Motor Strategies in Standing Up in Children With Hemiplegia

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In spastic hemiplegia, the organization of whole body movements is impaired by deficient postural control. We studied segmental motor patterns involved in standing up from supine position in 15 children with spastic hemiplegic cerebral palsy and 14 unimpaired children using a visual analysis scale previously validated for developmental research. This approach examines specific movement patterns in upper limbs, axis, and lower limbs. We found that children with hemiplegia use movement patterns described in normal children but with reduced interindividual variability and a significant preponderance of asymmetric patterns. One previously undescribed stereotyped lower limb pattern was observed in two children with spastic hemiplegia. Emergence of these patterns is consistent with the referent body image theory. This approach can systematically characterize the limited repertoire of movement in patients with disorders of movement and posture and therefore contribute to a better understanding of motor control. The approach may guide management proposals with particular reference to variability and symmetry and might be used as a follow-up tool.

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Introduction

Hemiplegic cerebral palsy is mostly characterized by unilateral paresis and spasticity. Although children with hemiplegic cerebral palsy often acquire motor milestones within the late-normal range, their patterns of motor development differ from that of unimpaired children [1-3]. Because of unilateral weakness and variable pelvic stability, they often favor side-sitting and asymmetric prone shuffling. Whole-body motor tasks such as standing up [4] and walking [5] are achieved at greater physiologic cost, primarily supported by the unaffected leg which bears more of the body weight in the upright position. Quality of movements and efficiency is impaired in these children [4,5] who display less selective and more global whole-body movements.

Whole-body movements have been used to identify specific strategies of motor control involving changes in posture in children with cerebral palsy. Multisegmental analysis has been used to describe systematically movement patterns of children standing up from a supine position [6-8]. By means of this component analysis of movement, a developmental sequence of patterns can be described by segmenting body action into three regions: upper limbs, lower limbs, and axial region [6,7]. Use of this component method rather than a total body approach in qualitative movement analysis allows recording of intra- and interindividual variation both in the rate of development and across different body regions. From cross-sectional studies of unimpaired children and adults, a developmental sequence of movements for each body region has been obtained, validated for clinical research and across different ages [9]. A segmental score quantifies the final assessment (Table 1) made up of discrete variables. This score may reflect the developmental age of the child [9], with higher scores obtained by older children (Table 1). For example, younger children tend to stand up by rolling from a supine to a prone position before pushing up to a quadrupedal position, whereas older children often sit up from a supine position then move their shoulders forward to stand up, often displaying more symmetrical flexion and extension of head, shoulder girdle, trunk, and hips. In a previous study using this method, we demon-

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Table 1. Movement patterns for the task of rising from a supine position to a standing one*

	Segmental Score
Upper limb categories	
Push and reach to bilateral push	1
Push and reach–asymmetric push	2
Symmetric push	3
Symmetric reach	4
Push and reach followed by pushing on leg	5
Push and reach to bilateral push followed by pushing on leg	6
Axial categories	
Full rotation with abdomen down	1
Full rotation with abdomen up	2
Partial rotation	3
Forward with rotation	4
Symmetric	5
Lower limb categories	
Pike	1
Pike-jump to squat	2
Kneel	3
Jump to squat	4
Half-kneel	5
Asymmetric/wide-based squat	6
Narrow-based symmetric squat	7

* Adapted from Marsala and VanSant [7].

strated that children with leukomalacic spastic diplegia use patterns from the repertoire described for unimpaired children but with markedly reduced intra- and interindividual variability [8]. In the present study, our aim was to describe patterns used by children with hemiplegic cerebral palsy.

Materials and Methods

Patients

Children with hemiplegic cerebral palsy able to walk a distance greater than 5 meters unsupported and able to stand up from supine without assistance were selected from the neurology outpatient department of the Children's University Hospital Queen Fabiola. Fifteen children (8 female, 7 male) participated in the study. They were selected to match the age group and gross motor skills of a group of children with leukomalacic spastic diplegia previously studied according to the same protocol.

They were aged between 5 and 10 years (mean 7.3 $\pm$ 2.8). Ten children manifested right-sided hemiplegia. All were born at term except for three (26, 33, and 35 weeks' gestation). Antenatal etiology was documented in six patients, three with stroke in the middle cerebral artery territory and three with unilateral developmental brain malformations (polymicrogyria and extensive abnormal gyration/migration in two, left fronto-temporal porencephalic cysts in one). Six children had a history of perinatal hypoxic-ischemic insult with variable magnetic resonance imaging findings of unilateral porencephalic changes involving the internal capsule in four, additional ipsilateral basal ganglia in one, and periventricular gliosis with univentricular dilatation in another. In one child, left capsular infarct was related to refractory supraventricular tachycardia in early infancy. Two developed hemiplegia as a sequel of purulent meningitis (pneumococcal and tuberculous) at the age of 8 months and 12 months, respectively.

