Quantification of energy expenditure during gait in children affected by cerebral palsy

L. PICCININI 1, V. CIMOLIN 2, M. GALLI 2, M. BERTI 1, M. CRIVELLINI 2, A. C. TURCONI 1

Aim. Children affected by cerebral palsy (CP) are generally characterised by some movement limitations and abnormalities that compromised gait pattern. These disabilities during deambulation may lead to excessive energy cost and so to a compromised energy efficiency.

Methods. In this study oxygen expenditure was evaluated during walking in 20 children affected by CP and in 20 healthy children, using Cosmed K4b2 (Cosmed, Italy). From obtained data about energy consumption, some parameters (heart rate, energy expenditure index, oxygen consumption, oxygen cost) were extracted, first in order to quantify energy cost during gait in pathological and healthy subjects and then to underline differences between the 2 groups of children.

Results. In particular, the results obtained revealed that heart rate (bpm) and oxygen consumption (mL/kg/min) mean values didn't differ significantly between normal subjects and those with CP; instead, energy expenditure index (b/m) and oxygen cost (mL/kg/m) presented higher mean values rather than control group at a statistically level and so they revealed to be significant parameters, in order characterized energy expenditure in children affected by CP.

Conclusion. This inefficiency characteristic of CP deambulation is probably directly connected to the presence of simultaneous contraction of agonist and antagonist muscle in these patients.

Key words: Cerebral palsy - Gait - Child.
interventions, such as ambulatory aids, orthotic prescriptions, physical therapy or surgery.

In literature some studies investigated energy expenditure in healthy subjects and in patients affected by musculoskeletal disorders, in particular in children affected by CP.

Rose et al.² investigated the relationship between oxygen uptake, determined by a microprocessor-based system, and heart rate (HR) in healthy children and in those with CP. From the results of this study, a linear relationship was found throughout a wide range of walking speeds and the mean slopes and y-intercepts were found not significantly different for healthy and pathological children.

Rose et al.³ compared 2 indices relating to energy expenditure during walking, in healthy children and in children with CP: energy expenditure index (EEI) based on oxygen uptake versus EEI based on HR. The comparison was conducted in order to determine whether heart rate provided an accurate estimate of energy expenditure. The obtained results about EEI based on heart rate were equivalent to those obtained using EEI based on oxygen uptake. For this reason, both two indices related to energy expenditure can be used to evaluate walking in the 2 groups of children.

Duffy et al.⁴ evaluated energy consumption in 19 children with CP, in 21 children with spina bifida and in 16 healthy children, using the Cosmed K2 oxygen-analysis system. The rate of oxygen consumption was found significantly higher in the children with diplegia than in the other pathological children. Oxygen cost was significantly higher and velocity was significantly slower in all subjects with disabilities than in normal children. Probably, diplegic children consumed more oxygen than other children during walking because their abnormal equilibrium reactions impair their balance and their ability to control walking speed.

Bowen et al.⁵ evaluated oxygen consumption measurements made on 5 repeated tests from 5 children with CP and 5 non-disabled children, using the Cosmed K2 oxygen-analysis system at free-walking velocity. They measured oxygen cost, oxygen consumption and physiological cost index (PCI). There were no statistically significant differences in the percentage of variability of all three analysed indices between pathological and healthy subjects. The results revealed that the most reliable measurement was oxygen cost and the least reliable one was PCI index: for this reason, oxygen cost was considered the most sensitive parameter of change in gait efficiency.

Bowen et al.⁶ conducted a study collecting oxygen consumption measurements from 8 patients with muscular dystrophy (MD) and 8 patients with CP, using the Cosmed K2 oxygen-analysis system. A significant difference in oxygen cost and oxygen consumption while walking between patients with MD and those with CP was found despite their common inability to walk similar distances. The values of the two indices were elevated in CP population, whereas all measurements for the MD patients were within normal ranges. These results may be due to different disabilities in gait of the 2 groups of patients. In MD molecular abnormalities cause a reduction in the amount of viable muscle protein available to consume oxygen and generate force, causing weakness; in contrast, in CP the disabilities during gait are not the result of lack of viable muscle but rather inappropriate control of muscle contraction, causing energy dissipation.

