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Aerobic capacity in children and adolescents with cerebral palsy

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ABSTRACT

This study described the aerobic capacity [VO_{2peak} (ml/kg/min)] in contemporary children and adolescents with cerebral palsy (CP) using a maximal exercise test protocol. Twenty-four children and adolescents with CP classified at Gross Motor Functional Classification Scale (GMFCS) level I or level II and 336 typically developing children were included. All children performed a progressive exercise test on a treadmill with respiratory gas-exchange analysis. The results are compared with normative values for age and gender-matched controls. Aerobic capacity of children and adolescents with CP, who are classified at GMFCS level I or II was significantly lower than that of typically developing controls. Especially in girls with CP, the aerobic capacity deteriorated with age. The aerobic capacity of contemporary children and adolescents with CP, who are classified at GMFCS level I or II is significantly lower than that of typically developing controls.

The peak oxygen uptake (VO_{2peak}) attained during graded maximal exercise to volitional exhaustion is considered by the World Health Organization as the single best indicator of aerobic physical fitness (Shephard, Allen, Benade, Davies, & Di Prampero, 1968). This variable, commonly expressed as the volume oxygen consumed per unit of time relative to body mass (ml/kg/min) (Rowland, 1991) is also a valid indicator of health status (Myers et al., 2002) and a powerful predictor of mortality in both healthy and diseased individuals (Blair, Cheng, & Holder, 2001). There is strong scientific evidence that youth with low aerobic capacity are more likely to display additional risk factors for cardiovascular disease such as elevated blood pressure and serum cholesterol levels (Carnethon et al., 2003; DuRant et al., 1993; Tolfrey, Campbell, & Jones, 1999).

Besides a health indicator, serial testing of aerobic capacity of children and adolescents with CP can be useful to provide a quantitative assessment of the change in the condition of the patient after for example an exercise rehabilitation program or can be helpful for the monitoring of athletic training (Unnithan, Clifford, & Bar-Or, 1998).

To date, only four studies (Hoofwijk, Unnithan, & Bar-Or, 1995; Lundberg, 1984; Maltais, Pierrynowski, Galea, & Bar-Or, 2005; Rieckert, Bruhm, & Schwalm, 1977) have studied the VO_{2peak} in children and adolescents with cerebral palsy (CP) during a maximal exercise test. Only two of these studies compared the VO_{2peak} to the values in typically developing children and adolescents (Hoofwijk et al., 1995; Lundberg, 1984). Both studies concluded that the aerobic capacity of children with CP is reduced compared to typically developing children.

The most functional and appropriate way to assess the VO_{2peak} in children with CP who are able to walk independently, is a progressive walking or running-based maximal exercise test (Verschuren, Takken, Ketelaar, Gorter, & Helders, 2006). From three studies there is data available on VO_{2peak} in children with CP, that is based on a maximal exercise test on a treadmill

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(Hoofwijk et al., 1995; Maltais et al., 2005; Rieckert et al., 1977). Hoofwijk et al. (1995) included 9 children with CP and compared the VO_{2peak} to the values in typically developing children and adolescents. The studies performed by Rieckert et al. (1977) and Maltais et al. (2005), examining respectively 12 and 11 children with CP did not compare the results with typically developing children, but provided useful information on VO_{2peak} values for children with CP.

The current available data on VO_{2peak} in children with CP is based on a small number of children. Therefore, the purpose of this article is to describe the VO_{2peak} in a group of contemporary children and adolescents with CP who are able to walk independently, using a maximal treadmill protocol, with the results being compared with normative values for age and gender. These results will be compared with the findings of earlier studies that assessed VO_{2peak} of children with CP using a maximal exercise test on a treadmill test. Moreover, the differences between Gross Motor Functional Classification Scale (GMFCS) level I and II will be assessed as well.

1. Method

1.1. Participants

Twenty-four participants with CP (16 boys and 8 girls), classified at GMFCS level I and II, participated in a previously published study that examined the reliability and validity of two newly developed shuttle run tests (SRT-I and SRT-II) to measure aerobic capacity in children and adolescents with CP (Verschuren et al., 2006). A secondary analysis of the previously collected data was conducted (Verschuren et al., 2006).

