Energy requirements in preschool-age children with cerebral palsy1–3

Jacqueline L Walker, Kristie L Bell, Roslyn N Boyd, and Peter SW Davies

ABSTRACT

Background: There is a paucity of data concerning the energy requirements (ERs) of preschool-age children with cerebral palsy (CP), the knowledge of which is essential for early nutritional management.

Objective: We aimed to determine the ERs for preschool-age children with CP in relation to functional ability, motor type, and distribution and compared with typically developing children (TDC) and published estimation equations.

Design: Thirty-two children with CP (63% male) of all functional abilities, motor types, and distributions and 16 TDC (63% male) aged 2.9–4.4 y participated in this study. The doubly labeled water method was used to determine ERs. Statistical analyses were conducted by 1-factor ANOVA and post hoc Tukey honestly significant difference tests, independent and paired t tests, Bland and Altman analyses, correlations, and multivariable regressions.

Results: As a population, children with CP had significantly lower ERs than did TDC (P < 0.05). No significant difference in ERs was found between ambulant children and TDC. Marginally ambulant and nonambulant children had ERs that were ~18% lower than those of ambulant children and 31% lower than those of TDC. A trend toward lower ERs with greater numbers of limbs involved was observed. The influence of motor type could not be determined statistically. Published equations substantially underestimated ERs in the nonambulant children by ~22%.

Conclusions: In preschool-age children with CP, ERs decreased as ambulatory status declined and more limbs were involved. The greatest predictor of ERs was fat-free mass, then ambulatory status. Future research should build on the information presented to expand the knowledge base regarding ERs in children with CP. This trial was registered with the Australian New Zealand Clinical Trials Registry as ACTRN 12612000686808. Am J Clin Nutr 2012;96:1309–15.

INTRODUCTION

Knowledge of energy requirements (ERs)4 of younger children with cerebral palsy (CP) is vital, because early nutritional management is essential for optimal development, especially in a population with well-documented growth concerns (1–3). ERs for children with CP are influenced by many factors that are not routinely found in typically developing children (TDC). The initial brain injury and consequently the motor type, distribution, and severity of impairment for each child influence patterns of movement and muscle function. These patterns can then alter total energy expenditure (TEE) (4). At a population level, TEE, which equates to ERs in a state of weight balance, has been reported to be significantly lower in most children with CP compared with TDC (5–8). Conversely, it has been hypothesized that children with athetosis (a form of dyskinesia) have similar or even increased ERs relative to recommendations for TDC, because of increased involuntary movements at rest. Current studies have only investigated ERs in adults with athetosis (4, 9–11). When considering functional ability, nonambulatory children have significantly lower TEE levels than do children with greater function (12). Ambulatory children have been shown to have lower TEE levels than TDC (6, 8).

Prediction equations for estimating ERs that have been developed and validated in TDC do not perform well in children with CP (5, 7, 13). Two population-specific equations exist to estimate ERs in children with CP (12, 14). An equation developed by Krick et al in 1992 (14) was later proven to be inaccurate when compared with the gold standard doubly labeled water (DLW) method (12). More recently, Rieken et al (12) developed 2 equations for use in nonambulant, school-age children with severe CP. One requires prediction of basal metabolic rate with the commonly used Schofield equation (15), and the other uses a multiple of total body water (TBW) measurements. From these baseline calculations, each equation then estimates TEE with

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2 Supported by an Australian Postgraduate Award Scholarship (to JLW), School of Medicine Research Scholar Scholarship (to JLW), National Health and Medical Research Council (NHMRC) for Project Grant, Queensland Cerebral Palsy Child Study: Growth, Nutrition and Physical Activity in Children (569905; to PSWD, RNB, and KLB), NHMRC Career Development Grant (473840; to RNB), Smart State Fellowship from the Queensland Government (RNB), Royal Children’s Hospital Foundation, Queensland (RB and PSWD), and the University of Queensland Foundation (RNB)

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4 Abbreviations used: CP cerebral palsy; DLW, doubly labeled water; ER, energy requirement; FFM, fat-free mass; FFMi, fat-free mass index; GMFCS, Gross Motor Function Classification System; MD, mean difference; TBW, total body water; TDC, typically developing children; TEE, total energy expenditure.