At the light of these studies, it’s evident that several methodologies have been described for measuring oxygen consumption: 1) directly by oxygen volume (VO₂); 2) measuring HR and using the correlation between VO₂ and HR as a mean of estimating oxygen uptake; 3) using Cosmed K2 or K4b2, in order to obtain VO₂, VCO₂, HR, oxygen consumption and oxygen cost.

The use of HR has the advantage that it is inexpensive and easy to record, but the limitations to the use of this parameter as an indicator of energy expenditure include the following: 1) the slope of the linear relation between VO₂ and HR varies among individuals; 2) within a single individual at different times, the relation changes with the effect of training or de training; this may represent a problem when a child is evaluated, for example, after a period of convalescence from surgery (a de training effect), who may have a higher HR for any given VO₂; 3) the relation of HR to VO₂ at high HRs is unpredictable; 4) anxiety and anticipation affect HR, especially at rest and at low rates of activity.⁸ One of the arguments in favour of using HR as an indicator of energy expenditure, despite its limitations, is the magnitude of the equipment required to measure VO₂ directly. In fact, the Douglas bag system and the mobile cart, both connected to a child by tubes, are cumbersome and may interfere with a subject’s normal gait. In order to avoid these difficulties and to bypass the limits of HR, a solution may be represented by Cosmed K2 and
K4b² system. In fact, it has a light weight, portable, telemetric system and able to measure accurately some physiological parameters including \( VO_2 \), \( VCO_2 \), HR, oxygen consumption and oxygen cost.

In this study, energy consumption evaluation was conducted using Cosmed K4b², the more recent version of Cosmed K2 system, in children affected by CP; in particular some parameters were extracted in order to quantify and characterize oxygen expenditure in pathological children during gait.

### Materials and methods

Twenty children affected by CP (CP group) between the ages of 5 and 14 years with a mean age of 8.69±2.59 years, and a control group composed by 20 healthy children (healthy group) between the ages of 4 and 11 years with mean age of 7.75±2.11 years were considered in this study (Table I). Selection criteria for CP children included a diagnosis of either spastic hemiplegia or diplegia with no history of cardiovascular disease, no previous treatments for spasticity within the preceding years and independent ambulation without the assistance of aids or orthoses. Selection criteria for normal subjects included no orthopaedic, neurological or cardiovascular abnormalities.

All subjects were volunteers and their parents gave their informed consent to the children’s participation in the study. Ethics committee of IRCCS Medea - La Nostra Famiglia, Bosisio Parini (LC), Italy, approved this study. Each subject was evaluated in the Gait Analysis Laboratory at IRCCS Medea - La Nostra Famiglia in Bosisio Parini (LC).

The Cosmed K4b² breath-by-breath system (Cosmed, Rome, Italy) and Polar® HR monitor were used, in order to assess energy expenditure during deambulation.

The Cosmed K4b² oxygen analysis system is a portable system designed to measure gas exchange on breath by breath basis. It consists of several components: a portable unit, placed on the subject's chest, which allows telemetry data transmission; a mask covering the nose and mouth is fitted to each subject with the K4b² flowmeter attached; a small elastic cap holds the mask and flowmeter securely to the subject’s face without leakage. Following the manufacturer’s instructions, the instrument was calibrated before every test.

Each child attended one session, during which oxygen uptake was acquired. After setting up subjects with K4b² device, the acquisition was conducted as the next protocol: a resting phase was performed with child resting in a sitting position quietly for a period of 2 min (resting phase); then subject was asked to walk 7 laps of the laboratory for a total distance of 250 m at his/her own natural pace (self-selected speed) and barefoot (walking phase); after walking, the subject rested in a sitting position for a period of 2 min (recovery phase).