1.2. Typically developing reference group

The patient group was compared with reference values obtained in a group of 336 active, healthy controls who were recruited from regular schools in The Netherlands. All participants performed a progressive treadmill exercise test to exhaustion (Binkhorst, Hof van het, & Saris, 1992). Continuous respiratory gas analysis and minute ventilation (VE), peak oxygen uptake (VO_2), and carbon dioxide production (VCO_2), were performed using comparable equipment as in a previous publication (Verschuren et al., 2006). The respiratory exchange ratio (RER) was calculated from the collected data (=VCO_2/VO_2). The healthy reference group was matched with the children and adolescents with CP according to age and gender.

1.3. Measurements

Anthropometry. Prior to testing, each child was weighed on electronic scales (Seca, Hamburg, Germany). Height measurements were taken on the same visit while the child was standing against a wall. Body composition was assessed using the sum of 4 skin fold measurements. The skin fold measurements were taken at 4 sites on the right side of the body (triceps, biceps, subscapular and suprailiac) by 2 investigators (OV and TT) in accordance with the American College of Sports Medicine guidelines (Armstrong, Whaley, Brubaker, & Otto, 2005). Body composition was reflected by the body mass index (BMI). The BMI was calculated as weight in kilograms divided by height in meters squared. Participants' weight and height were measured using a standard protocol. Each child was weighed to the nearest 100 g on electronic scales (Seca, Hamburg, Germany). Height was measured to the nearest 0.5 cm using a stadiometer.

GMFCS. The GMFCS, translated into the Dutch language, was used by a pediatric physical therapist (OV), who was experienced in using the GMFCS, to classify the children and adolescents with CP into groups based on their functional mobility. Level I represents the highest level of functional abilities, and level V represents the lowest level of functional abilities. Due to the physical demands of the tests, only children and adolescents who were classified at GMFCS level I (able to walk indoors and outdoors and climb stairs without limitation) or level II (able to walk indoors and outdoors and climb stairs holding on to a railing, but experience limitations in walking on uneven surfaces and inclines and in walking in crowds or confined spaces) were recruited. The original GMFCS has been reported to yield reliable and valid data for children aged 6–12 years (Palisano, Rosenbaum, & Walter, 1997). Children over 12 years of age were classified using the expanded and revised version of the GMFCS (GMFCS-E&R) (Palisano, Rosenbaum, Bartlett, & Livingston, 2008).

Physical characteristics of the patient group (according to GMFCS level) and the reference group have been summarized in Table 1 for completeness of data. There were no significant differences between the groups.

1.4. Progressive exercise test

Progressive exercise testing on a treadmill was performed on all subjects using a previously developed protocol for CP (Verschuren et al., 2006). Subjects with a level I or II classification on the GMFCS each performed a different protocol. The subjects who were classified at level I on the GMFCS started at a speed of 5 km/h with a increment of 0.25 km/h every minute, and the subjects who were classified at level II on the GMFCS started at 2 km/h with an increment of 0.25 km/h every minute.

All children were instructed to run until exhaustion. One subjective and two objective criteria were used to determine if the test was maximal. Every child had to meet the subjective criterion and one of the two objective criteria. The physiological criteria were: heart rate $>$ 180 beats/min (Schulze-Neick, Wessel, & Paul, 1992) and a respiratory exchange ratio (RER) $>$ 0.99 (Armstrong & Welsman, 2008). Subjective criteria were signs of intense effort such as unsteady running pattern, sweating,

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facial flushing, and clear unwillingness to continue running in spite of repeated strong verbal encouragement. Further details on subject preparation, location, and procedure have been previously published (Verschuren et al., 2006).

The previously published study was approved by the Medical Ethics Committee of the UMC Utrecht. Written informed consent was obtained from the parents of each child and from the subjects older than 12 years of age.

1.5. Data analysis

To control for changes in body size during growth the VO_{2peak} (l/min) data collected in the previously published study (Verschuren et al., 2006) were, based on the subjects body weight, converted into VO_{2peak} (ml/kg/min), and compared to reference values from age- and gender-matched Dutch controls (Binkhorst et al., 1992). A percentage of predicted was calculated using the values observed in the subjects with CP and the mean value for age and gender-matched control children. Moreover, the VO_{2peak} (ml/kg/min) values calculated for the subjects with CP were compared with the same values from previously published studies that performed a maximal exercise test on a treadmill (Hoofwijk et al., 1995; Maltais et al., 2005; Rieckert et al., 1977). Based on the description of the subjects included in three previously published studies (Hoofwijk et al., 1995; Maltais et al., 2005; Rieckert et al., 1977) the subjects have been classified according to the GMFCS levels. Children who usually walk with support are classified at GMFCS level III, and children who usually or always walk without support are classified at GMFCS level I or II.