Received May 23, 2012. Accepted for publication September 4, 2012. First published online November 7, 2012; doi: 10.3945/ajcn.112.043430.
consumed, either orally (17). Each child consumed, either orally (n = 43) or via a feeding tube (n = 5), a loading dose of deuterium and oxygen-18 in the form of water. The dose was dependent on body weight (1.25 g/kg 10% D2O and 0.05 g/kg 99.8% 2H2O) (18). Doses were recorded to 2 decimal places of a gram, with caution taken to ensure corrections for spillage. A single baseline urine sample from each child was collected by parents before dosing to determine natural baseline enrichment of the isotopes. After dosing, daily samples were required thereafter for 10 d. Urine bags and absorbent cotton wool balls were used to collect urine samples from children with poor or no bladder control. A Dual Inlet Isotope ratio mass spectrometer (Isoprime Dual Inlet IMRS–IonVantage Software, Isoprime) was used to analyze all urine samples to determine isotopic enrichments. Results were expressed relative to the international standard, Vienna Standard Mean Ocean Water. Standard equations were used to calculate dilution spaces for both deuterium and oxygen-18 (19).

**SUBJECTS AND METHODS**

**Participants**

Children living in the community in the state of Queensland, Australia, were invited to participate in this study. Children were included if they had a diagnosis of CP and were aged between 2.9 and 4.4 y at the time of assessment (chronologic age). Those with a progressive or neurodegenerative lesion, or a chromosomal or genetic abnormality known to affect growth, energy expenditure, or body composition, were excluded. A group of TDC in the same age range residing in Queensland, Australia, were invited to participate. Those with a condition or taking any medication that altered body composition or energy metabolism were excluded. Written informed consent was obtained from parents or legal guardians of all children before assessment. Children and parents/guardians attended their closest center or outreach location for one appointment. The same study team visited the 9 geographic locations throughout Queensland to collect data. Ethical approval for this study was obtained from the Children’s Health Services District Ethics Committee (HREC/09/QRCH/124) and The University of Queensland Medical Research Ethics Committee (2009001869).

**Total energy expenditure**

The DLW method was used to measure TEE (17). Each child consumed, either orally (n = 43) or via a feeding tube (n = 5), a loading dose of deuterium and oxygen-18 in the form of water. The dose was dependent on body weight (1.25 g/kg 10% D2O and 0.05 g/kg 99.8% 2H2O) (18). Doses were recorded to 2 decimal places of a gram, with caution taken to ensure corrections for spillage. A single baseline urine sample from each child was collected by parents before dosing to determine natural baseline enrichment of the isotopes. After dosing, daily samples were required thereafter for 10 d. Urine bags and absorbent cotton wool balls were used to collect urine samples from children with poor or no bladder control. A Dual Inlet Isotope ratio mass spectrometer (Isoprime Dual Inlet IMRS–IonVantage Software, Isoprime) was used to analyze all urine samples to determine isotopic enrichments. Results were expressed relative to the international standard, Vienna Standard Mean Ocean Water. Standard equations were used to calculate dilution spaces for both deuterium and oxygen-18 (19). Rate constants were determined via the multipoint method, which involved calculating the coefficient of the regression line of the natural logarithm of enrichment over time. The production rate of carbon dioxide was calculated as the difference between the elimination rates of deuterium and oxygen-18 in conjunction with their dilution space and accounting for isotopic fractionation (20). Oxygen consumption was determined by assuming a respiratory quotient of 0.85 (21), and TEE was calculated according to the abbreviated Weir equation (22). Results regarding TEE equate to ERs and are therefore expressed and discussed as ER results from this point forward.

**Body composition**

Body composition was measured via the measurement of TBW inherent within the DLW technique. TBW was determined by analysis of the isotopic enrichment of oxygen-18 to determine the dilution space, as described above. The oxygen-18 dilution space (N) is larger than the body water pool by ~1%, hence an appropriate adjustment was made (23). The subsequent TBW value was divided by age and sex-specific hydration factors to give a result for fat-free mass (FFM) (24). According to the 2-compartment model, fat mass was then determined by subtracting the FFM value from the total weight of the subject (25). To adjust for the influence of height, FFM was converted to the FFM index (FFMI) (FFM/height²) (26).