From data obtained by K4b² acquisitions, the following parameters were computed during each phase of the test (resting, walking and recovery), in order to quantify energy consumption of analysed subjects:

- HR, measured in beats per minute (bpm);
- velocity of progression (m/s) during walking phase;
- Velocity (m/s)
- HR (bpm)
- EEI (b/m)
- Oxygen Consumption (mL/kg/min)
- Oxygen cost (mL/kg/m)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Healthy group</th>
<th>CP group</th>
</tr>
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<tbody>
<tr>
<td>Age (years)</td>
<td>7.75 (2.11)</td>
<td>8.69 (2.59)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>132.23 (11.45)</td>
<td>127.31 (7.11)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>29.81 (6.10)</td>
<td>28.54 (10.39)</td>
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<thead>
<tr>
<th>Parameter</th>
<th>Healthy group</th>
<th>CP group</th>
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<tbody>
<tr>
<td>Velocity (m/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>83.90 (14.35)</td>
<td>103.53 (12.21)</td>
</tr>
<tr>
<td>EEI (b/m)</td>
<td>-</td>
<td>0.31 (0.16)</td>
</tr>
<tr>
<td>Oxygen Consumption (mL/kg/min)</td>
<td>7.22 (1.52)</td>
<td>15.16 (3.21)</td>
</tr>
<tr>
<td>Oxygen cost (mL/kg/m)</td>
<td>-</td>
<td>0.21 (0.05)</td>
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<thead>
<tr>
<th>Parameter</th>
<th>Healthy group</th>
<th>CP group</th>
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<tbody>
<tr>
<td>Velocity (m/s)</td>
<td>1.13 (0.19)</td>
<td>0.94 (0.15)*</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>83.49 (12.64)</td>
<td>81.88 (7.06)</td>
</tr>
<tr>
<td>EEI (b/m)</td>
<td>0.31 (0.16)</td>
<td>0.61 (0.18)*</td>
</tr>
<tr>
<td>Oxygen Consumption (mL/kg/min)</td>
<td>9.76 (1.79)</td>
<td>6.57 (1.81)</td>
</tr>
<tr>
<td>Oxygen cost (mL/kg/m)</td>
<td>0.21 (0.05)</td>
<td>0.29 (0.07)*</td>
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EEI (HR), calculated as walking heart rate minus resting heart rate, divided by walking speed, measured in beats per meter (b/m), according to

\[
\text{EEI (b/m) = } \frac{\text{HR (walking) - HR (resting)}}{\text{Walking speed}}
\]

Walking speed

— oxygen consumption, defined as millilitres of dry oxygen at standard temperature and pressure used per kilogram per minute (mL/kg/min);\(^1\) it is representative of the intensity of physical effort during exercise and it is time-dependent;

— oxygen cost, defined as millilitres of dry oxygen at standard temperature and pressure used per kilogram per meter walked (mL/kg/m);\(^1\) it is equivalent to normalized oxygen consumption divided by velocity. This index is not time-dependent and it represents a measure of gait efficiency.\(^1\)

These indices were computed for each subject and then the mean values and standard deviation related to all indices were calculated for CP group and healthy group.

Statistical analysis

Statistical analysis was conducted using parametric and nonparametric tests, in order to compare the condition of the 2 groups of children. Null hypotheses were rejected when probabilities were below 0.05 (P<0.05).

Results

In Table I the mean values (standard deviation) of age, height and weight of healthy and pathological groups are presented. There were no significant differences between the healthy and CP group in term of these indices. In particular, it should be noted that no statistical differences were found as concern height of analysed subjects, even if though it was emphasized in the introduction that “spasticity and reduced voluntary activity result in impaired longitudinal growth of skeletal muscles”.

All children were able to perform the assigned task without any difficulties and no interruptions during test execution.

Table II shows the mean values (standard deviation) of indices about energy expenditure during each phase of the test (resting, walking and recovery).

Children affected by CP were characterized by higher HR (bpm) mean value during walking phase than healthy group, even if this difference was not significant at a statistical level (walking: healthy group: 103.53±12.21 bpm; CP group: 114.67±12.50 bpm; P>0.05). There are no statistical differences of HR mean values between resting and recovery phase, both in pathological and normal children (resting: healthy group: 83.90±14.35 bpm; CP group: 81.88±7.06 bpm; P>0.05; recovery: healthy group: 83.49±12.64 bpm; CP group: 82.89±19.60 bpm; P>0.05).