Statistical comparisons between children and adolescents with CP and reference values were tested using a paired samples *t*-test. Differences between subgroups (GMFCS I and GMFCS II; boys and girls) were tested using an independent samples *t*-test ($\alpha = 0.05$). All statistical analyses were performed by using SPSS 15.0 for Windows (SPSS, Inc., Chicago, IL).

2. Results

Peak RER was ≥ 0.99 or peak heart rate was > 180 beats per minute in all subjects with CP ($n = 24$). Moreover, all children met the subjective criteria as well. These criteria indicate that a maximal effort was reached during the progressive treadmill exercise test. Table 2 presents the data that were collected during the progressive exercise test on the treadmill for the children with CP and the typically developing reference group.

As seen in Table 2 a significant difference in mean VO_{2peak} (ml/min/kg) was found between the group of children with CP and the healthy controls, with the CP group showing decreased aerobic capacity. There was also a significant difference between the boys with CP and the healthy controls as well as for the girls with CP and their age matched peers who are typically developing.

Table 1
Subject characteristics ($N = 24$).

Variable	GMFCS[a] level I ($n = 13$)			GMFCS level II ($n = 11$)			Healthy controls ($n = 336$)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Age (y)	11.2	2.8	7.5–16.1	12.5	3.0	7.2–17.0	11.8	2.9	7.2–17.0
Height (cm)	148.1	15.8	125–175	148.6	18.9	123–175	152	15.6	130–180
Body mass (kg)	39.4	11.6	23.8–60.8	38.6	12.1	24.0–59.7	43.2	12.3	27.1–66.1
Skin folds (mm)	34.4	14.4	20.5–69.0	36.0	10.6	22.5–60.0	31.5	4.0	25.6–43.2
Body mass index	17.7	3.6	14.2–26.1	17.7	2.3	13.9–21.4	17.5	1.4	15.8–19.7

There was no significant difference between the groups.
[a] Gross Motor Function Classification System.

Table 2
Physiological descriptives.

	Mean (SD)		*p*-Value
	CP group ($n = 24$)	Healthy controls ($n = 336$)	
HR_{peak} (beats/min)	193.1 (6.2)	200.6 (0.9)	<0.01
RER_{peak}	1.0 (0.1)	1.18 (0.02)	<0.01
VE_{peak} (L/min)	58.1 (21.7)	75.4 (19.6)	<0.01
VE_{peak}/VO_{2peak}	35.4 (6.0)	37.5 (3.6)	NS (0.192)
Peak O_2 pulse (ml O_2/beat)	8.58 (3.0)	10.3 (3.6)	0.003
VO_{2peak} (ml/kg/min)			
Total group	42.0 (8.2)	49.3 (3.5)	<0.01
Boys ($n = 16$)	44.7 (7.1)	51.7 (1.2)	0.001
Girls ($n = 8$)	36.4 (7.6)	44.7 (0.3)	0.02

HR_{peak}, peak heart rate; RER_{peak}, peak respiratory exchange ratio; VE_{peak} (L/min), maximum ventilation per minute; VE_{peak}/VO_{2peak}, ventilatory equivalent ratio for oxygen; Peak O_2 pulse (oxygen pulse) = VO_{2peak}/HR_{peak} VO_{2peak} (ml/kg/min) = peak oxygen uptake.

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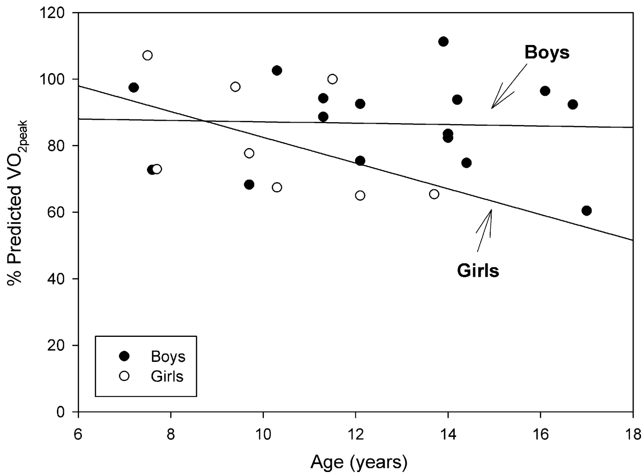

Fig. 1. Percent predicted oxygen uptake (ml/kg/min) values related to age for boys and girls with CP. The horizontal line and diagonal line represent the percentage of predicted VO_{2peak} values for respectively the boys and girls with CP.

