Published in final edited form as:

J Pediatr. 2014 November ; 165(5): 1011–1016. doi:10.1016/j.jpeds.2014.07.027.

Muscle activation and energy-requirements for varying postures in children and adolescents with cerebral palsy

Dr. Olaf Verschuren, PhD,

Brain Center Rudolf Magnus and Center of Excellence for Rehabilitation Medicine, University Medical Center Utrecht and De Hoogstraat Rehabilitation, Utrecht, The Netherlands, Rembrandtkade 10, 3583TM, Utrecht, The Netherlands, assistant professor. Phone: +3130-2561211

Mark D. Peterson, PhD, M.S,

Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor, MI, USA

Svenja Leferink, MsC, and

De Hoogstraat Rehabilitation, Utrecht, The Netherlands, Rembrandtkade 10, 3583TM, Utrecht, The Netherlands

Johanna Darrah, PhD

Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta, Edmonton Alberta, Canada T6G 2G4

Olaf Verschuren: o.verschuren@dehoogstraat.nl; Mark D. Peterson: mdpeterz@med.umich.edu; Svenja Leferink: svenjaa@live.nl; Johanna Darrah: johanna.darrah@ualberta.ca

Abstract

Objective—To determine energy expenditure and muscle activity among children and adolescents with cerebral palsy (CP), across several conditions that approximate sedentary behavior, and standing.

Study design—Subjects with spastic CP (n=19; 4–20 years of age; Gross Motor Function Classification System [GMFCS] levels I to V) participated in this cohort study. Energy-expenditure and muscle activity were measured during lying supine, sitting with support, sitting without support, and standing. Energy-expenditure was measured using indirect calorimetry and expressed in metabolic equivalents (METs). Muscle activation was recorded using surface electromyography. The recorded values were calculated for every child and then averaged per posture.

Results—Mean energy expenditure was >1.5 METs during standing for all GMFCS levels. There was a non-significant trend for greater muscle activation for all postures with less support.

© 2014 Published by Elsevier Inc.

Correspondence to: Olaf Verschuren, o.verschuren@dehoogstraat.nl.

The authors declare no conflicts of interest.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Only for children classified at GMFCS level III standing resulted in significantly greater muscle activation ($p<0.05$) compared with rest.

Conclusion—Across all GMFCS levels, children and adolescents with CP had elevated energy expenditure during standing that exceeded the sedentary threshold of 1.5 METs. Our findings suggest that changing a child's position to standing may contribute to the accumulation of light activity and reduction of long intervals of sedentary behavior.

Keywords

sedentary behavior; physical activity; exercise

Prolonged periods of sedentary behavior have been associated with several metabolic risk factors and all-cause mortality, independent of participation in physical activity. This suggests that the protective effects of physical activity for health may be negated by prolonged bouts of sedentary behavior.^{1–4} The study of sedentary behavior as a distinct concept, rather than the mere absence of moderate to vigorous physical activity (MVPA), is an important new area of research.⁵ However, over the last decade the definition of sedentary behavior has evolved, and consequently distinguishing it from physical inactivity has been confusing.⁶ Previously, being sedentary meant merely a lack of MVPA, regardless of the amount of habitual light and lifestyle activities. The currently accepted definition of sedentary behavior is “any waking behavior characterized by an energy expenditure 1.5 metabolic equivalents (METs) while in a sitting or reclining posture.”⁶

The MET is a physiological measure expressing the energy cost of activities, against a reference to the metabolic cost of rest (i.e., $3.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ or $1 \text{ kcal}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$). Due to the lack of demand for recruitment of larger muscle groups, activities that require 1.0–1.5 METs are considered to be sedentary behaviors.⁷ The second element defining sedentary behavior is related to posture, and is based on previously published definitions that describe sedentary as muscular inactivity in sitting and reclining positions, rather than the absence of exercise *per se*.^{8,9} Static standing should not be considered sedentary behavior because a large proportion of the body's muscles are activated to initiate and maintain standing, and there are generally some nondescript movements, such as shifting or fidgeting.^{10,11} Recent findings demonstrate a strong negative association between time spent standing and the risk of mortality, supporting the notion that even light physical activity like standing is a potentially viable target for intervention.¹²