Acquisition of motor milestones was variable. Sitting unsupported was achieved by 9 months in eight children. Six children walked unaided by 18 months, five others did so by their second birthday, and the remaining four between their second and fifth birthday.

All school-aged children attend mainstream schooling, except for two who attend a special school for motor-impaired children. According to the Gross Motor Function Measure, all the children were graded level 1. This validated test of gross motor skill was developed specifically for clinical and research use in children with cerebral palsy [10]. Items in this test include simple tasks performed while lying, rolling, sitting, creeping, kneeling, standing, walking, running, and jumping. Quantification is based on the extent to which the child can realize the tasks independently without any reference to the quality of the performance. Scoring is adapted to age. For children aged between 5 and 10 years, level 1 corresponds to the ability to run and jump with impaired coordination and balance.

All children in the study group have regular neurodevelopmental physiotherapy (1 to 3 sessions per week). Informed consent was obtained from parents and therapists for participation in the study.

Normal Control Subjects

The control group consisted of 14 unimpaired age-matched children with normal development recruited from a school.

Spastic Diplegia

Comparison was made with previously reported findings in a group of 10 children aged between 5 and 11 years (mean 7.5 $\pm$ 2.0 years) with spastic diplegia associated with periventricular leukomalacia [8]. Eight were born prematurely, six at 28-30 weeks of gestation, and two at 31-32 weeks. These children also scored level 1 on the Gross Motor Function Measure.

Movement Recording

The motor task consisted of standing up quickly from a supine position following simple verbal instructions without prior visual demonstration. Each child was asked to perform 10 consecutive trials at intervals of a few seconds. All the children were able to comply with these instructions. A very high speed (VHS) video camcorder (Sony Hi 8) was used. The camera was placed along the longitudinal axis of the child, 2 m away from the center of the mat, on a tripod with adjustment of the zoom lens to maximize the size of the child while still providing a full view of the child and the mat. A VHS videotape player with stop-play mode and a television monitor were used. For the study group, filming took place before any scheduled physiotherapy sessions.

Data Analysis

The primary investigator and one other independent observer viewed the videotaped performances of the unimpaired and hemiplegic children (confounded) serially, three times each and independently of each other. Although the observers were blinded to the tapes, real blinding is hard to achieve, as hemiplegia is a clinical diagnosis. Observed movements of the upper limbs, axial region, and lower limbs were rated according to movement pattern categories (Table 1; Fig 1A, B). The first viewing was to observe and classify upper limb movement patterns exclusively. The second one was to view and classify axial region movements, and the third, lower limbs. This procedure were performed to lessen any bias that could arise if all the trials of a particular child were viewed consecutively (within-child rater bias). If an observed movement pattern could not be classified, it was described in detail. In a few cases of disagreement between the observers, the tape was then reviewed simultaneously and if a consensus could not be reached a third party (A.M.M.) was asked for her opinion; this only happened twice.

