.8	18.3	149	28.4	134.4	17.6	115	12.9	108.8	8.6*	106.3	8.9**	104.3	8**	102.9	5.3*	99.8	6.8*
($n=8$) $[la^-]_b$ (mmol · l ⁻¹)	1.3	0.3					10.8	3.5**	10.2	3.5**	9.3	3.41**	8.35	2.9**	7.5	2.71**	6.5	2.39**	5.95	2.21**		

** Significant differences at $P < 0.01$, * Significant differences at $P < 0.05$ between $NS1$ and $CP1$

Table 3 Blood lactate concentration $[la^-]_b$ during passive recovery after the Maximal Anaerobic Lactic Test for normal (NS2) and cerebral palsy (CP2) swimmers

	$[la^-]_b$ (mmol·l ⁻¹)							
	Rest		3 min		12 min		$\Delta[la^-]_b$ (3 min-12 min)	
	mean	SD	mean	SD	mean	SD	mean	SD
Normal swimmers (NS2) <i>n</i> = 13	1.67	0.50	16.80	1.89	13.50	3.73	3.30	1.22
Cerebral palsy swimmers (CP2) <i>n</i> = 6	2.20	0.17	14.35	4.08	13.16	3.5	1.38	0.62*

* Difference between NS2 and CP2 statistically significant ($P < 0.05$)

for CP2 and NS2, respectively ($P < 0.01$). These speeds corresponded to 99.1 (SD 3.2) compared to 98.3 (SD 2.5)% of the velocity over 100-m measured during a competition for each class of swimmers, respectively. The mean HR at the end of the anaerobic test measured only for the disabled swimmers was 181 (SD 10.2) beats·min⁻¹. Mean $[la^-]_b$ measured at the 3rd min post-exercise of the anaerobic test was 16.8 (SD 1.9) and 14.4 (SD 4.1) mmol·l⁻¹ for NS2 and CP2, respectively ($P > 0.05$; Table 3). No significant difference was found at the 3rd and the 12th min post-exercise for $[la^-]_b$ between disabled and normal swimmers (Table 3). A significant ($P < 0.05$) difference was found in the decrease of $[la^-]_b$ between the 3rd and 12th min of passive recovery between CP2 [1.4 (SD 0.6) mmol·l⁻¹; 9.6%] and NS2 [3.3 (SD 1.2) mmol·l⁻¹; 19.6%].

Discussion

The results of this study indicated that the present maximal aerobic and anaerobic tests, usually used by normal swimmers, can also be used by disabled swimmers. A slower initial speed and smaller increases in speed in the aerobic test were the only adaptations used in the maximal aerobic test. These adaptations were necessary because of the small range of functional speeds of this class of swimmer, and to make sure that the test was long enough to stimulate maximally the aerobic component of energy production. The similar duration of the aerobic test (approximately 15 min) and the same relative maximal speed (approximately 55% of the speed of a 100-m race) were good indications that the FMAPT was well adapted to the needs of the disabled swimmers. On the other hand, the anaerobic test was the same as the one used for the normal swimmers. A good indication that the anaerobic test was appropriate for the disabled swimmers was illustrated by the similar maximal speed reached by both groups of swimmers when compared to their respective 100-m race time.

The disabled swimmers presented large variations in swimming efficiency as indicated by the measurement

of the arm-stroke index during the maximal aerobic test [236 (SD 125) compared to 75 (SD 4) for normal swimmers]. These values also indicated that swimming economy was much higher in the normal than in the disabled swimmers. Accordingly, the maximal speeds reached by the disabled swimmers during both tests were approximately 50% of the ones reached by the groups of normal swimmers. This can be explained by the handicap of the disabled swimmers but also, to a certain extent, by their relatively lower training state. In spite of these limitations, the results of this study clearly indicated that, with some modifications, the aerobic functional test which has been proposed by Lavoie et al. (1985) for normal competitive swimmers can be used by disabled competitive swimmers presenting low values of swimming economy. Moreover, the results obtained for the disabled competitive swimmers at the FMAPT would suggest that this test could also be adapted for normal recreational swimmers.