Despite the apparent advantages of this approach, any current definition of sedentary behavior for the general population may not be applicable to individuals with cerebral palsy (CP). The degree of neuromuscular deficits and mobility impairment is extremely variable among persons with CP, and there is likely heterogeneity in the energy expenditure and muscle activities between different levels of severity, even within similar postures.^{13,14} Children and adolescents with CP engage in prolonged periods of sedentary time,¹⁵ and have diminished capacity to participate in moderate to vigorous activities.¹⁶ In addition to the potential effectiveness of health-related physical activity in this population, an intuitive first-step out of chronic, sedentary lifestyles may be to focus simply on fragmenting sedentary time. An evaluation of the energy consumption and muscle activity profiles of

individuals with CP, during postures that are assumed to represent or approximate sedentary behavior (i.e., sitting and standing), would provide valuable information about their actual physiologic demand. The purpose of this study was to determine the energy expenditure and muscle activation during lying, sitting and standing, among individuals with CP with different levels of severity.

METHODS

This exploratory study focused on children, adolescents, and young adults with CP, between the ages of 4 and 20 years, who were classified at Gross Motor Function Classification System Expanded and Revised (GMFCS-E&R) levels I to V. The Institutional Review Board of the University Medical Center Utrecht approved the study.

Based on clinical examinations, pediatric physiatrists who worked in a school for special education referred suitable subjects. A total of 19 children and youth with spastic CP (five classified as having spastic unilateral CP, 14 as having spastic bilateral CP; 13 male, 6 female; age 4–20 years old) were recruited from the Mytylschool Ariane de Ranitz in Utrecht and their parents provided informed consent for participation in this study. All the children received rehabilitation services in The Netherlands at the time of participation. Eight children classified at GMFCS level I and II did not use any support for standing. The children classified at GMFCS level III, IV, and V used walking or standing frames to keep an upright position. Subject characteristics are provided in Table I.

Prior to the energy expenditure and electromyography (EMG) measurements, each child was weighed on electronic scales (Seca, Hamburg, Germany). Height measurements were taken on the same visit. The EMG electrodes were, on the basis of palpation, placed on eight large muscle groups, including: left and right quadriceps femoris; left and right biceps femoris; left and right gastrocnemius; and the left and right side of the erector spinae. A facemask, to measure oxygen consumption, was placed firmly around the mouth and nose.

After placement of the electrodes and the facemask, the child was asked to lie down in the supine position, on a comfortable treatment table. Each child's energy expenditure and muscle activity was measured during a standardized order of postures: (1) lying supine on a table; (2) sitting quietly on a chair with backrest; (3) sitting quietly on a chair without backrest; and (4) standing (with or without support). By using this order of testing, postures that require greater energy expenditures did not influence subsequent measures.

Measurement of energy expenditure and muscle activity for each posture started when the energy expenditure was stable for one minute (ie, not more than 2 ml/kg/min VO_2 difference). Thereafter, the measurement was performed for 5 minutes during lying, and for 2 minutes during sitting (with and without support) and standing. As a requirement for accurate measurements, energy expenditures had to reach a steady state prior to termination of the test. The measurement time for sitting and standing was only 2 minutes, because for children classified at GMFCS III–V, sitting without support and standing is difficult. The facemask and EMG electrodes remained in place during the measurement session.

Measures

GMFCS—A pediatric physical therapist experienced in evaluating the GMFCS-E&R^{17, 18} used the translated Dutch version to classify children and adolescents with CP, according to their functional ability. The GMFCS-E&R assesses activity limitations for gross motor function with a five-level ordinal grading scale. The GMFCS describes gross motor function of individuals with CP on the basis of self-initiated movement with an emphasis on sitting, walking, and wheeled mobility. Distinctions between levels are also based on the need for assistive technology, including hand-held mobility devices (walkers, crutches, etc.) or wheeled mobility. Individuals at “Level I” can generally walk without significant restrictions, but may experience limitations in advanced motor-related skills. Individuals at “Level V” are usually very restricted in their mobility, even with external assistive technology. Individuals at Level III are able to ambulate with an assistive device such as crutches or a walker. Individuals at Level IV are generally non-ambulatory, although they sometimes can walk short distances with walkers.