**Anthropometric measures**

Weight was measured to the nearest 100 g on portable electronic scales (Homemaker Ltd) or chair scales (Seca Ltd). Height was measured to the last completed millimeter by using a portable manual length measuring board (Shorr Productions). If the child could not stand on their own or had muscle contractures or deformities, such as scoliosis, that prevented the accurate measurement of height or length, knee height was used as a proxy measure for standing height by using published equations (27). This was measured to the nearest millimeter with an anthropometer (Holtain Ltd). All measurements were conducted by one of 3 trained dietitians.

**Functional ability**

The gross motor ability of each child was determined by 2 research physiotherapists with the use of the GMFCS—an internationally accepted and validated measure (28, 29). The GMFCS classifies children with CP on the basis of gross motor functional abilities and limitations and includes 5 levels, ranging from I (includes children who are most able) to V (children who are least able), and 4 age bands (<2, from 2 to <4, from 4 to <6, and from 6 to 12 y). The 5 levels represent differences in gross motor function that are thought to be meaningful in the daily lives of children with CP, such as locomotion, sitting ability, and balance. The age bands allow for age-related differences in gross motor function (30). Children were classified into 1 of 5 functional categories, which were then condensed into 2 groups to describe outcomes based on walking ability: ambulant children (GMFCS I and II: mild CP) and marginally ambulant and nonambulant children (GMFCS III–V: moderate to severe CP).
Motor type and distribution

The motor type (spasticity, dyskinesia, hypotonia, or ataxia) and distribution (hemiplegia, diplegia, triplegia, or quadriplegia) of CP was determined according to definitions by Sanger et al (31) and the internationally accepted classification system on the European CP Register (32). This was done independently by 2 research physiotherapists, who then came to a common agreement.

Power calculations

Sample size calculations were based on the primary outcome of the research, TEE, which was measured in kilojoules per day according to analyses involving the 2 functional ability levels described previously. The number of children required for each group was calculated by using standard power calculations. In theory, over a specified time period, TEE would be equivalent to energy intake for an individual who is in weight balance. It was determined that a difference of 20% between group means of TEE would be biologically and clinically significant. This figure is similar to the daily variations routinely seen in young children’s energy intake (33–35). Sample size calculations were based on 80% power and 5% significance by using available energy intake data from TDC (20, 36), because these are more readily available than national TEE data, and the formula shown below:

\[
 n = \frac{16}{f^2} \quad (1)
\]

where

\[
 f = \frac{\text{biologically significant difference to detect as an SD}}{\text{SD of the parameter of interest}} \quad (2)
\]

Mean energy intake among large groups of TDC, aged between 1 and 5 y, has been found to be 5271 kJ/d (20, 36). A difference in energy intake of 1054 kJ/d (20%) between either group of children with CP and the TDC was estimated to be biologically and clinically significant. The SD found by these researchers for TDC is 1042 kJ/d (20, 36). With the use of these data and the formula above, it was calculated that 16 children would be needed in each comparison group.

It is important to note that the energy intake data used as a basis for sample size calculations were combined data from 2 large studies. The first was conducted in the United Kingdom and were results of a national diet and nutrition survey. The dietary assessment method used in this study, a 4-d weighed food record, was further validated, indicating accurate data (20). The second study was completed in Greece and involved 2374 children aged 1–5 y. Dietary data were adjusted for within-person variance and corrected for underreporting (36). Available energy intake data from Australian children were unable to be used for sample size calculations. Results from the 2007 Australian National Children’s Nutrition and Physical Activity Survey do not provide SDs and do not include children younger than 2 y, and energy intake data for children aged 4 and 5 y could not be distinguished from data for older children (37).