The peak HR values reached at the end of the maximal aerobic test were on average 178.5 and 182.5 beats·min⁻¹ for the normal and cerebral palsy groups, respectively (Table 2). The peak HR measured at the end of the anaerobic test was 181 (SD 10.2) beats·min⁻¹ for the second group of disabled swimmers (Table 3). These values may be used as an indication that a maximal effort was reached by the disabled swimmers. In a previous study (Kofsky et al. 1983), similar peak HR values have been reported for trained and untrained disabled men. Peak $[la^-]_b$ measured at the end of the maximal aerobic test were significantly higher ($P < 0.01$) in the disabled than in the normal swimmers (10.8 mmol·l⁻¹ compared to 6.8 mmol·l⁻¹, respectively, Table 2). These results may also be used to support the contention that the disabled swimmers had reached a maximal aerobic swimming velocity during the FMAPT. Peak $[la^-]_b$ at the end of the anaerobic test reached values between 14 and 16 mmol·l⁻¹ in both groups of swimmers (Table 3). These data are close to those measured by Roi and Cerizza (1992) in top level healthy and disabled swimmers (paraplegic and polio) participating in a national competition of 50-m freestyle swimming. These results indicate that disabled swimmers are capable of high anaerobic work

and that the present anaerobic test can be used by this class of swimmer to determine their anaerobic work capacity.

The HR during recovery following the maximal aerobic test was significantly ($P < 0.05$) higher in the disabled than in the normal swimmers (Table 2). Since peak HR at the completion of the test was similar in both groups, this might be taken as an indication that disabled swimmers recovered more slowly than the normal swimmers. Peak $[la^-]_b$ at the end of the aerobic test was higher in the disabled than in the normal swimmers (Table 2), indicating a greater contribution of the anaerobic energy production in the former. During recovery, $[la^-]_b$ decreased similarly for both groups. However, following the anaerobic test, $[la^-]_b$ between the 3rd and the 12th min decreased more rapidly in the normal than in the disabled swimmers (Table 3). Although these calculations were made at two times only, they support the contention that disabled swimmers might recover more slowly than normal swimmers.

There are several reasons that can be put forward to explain the greater blood lactate accumulation of the disabled swimmers following the aerobic test, and the possibility that the cerebral palsy swimmers had lower blood lactate elimination than the normal swimmers as seen after the anaerobic test (Table 3). The first is related to the quantitative difference in the number of practice hours per week ($P < 0.01$), performed by both populations, which allowed the most trained athletes (normal swimmers) to improve their recovery abilities faster (Sahlin and Henriksson 1984). The second would be linked to the specificity of the disabled swimmer's physiological adaptations. The inactivity of the venous muscle pump resulting from paralysis may restrict venous return of blood to the heart from the legs (peripheral factors) and may consequently reduce blood availability to the active upper-body musculature and decrease its exercise capability (Glaser 1988).

Some hypotheses which must be verified may account for the slower recovery. During recovery in cerebral palsy, the lower vascularization of nonactive muscle mass, often located in the lower limbs and resulting in a possible reduction in total blood volume, might contribute to a slower transport and elimination rate of lactate. Alternatively, the decreased muscle mass in disabled swimmers would contribute to a decreased muscle metabolic elimination of lactate. This would be an anatomical but mainly functional heterogeneity that could explain a longer lactate life in the recovery phase after maximal and supramaximal exercises (Rieu 1988). The potentially slower metabolic recovery observed in disabled swimmers after the present tests suggests that coaches should increase recovery time in anaerobic type exercises, both in practice and in competition, and should standardise active recovery periods (Bonen and Belcastro 1977; Cazorla et al. 1983; McMaster et al. 1989; Weltmann et al. 1977). Cerebral palsy swimmers

suffering from spasticity and paralysis in the lower limbs should maintain muscle activity while recuperating to accelerate the rate of decrease of $[la^-]_b$.

In summary, the results of the present investigation indicate that the maximal aerobic functional test which has been proposed by Lavoie et al. (1985) for normal competitive swimmers can be adapted to the needs of competitive disabled swimmers. The present results also indicate that disabled swimmers can be submitted to anaerobic field tests. These results point to a need for the assessment of protocols in real conditions of practice to determine the optimal method to elicit a maximal response in a reasonable time without endangering the disabled population. From a practical point of view, the present study showed that both aerobic and anaerobic field tests could be used as tools to evaluate training programmes with disabled swimmers, and more importantly that they could be used to determine the content of these training programmes.

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