Energy Expenditure—Indirect calorimetry was used to assess the metabolic demand of different postures, and standing; it is noninvasive and accurate with high reproducibility.¹⁹ It is based on the indirect measure of the heat expended by nutrients oxidation, which is estimated by monitoring oxygen consumption (O₂) and carbon dioxide production (CO₂) for a given unit of time.^{19, 20}

Each measurement was completed at least two hours after a meal. The subjects wore a firmly fitted facemask attached to a calibrated mobile gas analysis system with a built-in gas analyzer, which allowed continuous gas analysis of cardiopulmonary variables throughout the test. The Cortex Metamax is a valid and reliable system for measuring ventilatory measures.^{21–23} The mobile gas analysis system consisted of a facemask, a transmitting unit (containing different oxygen and carbon dioxide gas analyzers), and a receiving unit. The transmitting unit with facemask and tubing (total weight 0.57 kg) was attached to the subjects with a harness, and the receiving unit was connected to a laptop computer located within 5 meters of the transmitting unit. Metabolic stress test software (Metasoft, Version 2.6) was used to measure minute ventilation, oxygen uptake (VO₂), and carbon dioxide production (VCO₂) every 10 seconds. Mean $\pm$ standard deviation VO₂ (ml/kg/min) were calculated for the last 5 minutes during lying, and during the last 2 minutes during sitting (with and without support) and standing. Energy expenditure, expressed in METs, was calculated as the mean VO₂ value during each condition divided by the mean VO₂ value during lying.

Muscle Activity—Muscle activity was measured at the same time as energy expenditure, using the “Porti” (TMS International), a surface EMG measurement device. Surface EMG is a reliable and valid way to measure muscle activity.²⁴ For this study the Porti was used as a stationary device. The device was connected with an optic fiber cable to a transmitter connected to a computer equipped with PortiLab software that makes it possible to record the measurements. The EMG electrodes (Kendall, Covidien, Germany) were connected to the Porti device with cables of a length up to 1 meter.

For individuals with CP, especially those classified at GMFCS levels III, IV and V, it is difficult or impossible to perform a maximal voluntary contraction (MVC). In order to normalize the muscle activity and compare the muscle activity of the children between the different GMFCS levels and postures, the muscle activity during rest (i.e. lying down) was used as a threshold for muscle inactivity. This threshold was calculated separately for each child.

Data Analyses

The data were analyzed using SPSS 21.0. The EMG data recorded from eight different muscle groups during four different postures were analyzed using Matlab. The “raw” signal was processed on the basis of the following 5 steps: (1) raw signal amplification: the EMG signal was recorded as the difference in voltage between two electrodes, which is a very weak signal; this signal needs to be amplified to be able to determine the burst during muscle contraction; (2) analog filtering: this has been done by a band pass filter and was applied to the raw signal before it was digitized; the band pass filter removes low and high frequencies from the signal; (3) analog to digital conversion: the analog EMG signal was converted to a digital signal by sampling; (4) digital high pass filter: this filter has been used to remove movement- and other artifacts; and (5) digital low pass filter: the rectified signal was low pass filtered, within the 5 – 100 Hz range.

The muscle activity per muscle group was expressed as the root mean square (RMS) of the total signal. The RMS is also known as the quadratic mean, and was used because of the positive and negative variants in the signal. The RMS value represents the average muscle activity over a period of time. The mean relative muscle activity, which is a measure of the relative percentage increase or decrease in muscle activity in relation to the rest measurement, was calculated for every child and averaged per posture (ie, lying, sitting with support, sitting without support and standing).

The muscle activity and energy expenditure of every child during rest was set as 1.0. Non-parametric test procedures were used due to the small sample size for each GMFCS level. Differences in muscle activity and metabolic demand for sitting with support, sitting without support, and standing compared with rest values were analyzed using the non-parametric Wilcoxon signed rank test. These analyses were performed for all GMFCS levels separately.

Partial correlation analyses were conducted to examine the independent association between the METs and RMS values in the different postures (sitting with and without support, and standing), adjusted for effect of age. For all statistical tests, a 95 % confidence interval (CI) was calculated and an alpha-value of less than 0.05 was considered statistically significant.

RESULTS

Thirteen boys and 6 girls completed the measurements without complications. Three children (one each from GMFCS levels II, IV and V) were not able to complete the metabolic testing due to discomfort. Three children (2 in GMFCS level IV and 1 in GMFCS level V) were not able to maintain the sitting without support position. The 95% CI of the

mean difference for each posture, compared with rest, and GMFCS level, are in Tables II and III.

