Validation of a Model of Gross Motor Function for Children With Cerebral Palsy

Background and Purpose. Development of gross motor function in children with cerebral palsy (CP) has not been documented. The purposes of this study were to examine a model of gross motor function in children with CP and to apply the model to construct gross motor function curves for each of the 5 levels of the Gross Motor Function Classification System (GMFCS). Subjects. A stratified sample of 586 children with CP, 1 to 12 years of age, who reside in Ontario, Canada, and are known to rehabilitation centers participated. Methods. Subjects were classified using the GMFCS, and gross motor function was measured with the Gross Motor Function Measure (GMFM). Four models were examined to construct curves that described the nonlinear relationship between age and gross motor function. Results. The model in which both the *limit* parameter (maximum GMFM score) and the *rate* parameter (rate at which the maximum GMFM score is approached) vary for each GMFCS level explained 83% of the variation in GMFM scores. The predicted maximum GMFM scores differed among the 5 curves (level I=96.8, level II=89.3, level III=61.3, level IV=36.1, and level V=12.9). The rate at which children at level II approached their maximum GMFM score was slower than the rates for levels I and III. The correlation between GMFCS levels and GMFM scores was −.91. Logistic regression, used to estimate the probability that children with CP are able to achieve gross motor milestones based on their GMFM total scores, suggests that distinctions between GMFCS levels are clinically meaningful. Conclusion and Discussion. Classification of children with CP based on functional abilities and limitations is predictive of gross motor function, whereas age alone is a poor predictor. Evaluation of gross motor function of children with CP by comparison with children of the same age and GMFCS level has implications for decision making and interpretation of intervention outcomes. [Palisano RJ, Hanna SE, Rosenbaum PL, et al. Validation of a model of gross motor function for children with cerebral palsy. *Phys Ther.* 2000;80:974–985.]

Key Words: *Cerebral palsy, Children, Classification, Gross motor function, Model, Motor development.*

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Although the natural history of development of children with cerebral palsy (CP) has been described anecdotally and there is evidence that "severity" of CP is related to motor outcome,[1–5] development of gross motor function (eg, the ability to sit, stand, walk, and climb stairs) in children with CP has not been documented. This lack of documentation is surprising given the number of health care professions that have a role in the management of children with CP, the number of interventions that have been advocated, and the cost of care for a person with a lifelong disability. Furthermore, some medical and therapeutic interventions (both conventional and alternative) may have adverse effects and place considerable demands on family and health care resources.[6–8] The gross motor function of children with CP and outcomes of intervention often have been evaluated using measures normed on children without motor impairments,[9,10] a practice that has been questioned.[11] Professionals also rely heavily on personal experience in

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addressing parental concerns about a child's prognosis for gross motor function.[12] Reliance on personal experience can create a situation in which parents receive conflicting information. A more meaningful approach would be to make management decisions and evaluate intervention outcomes based on expectations for children with CP of the same age and gross motor function.

The prognosis for gross motor function in children with CP is highly variable.[1,13] Attempts to document development of gross motor function have been hampered by the lack of a standardized system for classifying children with CP based on abilities and limitations in gross motor function.[14–17] To address this need, the Gross Motor Function Classification System (GMFCS) was developed (Appendix).[18] The GMFCS is based on the concepts of abilities and limitations in gross motor function and is analogous to the staging and grading systems used in medicine to describe cancer. We believe that this approach to classification can enhance communication among professionals and families with respect to: (1) utilization of rehabilitation services, (2) the creation of databases and registries, and (3) comparison and generalization of the results of program evaluations and clinical research. The GMFCS is designed for children with CP who are 12 years of age or younger. The system has 5 levels that are based on differences in self-initiated movement, with particular emphasis on sitting and walking. The results of nominal group process and Delphi survey consensus methods involving 48 experts provided evidence of content and construct validity of data obtained with the GMFCS, including a judgment that the 5 levels represent differences in gross motor function that are meaningful to children's everyday lives.[18]

Our research report describes the first phase of a prospective longitudinal study of the development of gross motor function in children with CP. Using cross-sectional data from an initial assessment, the objectives of this study were: (1) to formulate a model to describe the gross motor function of children with CP, (2) to apply the model to construct a gross motor function curve for each of the 5 levels of the GMFCS, (3) to examine differences in the limit of gross motor function and rate of improvement in gross motor function among the 5 curves, and (4) to further validate the GMFCS data by examining the relationship between classification levels and measured gross motor function.