EEI (b/m) mean values of the 2 groups were different statistically (healthy group: 0.31±0.16 b/m; CP group: 0.61±0.18 b/m; P< 0.05; Figure 1). This result may be directly connected to the slow velocity of progression that was present in children with CP (healthy group: 1.13±0.19 m/s; CP group: 0.94±0.15 m/s; P<0.05). In fact, CP subjects were characterised by a significant lower velocity than normal subjects.
Oxygen consumption (mL/kg/min) didn’t represent a significant index in order to differentiate the 2 groups considered in this analysis: the mean value of pathological children, in fact, was closed to those of healthy group during all acquisition phases (resting: healthy group: 7.22±1.52 mL/kg/min; CP group: 6.57±1.81 mL/kg/min; P>0.05; walking: healthy group: 15.16±3.21 mL/kg/min; CP group: 13.97±3.28 mL/kg/min; P>0.05; recovery: healthy group: 9.76±1.79 mL/kg/min; CP group: 9.21±2.33 mL/kg/min; P>0.05).

Finally, CP children presented abnormal oxygen cost (mL/kg/m) (Figure 2): the mean value, in fact, was high in comparison with healthy group value (healthy group: 0.21±0.05 mL/kg/m; CP: 0.29±0.07 mL/kg/m; P< 0.05). This result has been confirmed by other investigations in literature.2, 5

Discussion and conclusions

Gait abnormalities in children with CP, due to the presence of reduced selective muscle control, abnormal muscle tone, imbalance between muscle agonists and antagonists across joints and deficient equilibrium reactions, have been shown to increase walking energy expenditure compared with healthy children.1, 12 In this study, energy efficiency in CP children was evaluated, using the Cosmed K4b² oxygen-analysis system (Cosmed, Rome, Italy) and some parameters were considered, in order to quantify energy expenditure during deambulation in pathological children.

HR (bpm) and oxygen consumption (mL/kg/min) mean values don’t differ significantly between normal subjects and those with CP in the 3 phases of protocol acquisition (resting, walking and recovery phase). It appears for this reason that there is a common range of energy used, even if during walking phase, the velocity achieved was significantly lower for CP children than for healthy children.

Instead, EEI (b/m) and oxygen cost (mL/kg/m) revealed to be significantly different from range of normality. The EEI indicates the amount of energy required to walk a specified distance and reflects energy requirement. It was demonstrated that at slow speed the EEI is high, representative of poor economy during gait in these patients; instead, with increasing walking speed, the EEI decreases until an optimum range.3 The results obtained in this study confirm literature: CP group, in fact, walked with a lower velocity than healthy group, underlying the poor economy while walking of pathological subjects.2, 5

Finally, oxygen cost presented higher mean value in CP children versus the control group. It may be due to the presence of simultaneous contraction of agonist and antagonist muscle, that is a peculiar element in this type of patients. The presence of co contraction, in fact, can be both beneficial and negative. The out-of-phase muscle activity permits achieving joint stability, in particular at ankle and knee joints during deambulation. Then, the excessive activation of antagonist muscle causes a high metabolic cost, well represented by oxygen cost parameter.12

It should be noted that the comparison criteria used in this study is arbitrary and has limitation—it could as well be the duration of a walking period and/or normalize velocity (percentage of maximal) instead of a common distance—“walk 7 laps of the laboratory for a total distance of 250 m at his/her own natural pace (self-selected speed) and barefoot (walking phase)”. So the comparison is done for activity of different durations.

The obtained results highlight that children affected by CP are characterised by an own peculiar strategy, not only from a biomechanical point of view,1, 12 but also in term of energy expenditure while walking: they present, in fact, a reduced velocity during deambulation, in order to maintain oxygen consumption at an acceptable level close to normality; then, oxygen cost while walking increases to preserve energy consumption at an acceptable level, as confirmed by the outcomes of this study.

For this reason, interventions and rehabilitations in CP children are needed both to improve their poor biomechanics, connected to musculoskeletal abnormalities, and also in order to increase aerobic capacity. In this way, it is possible to obtain significant improvements in their walking efficiency and this concept has an important clinical implication: in fact, since walking in CP subjects requires a greater physical exertion than walking in healthy children, it may happen that pathological children prefer to walk less or to use a wheelchair, because of fatigue, limiting in this way their autonomy in daily activities and worsening their quality of life, too.

References