Energy expenditure

Mean resting energy consumption was 9.0 ± 1.8 ml/kg/min for children 4–12 years old and 6.7 ± 1.1 ml/kg/min for children 13 years and older. For all GMFCS levels the average energy expenditure was higher than 1.5 METs (range 1.53–1.88 METs) during standing. The average values for individual children ranged from 1.33 to 1.88. For children classified at GMFCS level III all positions required significantly more energy consumption compared with rest (Table II).

Muscle activity

Table III provides the differences in muscle activity related to the postures. As can be seen muscle activation for postures with less support increased considerably, though not significantly. Only for children classified at GMFCS level III standing resulted in significantly greater muscle activation ($p < 0.05$) compared with rest.

In the Figure, distinctive characteristics of the four different postures are illustrated with EMG patterns as an index of local contractile activity of the quadriceps muscles. In the examples provided, the subjects were resting for 5 minutes and then were sitting with back support, sitting without back support and standing for 2 minutes, respectively.

After adjustment for age, the partial correlations between the relative METs and RMS values were positive, but not significant ($|r| = 0.14$ – 0.36 , $p > 0.05$).

DISCUSSION

The aim of this study was to investigate the physiologic demand associated with different postures among children and adolescents with spastic CP, with varying levels of mobility limitations. The primary findings revealed that energy expenditure was >1.5 METs during standing for all GMFCS levels, and therefore may be considered as a viable, introductory intervention to reduce sedentary behavior among children with CP.

There was no correlation between the muscle activity and the energy expenditure for different postures that approximate sedentary behavior. One explanation could be that not all muscles that were active during the different postures were measured. For example, the activity of abdominal muscles and hip abductors and hip adductors were not measured. These muscles are typically used to keep the body in an upright position. A second explanation could be that spasticity and involuntary movements require energy, and thus represent an additional source of energy expenditure above resting metabolic requirements. Many children with CP, and particularly those classified at GMFCS levels I and II, may not have involuntary movements during rest that would increase resting energy expenditure.^{25, 26} However, it remains to be determined if the involuntary muscle activity that might be present for children classified at GMFCS levels III–V contributes to a meaningful increase in energy expenditure.

Recent findings in typical development suggest that it may be important to interrupt regularly the contractile inactivity in postural muscles that takes place during prolonged sitting.^{27, 28} Most research in sedentary behavior has not evaluated muscle activity. As discussed by Verschuren et al¹³, especially for children with CP it is a very important component to understand. Because the mechanisms underlying the negative health consequences of prolonged sitting may be directly due to muscle inactivity, it is important to establish how much muscle activity is sufficient to attenuate these consequences. The contribution of non-exercise activity thermogenesis,²⁹ which includes fidgeting, spontaneous muscle contraction, and maintaining posture, may represent a greater proportion of daily energy expenditure among children with CP, than for typically developing peers. For individuals classified at GMFCS level III, there was a significant difference in muscle activity for sitting without support compared with rest. This finding suggests that sitting without support for children with this level of involvement is an achievable but challenging task. Further research is needed to determine whether the exertion required for these children to maintain sitting without support is functionally viable.

Children who were fully supported during standing (ie, children classified at GMFCS level V) showed a smaller increase in muscle activity compared with children who used an assistive device to keep an upright position (ie, children classified at GMFCS level III and IV). Interestingly, despite lower muscle activation, there was higher energy expenditure during standing for the child at GMFCS V, as compared with the other subgroups. This child also had less muscle activity but a higher MET value during sitting with support as compared with rest. These findings could indicate that other muscle groups (including trunk and upper extremity) were being used and contributed to higher energy expenditure. Further research with a larger sample and inclusion of EMG measurements of more muscle groups is needed to explore this possibility.

Sedentary behavior and physical activity are different constructs in the activity continuum, and may have independent effects on health.⁶ However, the optimal patterns of physical activity and sedentary behavior in children and youth with CP require further evaluation. Determining the potential health benefits between encouraging MVPA and reducing sedentary behavior is fundamental to understanding metabolic and health consequences. The current paradigm of physical activity and exercise used for children and youth with CP may need to be reframed, and the benefits of instituting strategies to replace sedentary behavior with activity need to be evaluated. Resolving the problem of excess sedentary behavior requires a sustained change in individual daily sedentary patterns. A reduction in sedentary behavior for children may be easier than increasing physical activity because there are fewer restrictions (i.e., no need to change clothing or use special equipment), and such can be attained with minimal time or energy, or risk for adverse outcomes. Although this is likely applicable for all children with CP, it is especially relevant for children classified at GMFCS levels IV and V, as reducing sedentary behavior might be the only viable intervention. However, several personal and environmental barriers to fitness and physical activity have been identified for children classified at GMFCS level I and II.³⁰ Among this group of children who are previously sedentary, the transition from inactivity to a lifetime of habitual health-related physical activity participation might be easiest by starting with simple fragmentation of sedentary behavior.