Statistics

Statistical analyses were conducted by using Statistical Package for the Social Sciences version 20 (IBM SPSS Statistics 20.0). Children with CP were grouped according to the variables of interest. When functional ability, comparisons with TDC, and evaluation of prediction equations were considered, children with CP were placed into 2 groups according to their walking ability as described previously. The third group consisted of the TDC. When determining differences based on motor distribution, groups included those with hemiplegia, diplegia, triplegia, or quadriplegia. The motor type of CP was grouped as those children with spasticity, dyskinesia, and hypotonia. Weight and height z scores were calculated based on age and sex with the use of the CDC data and incorporating the least mean squares method (38). Comparisons of ERs, age, and anthropometric measures between the population of children with CP and the TDC were done with independent t tests. For the comparisons of the functional ability level of the children with CP and the TDC, comparisons of ER, age, and anthropometric measures were made by 1-factor ANOVA and post hoc Tukey honestly significant difference tests to adjust for multiple comparisons. Pearson’s correlations were used to determine relations between ERs and anthropometric and body-composition variables. Multivariable regression was used to determine the factors influencing the variability in ERs. Comparisons of ER, age, and anthropometric measures between varying motor distributions in children with CP and the TDC were made by using 1-factor ANOVA and post hoc Tukey honestly significant difference tests to adjust for multiple comparisons. Comparisons of ER, age, and anthropometric measures between children with CP—considering motor type (spasticity only)—and TDC were via independent t tests. Bland and Altman analyses and paired t tests were used to compare results from the current study with published estimation equations.

RESULTS

Thirty-two children with CP (63% male) ranging in age from 2.9 to 4.4 y, representing all GMFCS levels (Table 1), motor distributions (Table 2), and motor types (Table 3) participated in the study. At the time of assessment, all children were in good health and were not undergoing any medical or therapeutic procedures that could limit or change usual activity levels and hence affect ERs, such as intramuscular botulinum-toxin A injections or serial casting. Sixteen TDC participated (63% male), ranging in age from 3.0 to 4.5 y.

The anthropometric, body composition, and ER results for children with CP are shown in Table 1 according to functional ability level and the TDC. Overall, children with CP were shorter, lighter, and had lower FFMIs than did the TDC (P < 0.01). Mean height z scores and FFMIs for children with CP decreased as ambulatory status declined (P < 0.05).

At the population level, children with CP had significantly lower ERs than did TDC (P < 0.001; mean difference (MD) = −1212 kJ/d) (Table 1). Marginally ambulant and nonambulant children had significantly lower ERs than did both ambulant children (P < 0.001; MD = −1682 kJ/d) and TDC (P < 0.001; MD = −2053kJ/d). No statistical difference in ERs was found between ambulant children and TDC.

Results highlighting the overall contribution of GMFCS level and FFM to the variability in ERs were determined via multivariable regression. Overall, the model explained 67% of the variability in ER (r² = 0.67). As predicted, the FFM of the
Anthropometric, energy requirement, and body-composition results in children with cerebral palsy according to gross motor functional ability and in typically developing children

<table>
<thead>
<tr>
<th></th>
<th>Ambulant children (GMFCS I and II) (n = 16)</th>
<th>Marginally ambulant and nonambulant children (GMFCS III, IV, and V) (n = 16)</th>
<th>All children with cerebral palsy (n = 32)</th>
<th>Typically developing children (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>3.7 ± 0.5</td>
<td>3.7 ± 0.5</td>
<td>3.7 ± 0.5</td>
<td>3.7 ± 0.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>15.4 ± 1.7</td>
<td>14.1 ± 3.1</td>
<td>14.8 ± 2.6</td>
<td>16.9 ± 1.7</td>
</tr>
<tr>
<td>Weight z score</td>
<td>−0.1 ± 0.9</td>
<td>−1.1 ± 1.9</td>
<td>−0.6 ± 1.5</td>
<td>0.6 ± 0.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>100.2 ± 5.7t</td>
<td>94.0 ± 4.6w</td>
<td>97.1 ± 6.0t</td>
<td>101.9 ± 5.3</td>
</tr>
<tr>
<td>Height z score</td>
<td>0.1 ± 1.1t</td>
<td>−1.3 ± 1.1</td>
<td>−0.6 ± 1.3</td>
<td>0.5 ± 0.7</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>12.2 ± 1.5t</td>
<td>10.3 ± 1.7</td>
<td>11.3 ± 1.8</td>
<td>13.0 ± 1.4</td>
</tr>
<tr>
<td>FFMI (kg/m²)</td>
<td>12.2 ± 1.0t</td>
<td>10.9 ± 1.5</td>
<td>11.6 ± 1.4</td>
<td>12.7 ± 1.0</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>20.9 ± 3.7</td>
<td>25.5 ± 9.9</td>
<td>23.2 ± 7.7</td>
<td>22.9 ± 3.6</td>
</tr>
<tr>
<td>ER (kJ/d)</td>
<td>6040 ± 953t</td>
<td>4359 ± 1000t</td>
<td>5200 ± 1286t</td>
<td>6411 ± 755</td>
</tr>
</tbody>
</table>

1All values are means ± SDs. ER, energy requirement; FFM, fat-free mass; FFMI, fat-free mass index; GMFCS, Gross Motor Function Classification System.
2,3Significantly different from the typically developing children: 2,3P < 0.05 (1-factor ANOVA and post hoc Tukey honestly significant difference tests), 3P < 0.01 (independent t tests).