Method

Subjects

Subjects were selected from 18 of the 19 regional children's treatment centers in the Ontario Association of Children's Rehabilitation Services (OACRS) in Ontario, Canada, as well as one additional pediatric facility. Children were eligible if a diagnosis of CP had been made by a pediatrician, pediatric neurologist, or orthopedic surgeon or if CP was strongly suspected by the physical therapist based on examination of a child's posture and movement and the presence of neuromuscular impairments. The definition of CP proposed by Bax[19] was used in this study. Children were excluded from the study if they had other neuromotor disorders (eg, spina bifida) or a neuromuscular or musculoskeletal disease (eg, muscular dystrophy, other myopathy). Children also were excluded if they had received selective dorsal rhizotomy surgery, intrathecal baclofen, or botulinum toxin injections in the lower limbs prior to study recruitment, because, in our opinion, these interventions potentially alter gross motor function.

Our objective was to obtain a random sample of children with CP from the caseload lists of rehabilitation centers in the province of Ontario, stratified by age (birth year) and level of gross motor function (GMFCS level). Each of the rehabilitation centers compiled a list of eligible children from their caseload as of June 1996. It was not possible to use simple random sampling because GMFCS levels were not available for all children prior to subject selection. Therefore, a sampling strategy was developed to provide all children who met the eligibility criteria with an equal chance of being selected to participate in the study. For each birth year, a certain number of children with known GMFCS levels were selected, and then a quota of children whose GMFCS levels were not yet known were selected. Several rounds of selection were needed in order to meet sample size targets in each stratum (birth year-GMFCS level combinations). Subjects were not stratified by center; therefore, the probability that a child from a given center was selected is proportional to the number of children in the caseload of that center.

The subjects were 586 children with CP who were participating in an ongoing longitudinal study of development of gross motor function. The children ranged in age from 1 to 12 years, with a mean age of 6.5 years (SD=2.8). The sample consisted of 326 boys (56%) and 260 girls (44%). Of the 586 subjects, 561 (96%) had a diagnosis of CP at entry into the study and 25 (4%) were judged by the assessing therapist to have motor impairments and movement patterns consistent with a diagnosis of CP, although they had not been formally diagnosed. Information about type and distribution of CP for the children with a definitive diagnosis is provided in Tables 1 and 2. The children were fairly evenly distributed among the 5 levels of the GMFCS, with the highest number of children classified at level I and the lowest number classified at level II. The lower number of children classified at level II occurred because some children classified at level II prior to entry into the study

Table 1.
Type of Cerebral Palsy for Children With a Diagnosis of Cerebral Palsy (N=553)[a]

Type	Frequency	Percentage
Spastic	430	78
Mixed type	53	10
Dystonic/athetotic	34	6
Hypotonic	23	4
Ataxic	12	2
Missing	1	
Total	553	100

[a] N=553 based on the group of children with a formal diagnosis of cerebral palsy only.

Table 2.
Distribution of Motor Impairment for Children With a Diagnosis of Cerebral Palsy (N=553)[a]

Distribution	Frequency	Percentage
Quadriplegia	228	41
Diplegia	180	33
Hemiplegia	83	15
Triplegia	54	10
Missing	8	1
Total	553	100

[a] N=553 based on the group of children with a formal diagnosis of cerebral palsy only.

were subsequently classified at level I at the time of initial assessment for our study. The gross motor function of the children was classified on the GMFCS at the first study assessment as follows: 166 (28%) were classified at level I, 74 (13%) were classified at level II, 110 (19%) were classified at level III, 121 (21%) were classified at level IV, and 115 (19%) were classified at level V.