In general, interventions are more effective when focused on decreasing unhealthy behaviors rather than increasing healthy behaviors.³¹ Thus, interventions focused on decreasing sedentary behavior may be far more feasible and sustainable than merely imposing the current recommendations for increasing physical activity for children with CP. Interventions should focus not only on reducing or fragmenting sedentary time, but also on increasing light, moderate, and intense physical activity levels.¹³ The results of this study suggest that standing was light activity for children with CP. Designing and integrating standing work stations in classrooms and using standing desks or even standing frames that are easily applicable and not time consuming for children of all GMFCS levels may contribute to the accumulation of light activity. Time could be systematically allocated to regularly (2–3 minutes every hour) stand up or walk, rather than remaining stationary.

Our findings, however, must be interpreted in light of some limitations. The sample size is small, there was wide range of ages, and the subjects all had spastic CP. The results cannot necessarily be generalized to other clinical types of CP or adults with CP, such as dyskinetic or ataxic CP. The sample sizes across GMFCS levels were unequal and the larger sample in GMFCS level III may have contributed to the significant findings. Future research requires a larger sample size, smaller age-range and equal representation across the GMFCS levels. The large standard deviations in RMS-scores during different postures suggest large inter-individual variability in muscle activity. Whole room metabolic chambers could be used to estimate energy expenditure to increase the comfort level of the subjects. Finally, other muscle groups need to be evaluated to understand their contribution to the findings. There is variability in the physiologic and metabolic stimulus once support or posture is changed. Children and adolescents with spastic CP across all GMFCS levels had energy expenditures higher than 1.5 METs during standing. During sitting with or without support the energy expenditure was lower than 1.5 METs. Therefore, the energy expenditure factor (a person is sedentary when energy expenditure is $\leq$ 1.5 METs) and the posture factor (a person is sedentary while sitting or reclining) in the currently accepted definition of sedentary behavior are met in this sample of participants. Our findings related to energy expenditure suggest that changing children's position to a standing position may contribute to the accumulation of light activity and reduce sedentary behavior. This type of intervention is not typically provided to children with CP and merits evaluation.

Acknowledgments

Supported by the Phelps Foundation (PI: O.V.). M.P. is funded by the National Institutes of Health (1K01-HD074706).

We thank the subjects in this study.