Table 3
Survey of studies using VO_{2peak} testing in children with CP using a progressive exercise test on a treadmill.

Reference	No. of participants	Type of CP	GMFCS level	Age	VO_{2peak} (ml/kg/min)
Rieckert et al. (1977)	6 (1 boy and 5 girls)	3 spastic quadriplegia 3 spastic diplegia	GMFCS III	7–19	28
	6 (4 boys and 2 girls)	4 spastic hemiplegia 2 spastic quadriplegia	GMFCS I or II	14–18	34.7
Hoofwijk et al. (1995)	9 (7 boys and 2 girls)	1 spastic hemiplegia 7 spastic diplegia 1 spastic quadriplegia	GMFCS I or II	10–16	32.7
Maltais et al. (2005)	11 (7 boys and 4 girls)	7 spastic hemiplegia 4 spastic diplegia	GMFCS I or II	10–16	34.0
This study	24 (16 boys and 8 girls)	12 spastic hemiplegia 12 spastic diplegia	GMFCS I or II	7–17	42.0

GMFCS: Gross Motor Functional Classification System; VO_{2peak}: peak oxygen uptake.

As can be seen in Fig. 1 the percentage predicted VO_{2peak}/kg (ml/kg/min) for children and adolescents with CP is lower than predicted (100%). Moreover, predicted VO_{2peak}/kg remained stable for the boys (approx. 88% of predicted), whereas it decreased for the girls (from 97% to 50% of predicted) with CP throughout childhood and adolescence. Individual values for predicted VO_{2peak} varied from 60.4% to 111.2%. As can be seen only 3 children (2 boys and 1 girl) scored higher than predicted. Two of these children were classified at GMFCS level I, and one child was classified at GMFCS level II.

Table 3 summarizes the findings on VO_{2peak} values in children and adolescents with CP who performed a maximal exercise test on a treadmill. The values found by Rieckert et al. (1977), Maltais et al. (2005) and Hoofwijk et al. (1995) are lower than our values.

There was no significant difference ($p = 0.253$) between the VO_{2peak} (ml/kg/min) for the children who are classified at GMFCS level I (43.8 ± 6.5) and GMFCS level II (39.9 ± 9.7).

3. Discussion

The purpose of this study was to investigate the VO_{2peak} of children and adolescents with CP. We found that children with CP had a significantly reduced VO_{2peak} compared to healthy subjects. However, we found no difference in VO_{2peak} between subjects with CP, classified at GMFCS level I and GMFCS level II.

The VO_{2peak} (ml/kg/min) values found by Rieckert et al. (1977), Hoofwijk et al. (1995) and Maltais et al. (2005) are lower than our values. However, the groups of children that are being compared are not similar. Our group of children who walk without support (GMFCS I and II) have less body mass (39.4 ± 11.6 kg) compared to the children and adolescents included in earlier studies (48.2 ± 17.5 kg (Hoofwijk et al., 1995); 49 ± 11.0 kg (Rieckert et al., 1977); and 44.8 ± 18.1 kg (Maltais et al., 2005)). Aerobic capacity of the subjects with CP is below values observed in healthy children, especially in girls with CP.

The decrease throughout childhood into adolescence could be explained by the fact that adolescent girls with CP have low levels of physical activity as previously observed in our country (van Eck et al., 2008). Studies have suggested that individuals with CP are less active than their able-bodied peers (Maher, Williams, Olds, & Lane, 2007). Comparisons with normative data sets suggested that adolescents with CP tend to participate in less structured and lower intensity physical activity compared with non-disabled adolescents. Durstine et al. (2000) described a circular process whereby persons with a chronic illness or disability experience less physical activity (PA), which then leads to a cycle of deconditioning and further physical deterioration and reduction in activity. As seen in this study, children with CP at age 7 have already lower VO_{2peak} values compared to typically developing peers. An early introduction to an active lifestyle that includes physical fitness promotion might be beneficial for future health and function for children with CP.