Measures
The GMFCS was used to classify each child's level of gross motor function (Appendix). A classification is made by determining which of the 5 levels best corresponds to the child's abilities and limitations in gross motor function in home, school, and community settings. The description for each level is broad and is not intended to describe all aspects of gross motor function. For each level, separate descriptions are provided for children in the following age bands: less than 2 years, 2 to 4 years, 4 to 6 years, and 6 to 12 years. Distinctions between GMFCS levels are based on functional limitations, the need for assistive mobility devices (walkers, crutches, canes) or wheeled mobility, and, to a lesser extent, quality of movement. The GMFCS scores are ordinal, with no assumption that the distances between levels are equal or that children with CP are equally distributed among the 5 levels.

Interrater reliability of data obtained with the GMFCS has been examined by Palisano et al[18] and Wood and Rosenbaum.[20] Wood and Rosenbaum[20] reported an interrater reliability value (generalizability quotient [G]) of .93 between 2 raters who independently classified 85 children at 4 ages from blinded chart review. In the study by Palisano et al,[18] 51 physical therapists and occupational therapists worked in pairs to classify independently the gross motor function of 77 children with CP. Kappa values for agreement beyond chance were .55 for children less than 2 years of age and .75 for children 2 to 12 years of age. The therapists in the current study did not receive formal training in use of the GMFCS. Rather, following the procedure used by Palisano et al,[18] the therapists were instructed to read carefully the description for each level of the GMFCS and to classify children independently based on their knowledge of a child's motor abilities or their observation of the child's motor abilities, or both.

The Gross Motor Function Measure (GMFM) was administered to measure gross motor function quantitatively. The GMFM is a criterion-referenced measure constructed for the purpose of evaluating change in gross motor function in children with CP.[21,22] The GMFM consists of 88 items grouped into 5 dimensions: (1) lying and rolling (17 items), (2) sitting (20 items), (3) crawling and kneeling (14 items), (4) standing (13 items), and (5) walking, running, and jumping (24 items). The GMFM takes approximately 45 minutes to administer. All items generally can be completed by age 5 years in children without motor delays.[22] The GMFM is scored by observation of a child's performance on each item. Items are scored on a 4-point ordinal scale. Scores for each dimension are expressed as a percentage of the maximum score for that dimension. A total score is obtained by adding the scores for all dimensions and dividing by 5 (ie, the total number of dimensions). Each dimension, therefore, contributes equally to the total score. The GMFM total scores can range from 0 to 100. The reliability, validity, and responsiveness of the GMFM scores are documented for children with CP[21,23,24] and are considered by us to be acceptable.

Procedure
The GMFM was administered by 115 therapists (104 physical therapists, 10 occupational therapists, and 1 kinesiologist). Prior to administration of the GMFM, all therapists were trained to administer and score the GMFM and tested to ensure that they reached a high level of agreement (weighted kappa >.80) against a criterion test videotape.[25] The therapist who performed the testing was not always the therapist who provided services to the child. Of the 113 therapists for whom we have complete information, the therapists' mean years

of experience providing services to children with CP was 9.7 years (SD=7.3) and varied from less than 1 year to 38 years.

Each child was classified using the GMFCS and administered the GMFM following standardized procedures. Of the 586 GMFM assessments, 468 (80%) were completed in 1 session, 117 (20%) were completed in 2 or more sessions, and the number of sessions was not reported for one subject. Testing was completed within 1 week for 82 (70%) of the assessments that were administered in more than 1 session. The mean time for administration of the GMFM was 62 minutes (SD=27) and varied from 10 to 210 minutes. A child's age and severity of motor impairment and whether items in the standing and the walking, running, and jumping dimensions were assessed both with and without orthoses or walking aids contributed to the variability in the time needed to administer the GMFM.