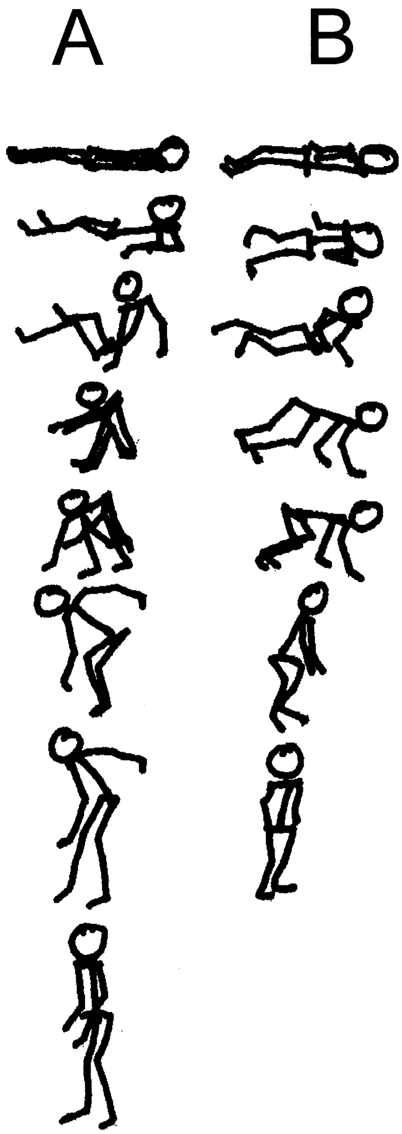

Figure 1. Sketched drawings illustrating typical patterns involved in standing up from supine. (A) "Push and reach–asymmetric push" upper limb pattern, "full rotation with abdomen down" axial pattern, "half-kneel" lower limb pattern. (B) "Push and reach to bilateral push" upper limb pattern, "full rotation with abdomen up" axial pattern, "pike-jump to squat" lower limb pattern.

For each trial, the score per body segment (upper limbs, axial region, lower limbs) was defined as a segmental score. The scoring system is made up of discrete variables, with higher scores reflecting more advanced developmental or chronological age [7,9]. For each child, the mean segmental score, calculated according to the total number of trials, was used for statistical analyses. A total of 900 segmental trials were analyzed, including 480 from the study group and 420 from control subjects. Wilcoxon test was applied to the two independent samples to characterize the variability of strategies or movement patterns and to study differences in mean segmental score. We used Spearman's coefficient of correlation to test if there was a correlation between age at the time of recording and mean segmental score. Interobserver reliability for this method has a high degree of consistency between observers with Kappa values >0.6 for each body segment [8].

Results

All segmental movement patterns were identifiable according to the revised description (Table 1), except for one lower limb pattern. Overall children with hemiplegia adopted a more global flexor attitude than control subjects. Standard deviations for mean segmental score revealed a greater spread in the control group than in the study group, with a high degree of statistical significance for upper limbs ($P < 0.01$) and lower limbs ($P < 0.001$) but not reaching significance for the axial region ($P > 0.05$). Overall Wilcoxon test indicates that the two groups constitute distinct populations ($P < 0.01$ for upper limbs and $P < 0.001$ for axial region and lower limbs).

Upper Limb Patterns

A significant excess ($P < 0.01$) of asymmetric patterns was observed in the study group (mean segmental score 2.1, S.D. 0.20), whereas control subjects preferentially used symmetric patterns (mean segmental score 2.7, S.D. 0.26). Children with hemiplegia used the upper limbs pattern "push reach with asymmetric push" (one arm pushing against the ground or an asynchronous pushing action) in over 65% of trials. This pattern, which features among strategies used by control subjects, is rarely observed beyond 4 years of age in normal individuals [6]. The other patterns used by children in the study group included "push and reach to bilateral push" and "push and reach followed by pushing on one leg".

Axial Patterns

Greater diversity was observed in the study group in the axial region compared with upper limb patterns. However, there was still a significant difference when compared with the control group ($P < 0.001$). In 55% of trials, children with hemiplegia used the pattern "forward with rotation". In $>$95% of trials, patterns involving rotation were used (mean segmental score 3.26, S.D. 0.29). With regard to unimpaired children, they only displayed the last two strategies as defined by Marsala and VanSant [7] (mean segmental score 4.4, S.D. 0.27), namely symmetric patterns that require anteroposterior weight transfer.

Lower Limb Patterns

A highly significant difference in lower limb strategies used by the two groups was also observed ($P < 0.001$). Two patterns were used preferentially in the study group: "half-kneel" and "asymmetric/wide-based squat" in over 75% of cases (mean segmental score 4.95, S.D. 0.18—values for described strategies in 13 patients). The other patterns included "pike" and a previously undescribed pattern observed in two patients (aged 5 and 10 years). As for the children without motor problems, only asymmetric/wide-based squat or symmetric/narrow-based squat strategies were used (mean segmental score 6.5, S.D. 0.22). The previously undescribed lower limb pattern consists of pronounced flexed position of the unimpaired arm used as a lever on the ground while the child flexes his/her unimpaired leg, bringing it toward the ipsilateral hip. The trunk is then flexed further forward, aligning it in the vertical axis. This stance is achieved with the child in a global attitude of flexion, with the head and neck flexed and eyes pointing toward the ground. The child then kneels on the unimpaired knee with an associated flexion-rotation of the trunk, while weight bearing on the unimpaired side. The affected arm is observed to rest on the ipsilateral flexed leg.

This procedure is followed by bilateral hip flexion. The head and neck gradually extend during completion of trunk extension until the child is fully upright.