List of abbreviations

CP cerebral palsy

References

1. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes*. 2007; 56:2655–2667. [PubMed: 17827399]
2. Ekelund U, Brage S, Froberg K, Harro M, Anderssen SA, Sardinha LB, Riddoch C, Andersen LB. Tv viewing and physical activity are independently associated with metabolic risk in children: The european youth heart study. *PLoS Med*. 2006; 3:e488. [PubMed: 17194189]
3. van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 australian adults. *Archives of internal medicine*. 2012; 172:494–500. [PubMed: 22450936]
4. Chau JY, Grunseit A, Midthjell K, Holmen J, Holmen TL, Bauman AE, Van der Ploeg HP. Sedentary behaviour and risk of mortality from all-causes and cardiometabolic diseases in adults: Evidence from the hunt3 population cohort. *Br J Sports Med*. 2013
5. Owen N, Leslie E, Salmon J, Fotheringham MJ. Environmental determinants of physical activity and sedentary behavior. *Exerc Sport Sci Rev*. 2000; 28:153–158. [PubMed: 11064848]
6. Sedentary Behaviour Research N. Letter to the editor: Standardized use of the terms “sedentary” and “sedentary behaviours”. *Appl Physiol Nutr Metab*. 2012; 37:540–542. [PubMed: 22540258]
7. Pate RR, O'Neill JR, Lobelo F. The evolving definition of “sedentary”. *Exerc Sport Sci Rev*. 2008; 36:173–178. [PubMed: 18815485]
8. Yates T, Wilmot EG, Khunti K, Biddle S, Gorely T, Davies MJ. Stand up for your health: Is it time to rethink the physical activity paradigm? *Diabetes research and clinical practice*. 2011; 93:292–294. [PubMed: 21507499]
9. Ekblom-Bak E, Hellenius ML, Ekblom B. Are we facing a new paradigm of inactivity physiology? *Br J Sports Med*. 2010; 44:834–835. [PubMed: 20133325]
10. Lanningham-Foster LM, Jensen TB, McCrady SK, Nysse LJ, Foster RC, Levine JA. Laboratory measurement of posture allocation and physical activity in children. *Med Sci Sports Exerc*. 2005; 37:1800–1805. [PubMed: 16260984]
11. Harris AM, Lanningham-Foster LM, McCrady SK, Levine JA. Nonexercise movement in elderly compared with young people. *Am J Physiol Endocrinol Metab*. 2007; 292:E1207–1212. [PubMed: 17401138]
12. Katzmarzyk PT. Standing and mortality in a prospective cohort of canadian adults. *Med Sci Sports Exerc*. 2014; 46:940–946. [PubMed: 24152707]
13. Verschuren O, Darrah J, Novak I, Ketelaar M, Wiart L. Health-enhancing physical activity in children with cerebral palsy: More of the same is not enough. *Phys Ther*. 2014; 94:297–305. [PubMed: 24092902]
14. Innes J, Darrah J. Sedentary behavior: Implications for children with cerebral palsy. *Pediatr Phys Ther*. 2013
15. Obeid J, Balemans AC, Noorduyn SG, Gorter JW, Timmons BW. Objectively measured sedentary time in youth with cerebral palsy compared with age-, sex-, and season-matched youth who are developing typically: An explorative. *Phys Ther*. 2014
16. Verschuren O, Takken T. Aerobic capacity in children and adolescents with cerebral palsy. *Res Dev Disabil*. 2010; 31:1352–1357. [PubMed: 20674266]
17. Palisano RJ, Rosenbaum P, Walter S. The development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol*. 1997; 39:214–223. [PubMed: 9183258]
18. Palisano RJ, Rosenbaum P, Bartlett D, Livingston MH. Content validity of the expanded and revised gross motor function classification system. *Dev Med Child Neurol*. 2008; 50:744–750. [PubMed: 18834387]
19. Schutz Y. The basis of direct and indirect calorimetry and their potentials. *Diabetes Metab Rev*. 1995; 11:383–408. [PubMed: 8718497]
20. Schroder JM. Ferritinopathy: Diagnosis by muscle or nerve biopsy, with a note on other nuclear inclusion body diseases. *Acta Neuropathol*. 2005; 109:109–114. [PubMed: 15645266]

21. Medbo JL, Mamen A, Elde BW, von Heimburg E, Stokke R. Examination of the metamax i and ii oxygen analysers during exercise studies in the laboratory. *Scand J Clin Lab Invest*. 2002; 62:585–598. [PubMed: 12564617]
22. Meyer T, Georg T, Becker C, Kindermann W. Reliability of gas exchange measurements from two different spiroergometry systems. *Int J Sports Med*. 2001; 22:593–597. [PubMed: 11719895]
23. Brehm MA, Harlaar J, Groepenhof H. Validation of the portable vmaxst system for oxygen-uptake measurement. *Gait Posture*. 2004; 20:67–73. [PubMed: 15196523]
24. Smoliga JM, Myers JB, Redfern MS, Lephart SM. Reliability and precision of emg in leg, torso, and arm muscles during running. *Journal of electromyography and kinesiology: official journal of the International Society of Electrophysiological Kinesiology*. 2010; 20:e1–9. [PubMed: 19850498]
25. Bell KL, Davies PS. Energy expenditure and physical activity of ambulatory children with cerebral palsy and of typically developing children. *Am J Clin Nutr*. 2010; 92:313–319. [PubMed: 20534743]
26. Johnson RK, Goran MI, Ferrara MS, Poehlman ET. Athetosis increases resting metabolic rate in adults with cerebral palsy. *J Am Diet Assoc*. 1996; 96:145–148. [PubMed: 8557940]
27. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, Shaw JE, Bertovic DA, Zimmet PZ, Salmon J, Owen N. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. *Diabetes Care*. 2012; 35:976–983. [PubMed: 22374636]
28. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: A randomized crossover trial. *Am J Clin Nutr*. 2013; 98:358–366. [PubMed: 23803893]
29. Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science*. 1999; 283:212–214. [PubMed: 9880251]
30. Verschuren O, Wiart L, Hermans D, Ketelaar M. Identification of facilitators and barriers to physical activity in children and adolescents with cerebral palsy. *J Pediatr*. 2012; 161:488–494. [PubMed: 22494875]
31. Kamath CC, Vickers KS, Ehrlich A, McGovern L, Johnson J, Singhal V, Paulo R, Hettinger A, Erwin PJ, Montori VM. Clinical review: Behavioral interventions to prevent childhood obesity: A systematic review and metaanalyses of randomized trials. *J Clin Endocrinol Metab*. 2008; 93:4606–4615. [PubMed: 18782880]