Data Analysis

Building a developmental model of gross motor function. A hierarchical strategy of model building was used. First, we developed a base model to describe the nonlinear relationship between age and gross motor function among children with CP. At subsequent stages of model building, GMFCS level was included in the model to test the degree to which the relationship between age and gross motor function differs by children's GMFCS level.

The base model assumes that, at birth, infants are unable to perform items on the GMFM (GMFM score of 0). Based on previous data, we also assumed that the gross motor function of children with CP improves most rapidly during infancy and early childhood, with the rate of improvement slowing as children become older and approach their potential for gross motor function (maximum GMFM score).[18,26] Thus, the base model, in our opinion, must express both the upper limit of gross motor function and the progress toward this limit at any given age (ie, the rate of development). The equation for the nonlinear model is:

(1) $GMFM = limit(1 - \exp[-rate \times age])$

In this model, *GMFM* is the predicted GMFM score as a nonlinear function of a child's *age* (in months). The *limit* parameter expresses the asymptote or maximum GMFM score that children with CP will approach as they reach their potential for gross motor function. The *rate* parameter is an index of the rate at which children approach the limit of their gross motor function. The larger the value of *rate,* the faster children approach their maximum gross motor function. As in ordinary linear regression, the data are used to compute estimates of these

parameters, but special estimation techniques are required for nonlinear models such as that shown in equation 1. For a description of standard estimation procedures suitable for nonlinear models, see Bates and Watts.[27]

Equation 1 assumes that all children with CP have similar limits of gross motor function and rates of development (model 1). We hypothesized that this model would be inadequate because it does not account for differences in gross motor function among children with CP. In subsequent refinements of the model, we tested the differences in the *limit* and *rate* parameters among GMFCS levels. In 2 exploratory models, GMFCS levels were hypothesized to affect either the *limit* or *rate*, but not both. In model 2a, children at different GMFCS levels are hypothesized to differ in their limit of gross motor function but have a similar rate of development. By contrast, in model 2b, children at different GMFCS levels are hypothesized to have similar limits of gross motor function but different rates of development. In the "full" model (model 3), children at different GMFCS levels were assumed to differ in both their limit of gross motor function (*limit*) and the rate at which they approach their limit of gross motor function (*rate*).

We evaluated the 4 models (1, 2a, 2b, and 3) by comparing the size of their residuals. As with linear regression or analysis of variance, the residuals from these nonlinear regressions are an index of the amount of variability in observed GMFM scores that is *not* explained by the model (unexplained variance). That is, the residuals are a measure of how well the models fit the data, such that the model having the smallest residuals provides the best fit. Because the models are "nested," so that each successive model incorporates the one before it, the changes in residuals from one model to the next were evaluated using standard F tests.[28]

Following the selection of the best-fitting model, standard procedures for coding categorical predictors in regression[27–30] were used to provide *t* tests of the differences in *limit* and *rate* parameters between adjacent GMFCS levels.

Interpretation of motor curves. The interpretation of the gross motor function curves from the previous analyses depends somewhat on understanding the meaning of GMFM scores. The GMFM is a criterion-referenced measure. A perfect score (ie, 100) reflects successful performance of all 88 items of the GMFM. To facilitate the interpretation of scores below 100, analyses were performed to illustrate how GMFM total scores are related to the likelihood of successfully performing key gross motor functions, as measured by items on the GMFM. Sixteen items that represent gross motor func-

Table 3.
Gross Motor Function Measure[21,22] (GMFM) Total Scores at Which Children With Cerebral Palsy (N=586) Are Estimated to Achieve Specific Gross Motor Functions in Order of Difficulty