Mean Segmental Score and Age

In the control group, correlation between age at the time of recording and mean segmental score of upper limbs ($P < 0.01$) and lower limbs ($P < 0.05$) was recorded, but not for axial region patterns. In the study group, correlation was demonstrated between age at the time of recording and mean segmental score of axial region patterns ($P < 0.01$) but not with lower limbs or upper limbs ($P > 0.05$).

Hemiplegic Cerebral Palsy and Leukomalacic Spastic Diplegia

No statistically significant differences between mean segmental score of upper limbs, axial region, and lower limbs of children with hemiplegia or diplegia were observed. However, differences between the two groups in variability of strategies were highly significant for all three body regions: upper limbs, axial region, and lower limbs ($P < 0.001$), with greater variability displayed by children with hemiplegia. Upper limbs asymmetric patterns predominated in the diplegic group (mean segmental score 1.8, S.D. 0.05) with "push reach to bilateral push" used in over 85% of trials [8].

Discussion

This study demonstrates that children with hemiplegic cerebral palsy stand up from a supine position using general patterns of movement, including those described in toddlers and children [6,7], but with reduced interindividual variability compared with age-matched unimpaired children, and with a significant preponderance of asymmetrical patterns with systematic support on the unaffected side. A previously undescribed lower limb movement pattern was also observed in 2 of the 15 children with hemiplegia. Although most of these observations could be expected in the context of hemiplegic cerebral palsy, the lower prevalence of asymmetric postures in the hemiplegic group compared with the group with leukomalacic spastic diplegia raises specific questions pertaining to motor control.

Within the musculoskeletal system, group behaviors of joints acting together as if they were a single element can be identified so as to be incorporated into simple templates dealing with a reduced number of control targets [11]. Such templates can be described using the present multisegmental approach. This method has been used to address motor control issues in relation to changes in posture in unimpaired patients and patients with bilateral motor impairment, for example, leukomalacic spastic diplegia [8], Down's syndrome [12], and Angelman's syndrome [13]. In multijoint movements, hence in whole-body movements, the motor control redundancy problem [14] can be partially solved through joint locking or stiffening, as demonstrated by the children with hemiplegia who adopted more global flexor attitudes. This strategy, which is part of the limited repertoire of patients with hemiplegic cerebral palsy, also simplifies the motor transformation of body position necessary for the control of movement and equilibrium. Dynamic equilibrium depends on postural steadiness itself related to mobility of postural chains [15], whereas static equilibrium is ensured by maintaining a wide base of support (see three-point ground contact). Compensatory postural behavior during standing up was observed in both normal control subjects and children in the study group. However, the movements were of larger magnitude in the latter and resulted in a wider base of support, as previously observed in locomotion [5].

Through a series of adaptive body changes involving active biomechanical stabilization of the body axis, children are able to stand up from supine [4]. Such axial righting or alignment reactions are more difficult in hemiplegic cerebral palsy [16]. Nonetheless, our studies revealed asymmetric postures to be less prevalent in the hemiplegic group than in children with leukomalacic spastic diplegia. Symmetric upper limb patterns were present in up to 25% of younger children with hemiplegia. This apparent discrepancy could be explained by the referent body image theory [17]. In this theory, the nervous system produces inverse dynamic computations of muscle forces based on the desired kinematics and then specifies these forces to produce the movement. All sensory afferent information is integrated into a virtual geometrical image of the body. This image then serves as a reference not only for the kinesthetic perception of the body but also for the active control of posture and movement. As the referent body image is centered on the body axis, diminished axial righting control in patients with leukomalacic spastic diplegia [18] could explain the higher tendency for asymmetric patterns (85% of trials for upper limbs). Relatively better axial control in hemiplegic cerebral palsy thus allows greater variability and the emergence of symmetric proximal limb movements around the axis as compared with bilateral cerebral palsy [16]. This tendency toward symmetrization can be interpreted as part of adaptive functional rearrangements [19].

The greater diversity in strategies adopted by hemiplegic children than children with spastic diplegia reached a high degree of significance ($P < 0.001$ for upper limbs, axial region, and lower limbs), although this remained less than in unimpaired children. No difference was observed in relation to the etiology of hemiplegia, but this may be the result of a small sample size.