A cause for the reduced VO_{2peak} in children with CP may be the muscle spasticity in children with CP. The spasticity can cause a local obstruction of the venous return in the leg muscles (Lundberg, 1978), leading to a reduction in the cardiac output and hence the oxygen transport to the working muscles. Oxygen pulse is a measure of oxygen consumed per heart beat and is a measure for stroke volume and peripheral oxygen extraction during exercise (Bar-Or & Rowland, 2004). The low oxygen pulse for children with CP found in this study supports this finding. However, this hypothesis should de investigated in a future study.

Hoofwijk et al. (1995) and Lundberg (1984) presented the ventilatory equivalent ratios for children with CP and the healthy control groups. In their studies for children with CP they found higher values, being respectively 41.4 (6.5) and 34.0 (3.0) for the children with CP, as compared with the healthy control group, respectively 33.6 (3.9) and 30.0 (2.0). This finding was used as an explanation for the lower VO_2 (l/min) of children with CP. The present study found comparable values between children and adolescents with CP and typically developing peers, and therefore does not support this explanation.

Maher et al. (2007) found that PA participation was related to the level of gross motor function. Children who are able to walk without assistive devices (GMFCS level I and II) have probably similar PA levels in daily life and therefore increase or maintain their aerobic fitness in the same way. This might explain the fact that in this study there was no significant difference between children classified at GMFCS level I and II.

In the child with neuromuscular diseases it is muscle function rather than aerobic capacity that usually limits the child's physical capacity (Bar-Or, 1986). Therefore, it is also important to include functions such as muscle strength, agility, short-term muscle power in the training repertoire of the child and adolescent with CP. This does not imply that we should not focus on aerobic exercise training programs for children with CP. In adulthood, the activity patterns shift towards an aerobic activity pattern. This would make aerobic capacity more important with increasing age and especially important for the adolescents included in this sample.

A recently published fitness program shows that a fitness training program with an aerobic and anaerobic training focus is able to improve the aerobic and anaerobic capacity in children with CP, who are classified at GMFCS level I and II (Verschuren, Ketelaar et al., 2007). After this training program, observed improvements were 38% (2 sessions a week for 8 months) for aerobic capacity estimated from a shuttle run test capacity (Verschuren, Ketelaar et al., 2007). Although long-term effects of fitness training are not known, one can only assume that an early introduction to a lifestyle that includes fitness would be beneficial for future health and function for children with CP. Physical therapists might consider fitness programs for children and adolescents with spastic CP by familiarizing them with exercising at school or in the community. Active healthy living habits created at a young age begin with experience, success and satisfaction derived from the benefits of a good exercise program.

It is hard to compare the children from all studies that provided information on VO_{2peak} for children and adolescents with CP. In the present study all children were recruited from a school for special education in The Netherlands which is not necessarily a representative sample and makes it difficult to generalize the results to other children with CP, especially in other countries where children with CP might be included in regular school programs. Moreover, there is no information regarding prior surgical procedures. Some of the patients might have been undergoing different surgery or treatment which may influence the functional level and consequently the aerobic capacity. In the present study the subjects were volunteers in a research project on the development of fitness tests (Verschuren et al., 2006; Verschuren, Takken, Ketelaar, Gorter, & Helders, 2007; Verschuren et al., 2008), and therefore might be probably more fit than the average CP population. It is known from the literature that a self-selected population has a 5–10% higher fitness level compared to an at-random selected population (Mitchell & Saltin, 2003).

Although this is the largest study reporting aerobic capacity in children and adolescents with CP, a limitation of our study is still the relatively small sample size, especially for the girls. There were only 8 girls with CP participating in this study, ranging from 7.5 to 13.7 years of age. Therefore, the conclusions based on this small number of subjects needs to be considered cautiously. Future studies should include more and older girls with CP.

4. Conclusions

In conclusion, the aerobic capacity of contemporary children and adolescents with CP, who are classified at GMFCS level I or II is significantly lower than that of typically developing controls. Especially in girls with CP the VO_{2peak} (ml/kg/min) deteriorated with age. Furthermore, there was no significant difference in VO_{2peak} (ml/kg/min) between children and adolescents with CP, classified at GMFCS level I or II. However, the aerobic capacity in the subjects with CP from the current study reported higher values compared to values previously reported in the literature.

Conflict of interest statement

This study did not have any conflict of interest.

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