GMFM Item and Score(s)	Gross Motor Skill	GMFM Total Score at Which the Chance of Passing Is	
		50%	95%
(#8 or #9=3)	From supine, can roll prone to right or left side	18.8	46.1
(#24=3)	From sitting, can maintain sitting position with arms free for 3+ seconds	23.5	41.7
(#34=2 or 3)	From sitting on a bench, can maintain sitting position with arms free but feet supported for 10+ seconds	29.8	54.3
(#67=3)	From standing, can walk forward 10+ steps with hands held	40.8	63.6
(#44=3)	From 4-point, can crawl or hitch 6+ feet	43.6	61.4
(#45=3)	From 4-point, can crawl reciprocally 6+ feet forward	53.6	75.5
(#36=3)	From the floor, can sit on a bench	55.6	68.6
(#35=3)	From standing, can sit on a bench	56.1	72.0
(#56=2 or 3)	From standing, can maintain standing for 3+ seconds with arms free	66.5	86.8
(#69=3)	From standing, can walk forward 10+ steps with arms free	69.6	87.0
(#59=3)	From sitting on a bench, can stand with arms free	71.8	88.7
(#84=1, 2, or 3)	From standing, can walk up 2+ steps, same foot leading, while holding one rail	71.4	87.7
(#70=3)	From standing, can walk 10 steps, turn and walk back	72.0	87.3
(#77=3)	From standing, can run 15 feet, stop and run back	83.7	98.8
(#81=2 or 3)	From standing, can jump foward 2+ inches with both feet simultaneously	85.3	98.2
(#86=1, 2, or 3)	From standing, can walk up 2+ steps, same foot leading, with arms free	86.6	97.8

tions that we believe are meaningful for the daily activities of children with CP were selected for analysis (Tab. 3). The raw score for each of the selected items was recoded as achieved or not achieved based on the criteria presented in Table 3. Logistic regression was used to estimate the probability that children with CP are able to achieve each gross motor function based on their GMFM total scores. The resulting regression equations were then used to compute the GMFM total score at which children were estimated to have a 50% and 95% probability of achieving each gross motor function. Thus, these analyses are oriented to interpreting GMFM scores by addressing questions such as "At what GMFM score is a child probably (50%) or almost certainly (95%) able to sit up, walk 10 steps, etc?"

Relationship between the GMFCS and GMFM. The relationship between the GMFCS and the GMFM, with and without adjustment for children's age, was analyzed using a Pearson correlation (r) and partial correlation (pr), respectively.

Results

Validity of Scores for the Model of Gross Motor Function
The residual sums of squares for the 4 models that were examined are presented in Table 4. Model 1, the base model, is a description of the average gross motor function between birth and 12 years of age for all 586 children in the sample. The predicted motor curve for model 1 is illustrated in Figure 1, along with the observed values. Figure 1 illustrates that age alone is a poor predictor of gross motor

Table 4.
Model Residuals for Four Nested Nonlinear Models of Gross Motor Function

Model Parameters	df	Residual SS	Residual MS
Model 1: base model; *limit* and *rate* do not vary by GMFCS[a]	584	589491.9	1009.40
Model 2a: *limit* varies by GMFCS; *rate* is constant for all GMFCS levels	580	74859.1	129.07
Model 2b: *limit* is constant for all GMFCS levels; *rate* varies by GMFCS	580	101530.5	175.05
Model 3: full model; both *limit* and *rate* vary by GMFCS	576	73124.7	126.95

[a] GMFCS=Gross Motor Function Classification System.[18]

function in children with CP, given the enormous variability around the plotted curve.