The anthropometric, ER, and body-composition results are shown in Table 2 according to distribution and in comparison with values from TDC. A trend toward lower ERs with an increasing number of limbs involved was observed (P < 0.05). Children with triplegia or quadriplegia were significantly shorter and lighter and had lower FFMI and lower ERs than did both the children with hemiplegia (P < 0.05) and TDC (P < 0.001), despite low sample sizes.

The anthropometric, ER, and body-composition values for children with CP are shown in Table 3 according to motor type and compared with TDC. Children with spasticity had significantly lower ERs than did the TDC (P < 0.05). Statistical comparisons between the varying motor types could not be made because of the small sample sizes of children with dyskinesia and hypotonia.

The results obtained from a comparison of the 2 prediction equations developed by Reiken et al (12) with the data from the nonambulant children (GMFCS IV and V) in the current study are shown in Table 5. The estimated ERs from both models were significantly less than the measured ER values, with a consistent bias of ~−1089kJ, representing an underestimation in ERs in the current population of ~22%. Limits of agreement for both models were large, which represented great individual variation, and only 45–55% of children had estimated ER values that were

### Table 2

<table>
<thead>
<tr>
<th>Hemiplegia (n = 11)</th>
<th>Diplegia (n = 7)</th>
<th>Triplegia or quadriplegia (n = 14)</th>
<th>Typically developing (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>3.8 ± 0.5</td>
<td>3.4 ± 0.5</td>
<td>3.7 ± 0.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>10.2 ± 0.9t</td>
<td>−0.7 ± 1.1</td>
<td>−1.2 ± 1.9t</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.4 ± 1.1t</td>
<td>−0.6 ± 0.8</td>
<td>−1.3 ± 1.1t</td>
</tr>
<tr>
<td>FFMI (kg/m²)</td>
<td>0.5 ± 1.2t</td>
<td>11.7 ± 1.1</td>
<td>10.8 ± 1.5t</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>21.5 ± 4.4</td>
<td>20.1 ± 3.0</td>
<td>26.1 ± 10.3</td>
</tr>
<tr>
<td>ER (kJ/d)</td>
<td>6098 ± 769t</td>
<td>5466 ± 1408</td>
<td>4360 ± 1046t</td>
</tr>
</tbody>
</table>

1All values are means ± SDs. ER, energy requirement; FFMI, fat-free mass index.
2,3Significantly different from the typically developing children, P < 0.05 (1-factor ANOVA and post hoc Tukey honestly significant difference tests).
4Significantly different from the typically developing children, P < 0.001 (1-factor ANOVA and post hoc Tukey honestly significant difference tests).
within 20% of measured ER values. The corresponding Bland Altman plots can be seen in Figure 1.

DISCUSSION

To our knowledge, this was the first study to provide data concerning ERs in a group of preschool-age children with CP, across the spectrum of functional abilities, motor types, and distributions. As an overall population, the ERs of young children with CP were lower than those of the TDC, which is consistent with the findings of most previous studies (5–8). ERs decreased as functional ability decreased; therefore, marginally ambulant and nonambulant children had significantly lower ERs than did ambulant children. An interesting outcome was that, at the group level, ambulant children had ERs similar to those of the TDC, whereas studies of older children have shown decreased requirements as a result of lower activity-related energy expenditure (6, 8). The differences between studies could partly be explained by differences in the structure and purpose of physical activities in younger children. Physical activities for school-age children are generally organized and therefore may be more difficult for those with greater motor impairments, who will not willingly participate. Conversely, the nature of play in young children means that they are usually spontaneously engaging in physical activity without purposefully choosing to do so, and the functional ability of the child may be less of a restriction (39–41).