Figure.

Example of EMG data of the mm. quadriceps in children classified at GMFCS level I (a), III (b) and V(c) during 3 (lying, sitting with support and standing) or 4 (lying, sitting with support, sitting without support and standing) postures.

Table 1

Subject characteristics

	GMFCS I	GMFCS II	GMFCS III	GMFCS IV	GMFCS V
Number	4	4	6	3	2
Sex	4 male, 0 female	1 male, 3 female	4 male, 2 female	3 male, 0 female	1 male, 1 female
Age(y.m)	12.0 ±2.3	10.8 ±6.8	14.3 ±4.8	12.3 ±5.7	10.5 ±7.8
Weight(kg)	44.4 ±13.3	34.3 ±20.3	44.1 ±13.3	45.7 ±19.8	38.4 ±30.5
Height(cm)	152.3±13.6	132.0 ±31.3	149.8 ±16.4	142.7 ±19.7	141.5 ±36.1
BMI (kg/m ²)	18.7±3.1	18.2 ±3.9	19.1 ±2.6	21.8 ±5.9	17.0 ±6.4
BMI percentile	56.3±37.3	41.3±45.6	40.8±30.8	66.3±53.1	29.5±40.3
Type CP (uni/bi)	4/0	1/3	0/6	0/3	0/2

BMI percentile reference values were obtained from stature-for-age and weight-for-age data files from the Centre and Disease Control, respectively.

GMFCS= Gross Motor Function Classification System; BMI= Body Mass Index; uni=unilateral; bi=bilateral.

Table 2

Relative MET values for different postures for all GMFCS levels.

GMFCS	Rest	Sit with support		Sit without support		Standing	
		Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
I (n=4)	1.0	1.10 ± .10	-.06–.24	1.11 ± .17	-.16–.37	1.53 ± .04	.47–.60
II (n=3)	1.0	1.10 ± .09	-.12–.34	1.18 ± .15	-.20–.56	1.54 ± .19	.06–1.02
III (n=6)	1.0	1.21 ± .19*	.01–.42	1.33 ± .25*	.06–.59	1.60 ± .25*	.33–.87
IV (n=2)	1.0	1.03 ± .13	-1.77–1.24			1.70 ± .06 (with support ^d)	.83–1.22
V (n=1)	1.0	1.42	-			1.88 (with support ^d)	-

GMFCS= Gross Motor Function Classification System;

^a walking or standing frame;

^b standing frame;

* p<0.05 tested with raw data using the Wilcoxon signed-rank test

Table 3

Relative RMS values for all muscle groups for different postures.

GMFCS	Rest	Sit with support		Sit without support		Standing	
		Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
I (n=4)	1.0	.91 ± .21	-.43-.25	1.17 ± .58	-.75-1.10	2.35 ± 1.0	-.25-2.95
II (n=4)	1.0	1.10 ± .47	-1.10-1.26	1.68 ± 1.0	-1.88-3.24	5.64 ± 1.6	.68-8.62
III (n=6)	1.0	1.22 ± .70	-.51-.96	1.69 ± .73	-.08-1.46	4.76 ± 3.0*	.61-6.92
IV (n=3)	1.0	1.58 ± .46	-3.6-4.75			8.80 ± 2.6 (with support ^d)	-15.97-31.57
V (n=2)	1.0	.77 ± .57	-5.34-4.88			1.7 ± 1.4 (with support ^d)	-11.71-13.17

GMFCS= Gross Motor Function Classification System;

^a walking or standing frame;

^b standing frame;

* p<0.05 tested with raw data using the Wilcoxon signed-rank test