These results confirm that an observational study of postural organization in a fundamental movement skill can contribute to a better understanding of modular postural control. The finding of greater emergence of symmetric upper limb patterns in hemiplegic cerebral palsy than in spastic diplegia supports the importance of control of movements around the axis. These findings may help in treatment options such as neurodevelopmental therapy, where a functional approach regarding movement variability is adopted [1]. Righting and axial control is also important in this therapy to favor coordination and symmetrical movements around the axis. The finding of previously undescribed alternative patterns in these two groups of children with cerebral palsy supports the fact that this visual analog scale should remain an open evaluation system. This noninvasive approach could also be used as an instrument for clinical studies to evaluate change over time. Compared with computerized kinematic analysis, it is more easily accessible, less costly both in terms of equipment and time, requires less expertise, and is a reliable qualitative movement analysis tool.

References

[1] **Bobath** B, Bobath K. Hemiplegia. Motor development in the different types of cerebral palsy. London: Heinemann Medical Books, 1975:42-57.

[2] **Scrutton** D, Rosenbaum P. The locomotor development of children with cerebral palsy. In: Connolly KJ, Forssberg H, editors. Neurophysiology and neuropsychology of motor development. London: MacKeith Press and Cambridge University Press, 1997:116-34.

[3] **Yokochi** K, Yokochi M, Kodama K. Motor function of infants with spastic hemiplegia. Brain Dev 1995;17:42-8.

[4] **Park** ES, Park C, Lee HJ, Kim DY, Lee DS, Cho S-R. The characteristics of sit-to-stand transfer in young children with spastic cerebral palsy based on kinematic and kinetic data. Gait and Posture 2003;17:43-9.

[5] **Jeng** SF, Holt KG, Fetters L, Certo C. Self-optimization of walking in nondisabled children and children with spastic hemiplegic cerebral palsy. J Mot Behav 1996;28:15-27.

[6] **VanSant** AF. Age differences in movement patterns used by children to rise from a supine position to erect stance. Phys Ther 1988;68:1330-8.

[7] **Marsala** G, VanSant AF. Age-related differences in movement patterns used by toddlers to rise from a supine position to erect stance. Phys Ther 1998;78:149-59.

[8] **Mewasingh** LD, Demil A, Christiaens FJC, Missa A-M, Cheron G, Dan B. Motor strategies in standing up in leukomalacic spastic diplegia. Brain Dev 2002;24:291-5.

[9] **VanSant** AF. Life-span motor development. In: Lister MJ, ed. Contemporary management of motor control problems: Proceedings of the II Step Conference. Alexandria, VA: Foundation for Physical Therapy, 1991:77-84.

[10] **Palisano** RJ, Rosenbaum PL, Walters SD, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. Dev Med Child Neurol 1999;39:214-23.

[11] **Full** RJ, Koditschek DE. Templates and anchors: Neuromechanical hypotheses of legged locomotion on land. J Exp Biol 1999;202: 3325-32.

[12] **Unrau** K, Hanrahan SM, Pitetti KH. An exploratory study of righting reactions from a supine to a standing position in adults with Down syndrome. Phys Ther 1994;74:1116-24.

[13] **Esposito** D, Demil A, Missa A-M, Christiaens F, Dan B. Segmental motor patterns for standing up from the supine position in Angelman Syndrome. 1st world conference of the International Angelman Syndrome Organisation, July 4-8, 2000, Tempere, Finland.

[14] **Bernstein** NA. The co-ordination and regulation of movements. Oxford: Pergamon Press, 1967.

[15] **Kantor** E, Poupard L, Le Bozec S, Bouisset S. Does body stability depend on postural chain mobility or stability area? Neurosci Lett 2001;308:128-32.

[16] **Hadders-Algra** M, van der Fits IB, Stremmelaar EF, Touwen BC. Development of postural adjustments during reaching in infants with CP. Dev Med Child Neurol 1999;41:766-76.

[17] **Feldman** AG, Archambault P, Lestienne FG. Multi-muscle control is based on the specification of referent body image. In: Gantchev GN, Mori S, Massion J, editors. Motor control, today and tomorrow. Sofia, Bulgaria: Drinov Academic Publishing House, 1999:163-79.

[18] **Dan** B, Bouillot E, Bengoetxea A, Boyd SG, Cheron G. Distinct multi-joint control strategies in spastic diplegia associated with prematurity or Angelman syndrome. Clin Neurophysiol 2001;112:1618-25.

[19] **Carr** LJ, Harrison LM, Evans AL, Stephens JA. Patterns of central motor reorganization in hemiplegic cerebral palsy. Brain 1993; 116:1223-47.