Approximately 67% of the variability in ERs in the current cohort of children with CP can be explained by differences in FFM and GMFCS group (ambulant and marginally ambulant or nonambulant). When the value of the unstandardized regression coefficient for the GMFCS group from multivariable regression results was considered, marginally ambulant and nonambulant children had an ER that was, on average, 31% lower than that of the TDC and 18% lower than that of the ambulant children—values that should be taken into account in clinical situations when feeding regimens are prescribed and ERs are determined. Individually, ambulant children have an ER that is, on average, 16% lower than that of the TDC. These values, although less clinically relevant, still indicate that as a child becomes more impaired in their overall gross motor function, their ER is decreased, independent of the influence of FFM.

The distribution of CP was hypothesized to have an influence on the ER as it affects the overall physical activity level of the child. Results confirmed a trend toward lower ERs with an increasing number of limbs involved. This finding is consistent with results related to functional ability. In most cases, the greater the number of limbs involved, the more likely a child will be classified into a lower functioning GMFCS level and will have more activity restrictions and movement limitations. Clinicians are encouraged, therefore, to consider motor distribution when determining ERs in preschool-age children with CP, but to focus more intently on ambulatory status and subsequent FFM values.

The particular motor type of CP has been considered a factor that greatly influences ERs. Results of the current study were unable to draw solid conclusions regarding ERs based on motor type. The results were not able to statistically confirm whether children with dyskinesia (particularly athetosis) had similar or increased ERs relative to the TDC. Although the finding that children with spasticity had lower ERs than did the TDC is consistent with the findings of previous studies (5–8), statistical comparisons between varying motor types were unable to be made because of the small sample sizes of children with dyskinesia and hypotonia. A previous study investigated the influence of motor type on ERs in nonambulant children, with a mean age of 10.1 ± 4.3 y, and, although no statistical outcomes were presented, trends were still evident (12). Children with mixed muscle tone had greater ERs than did children with either hypertonia or hypotonia. This finding may suggest that motor type plays a greater role in ERs as children grow older.

### TABLE 3

Anthropometric, energy requirement, and body-composition results in children with cerebral palsy according to motor type and in typically developing children

<table>
<thead>
<tr>
<th>Spasticity (n = 26)</th>
<th>Dyskinesia (n = 5)</th>
<th>Hypotonia (n = 1)</th>
<th>Typically developing children (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y) 3.7 ± 0.5</td>
<td>Weight z score −0.4 ± 1.3²</td>
<td>−0.5 ± 1.3²</td>
<td>−0.5 ± 1.3²</td>
</tr>
<tr>
<td>Height z score −0.5 ± 1.3²</td>
<td>−1.1 ± 1.4</td>
<td>−1.5</td>
<td>0.5 ± 0.7</td>
</tr>
<tr>
<td>FFMI (kg/m²) 11.7 ± 1.4²</td>
<td>10.7 ± 1.7</td>
<td>11.1</td>
<td>12.7 ± 1.0</td>
</tr>
<tr>
<td>Body fat (%) 23.2 ± 7.4</td>
<td>20.9 ± 8.6</td>
<td>36.0</td>
<td>22.9 ± 3.6</td>
</tr>
<tr>
<td>ER (kJ/d) 5722 ± 1378²</td>
<td>4924 ± 875</td>
<td>4707</td>
<td>6411 ± 755</td>
</tr>
</tbody>
</table>

¹All values are means ± SDs, except for the child with hypotonia. ER, energy requirement; FFMI, fat-free mass index.
²Significantly different from the typically developing children, P < 0.05 (independent t tests). Statistical comparisons between other motor types could not be made because of small sample sizes.

### TABLE 4

Relations between energy requirements and anthropometric and body-composition variables known to influence energy requirements as determined by Pearson’s correlation in children with cerebral palsy and in typically developing children

<table>
<thead>
<tr>
<th>Children with cerebral palsy (n = 32)</th>
<th>Typically developing children (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>P value</td>
</tr>
<tr>
<td>FFMI (kg) 0.76</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>GMFCS group ²</td>
<td>−0.66</td>
</tr>
<tr>
<td>Weight (kg) 0.38</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Height (cm) 0.59</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Age (y) 0.32</td>
<td>0.08</td>
</tr>
</tbody>
</table>

¹FFM, fat-free mass; GMFCS, Gross Motor Function Classification System; NA, not applicable.
²The GMFCS group is either ambulant (GMFCS I and II) or marginally ambulant and nonambulant (GMFCS III, IV, and V).
Providing evidence to support this theory, however, is challenging. Difficulties lie in obtaining large enough sample sizes to elicit statistically significant results, which require expensive methodologic procedures. The term CP encompasses a variety of motor disorders that affect body movement, posture, and balance, and the prevalence of the motor types of dyskinesia and hypotonia in comparison with spasticity is low (42). In addition, clinical signs of athetosis may not be evident in young children, because they usually develop when a child is older (43), hence the decreased prevalence in the current age group. It is recommended that both the influence of motor type and motor distribution on ER in preschool-age children with CP are further investigated in future studies.

Use of previously published estimation equations showed consistent underestimation of ERs in the 11 nonambulant children in the current study population. Large limits of agreement meant that some children had estimated ERs that were up to 50% less than the actual measured requirement. Many factors influence these results. First, the equations were developed from a comparatively older CP population (mean age: 10.1 ± 4.3 y) and thus may not be applicable to a younger group of children. Second, the additional corrections for both equations include a very subjective interpretation of a low or high movement for each individual child. Activity was measured by Reiken et al (12) with the use of a nonvalidated method and hence is not yet reproducible in other populations. Judgments in the current study about whether to classify children into the low- or high-movement group were based on the collective decision of authors to group all children as having low movement unless their motor type was athetosis (with subsequent involuntary movements). This arbitrary classification of movement needs to be clarified, and the equation requires further refinement and validation before incorporation into future research studies and clinical practice.

A limitation of this study was the moderate sample size and limited representation of some motor types; however, a larger study including more children is not practical or affordable in many research settings. The results described here are unique as this study is the first ever conducted measuring ER in preschool-age children with CP across the spectrum of functional abilities, motor types, and distributions. Future research should build on the information presented to confirm findings in other CP populations and expand the knowledge base regarding ERs.

The results confirm that Australian national recommendations for ERs and hence energy intake are not valid for use in this population, especially for those children who are more severely impaired. It is recommended that clinicians understand that, in our population, marginally ambulant and nonambulant children had

| TABLE 5 |
|-----------------|-------------------|
| Estimated ER (kJ/d) | 3295 ± 902 | 3398 ± 791 |
| Measured ER (kJ/d) | 4436 ± 1045 | 4436 ± 1045 |
| \( P \) value for the difference between measured and estimated ERs | 0.004 | 0.003 |
| Bias (kJ) | −1141 | −1038 |
| Limits of agreement (kJ) | −3162 to 880 | −2849 to 773 |
| Children with estimated ER values within 20% of measured ER values [%] | 5 (45) | 6 (55) |

1Pearson’s correlations between the mean of the measurements and the differences were not statistically significant for any of the equations. DLW, doubly labeled water; ER, energy requirement; TBW, total body water.

2Mean ± SD (all such values).

FIGURE 1. Bland and Altman plots of the differences between estimated ERs via 2 equations developed by Rieken et al (12) and measured ERs by using the doubly labeled water method in nonambulant children with cerebral palsy (Gross Motor Function Classification System IV and V) for the model with the Schofield equation (A; \( n = 11 \)) and the model using total body water (B; \( n = 11 \)). ER, energy requirement.
ERs that were ~31% lower than those of the TDC. This information is important for clinical decision-making in combination with frequent follow-up to monitor weight and body-composition changes when ERs are determined for children with CP.

In conclusion, this study provides evidence that supports altered ERs in young children with CP when overall functional ability level is considered. Comparisons with the TDC enabled meaningful clinical interpretations that have the potential to be incorporated into everyday clinical practice and early intervention strategies. Further research is required to determine the influence of other factors on ER, particularly motor type.

We thank all of the children and families who participated in the study for their time and efforts.

The authors’ responsibilities were as follows—JLW, KLB, RNB, and PSWD: designed the research and reviewed and approved the final content; JLW: conducted the research, analyzed the data, performed the statistical analyses, and wrote the manuscript; and PSWD and RNB: provided essential materials. None of the authors disclosed any conflicts of interest.

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