The results of incorporating GMFCS levels into the model also are reported in Table 4. Model 3 is the full model, in which we assume that children with different GMFCS levels differ in both their limit of gross motor function (*limit*) and rate of development (*rate*). Compared with model 1, there is a 87.5% reduction in the residual sum of squares (the amount of variability in GMFM scores that is not explained by the model) for model 3 (F=508.43; df=8,576; P<.0001). Model 3 also fits the data better than does model 2a, which assumes that children with different GMFCS levels vary in the
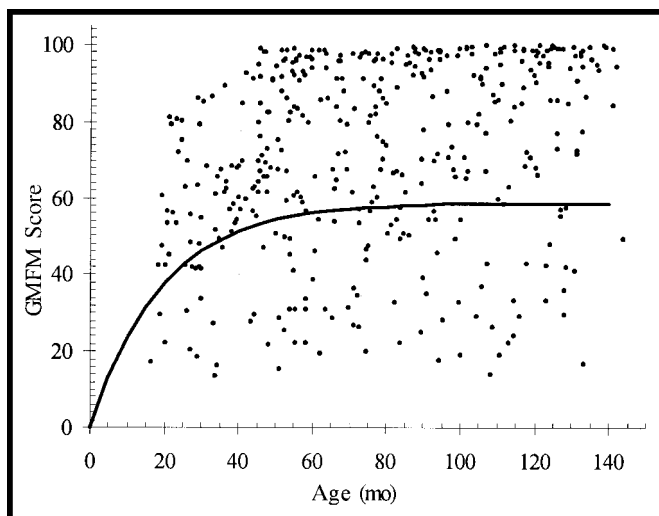
Figure 1.
Gross Motor Function Measure[21,22] (GMFM) scores as an exponential function of age for the complete sample (N=586).

Figure 2.
Gross Motor Function Measure[21,22] (GMFM) scores as an exponential function of age, by Gross Motor Function Classification System[18] level, with n=166 in level I, n=74 in level II, n=110 in level III, n=121 in level IV, and n=115 in level V.

Table 5.
Pair-wise Comparisons of the Difference in *Limit* and *Rate* Parameters Between Adjacent Gross Motor Function Classification System[18] (GMFCS) Levels (Model 3)

	Estimate (±95% Limit)
Average *limit* in whole sample	59.26 ± 1.58^{a}
Difference in *limit*, GMFCS level I vs level II	7.49 ± 6.07^{b}
Difference in *limit*, GMFCS level II vs level III	28.04 ± 6.19^{b}
Difference in *limit*, GMFCS level III vs level IV	25.23 ± 4.05^{b}
Difference in *limit*, GMFCS level IV vs level V	23.19 ± 4.17^{b}
Difference in *rate*, GMFCS level I vs level II	0.016 ± 0.009^{b}
Difference in *rate*, GMFCS level II vs level III	-0.023 ± 0.017^{b}
Difference in *rate*, GMFCS level III vs level IV	0.003 ± 0.3
Difference in *rate*, GMFCS level IV vs level V	-0.002 ± 0.07

^{a} Average is different than 0, $P<.05$, 2-tailed t test.
^{b} Difference is different than 0, $P<.05$, 2-tailed t test.

limit of their gross motor function but not in their rate of development (F=3.42; df=4,576; $P<.01$). Finally, model 3 fits the data better than does model 2b, which assumes that children of different GMFCS levels have the same limit of gross motor function but vary in their rate of development (F=55.94; df=4,576; $P<.0001$). From these analyses, we concluded that GMFCS level affects both the limit of gross motor function and the rate of development (model 3). In model 3, GMFCS levels account for 83% of the (mean corrected) variation in GMFM scores (ie, the coefficient of determination [r^2]).

As derived from model 3, the equations describing the gross motor function curve for each of the GMFCS levels, with 95% confidence intervals (CIs) for the predicted *limit* and *rate* parameters, are:

(2) GMFCS I: *GMFM=*

$$(96.8 \pm 2.6) \ (1 - \exp[-(.0478 \pm .0069) \times age])$$

(3) GMFCS II: *GMFM=*

$$(89.3 \pm 5.5) \ (1 - \exp[-(.0316 \pm .0064) \times age])$$

(4) GMFCS III: *GMFM=*

$$(61.3 \pm 2.9) \ (1 - \exp[-(.0541 \pm .0156) \times age])$$

(5) GMFCS IV: *GMFM=*

$$(36.1 \pm 2.9) \ (1 - \exp[-(.0506 \pm .0253) \times age])$$

(6) GMFCS V: *GMFM=*

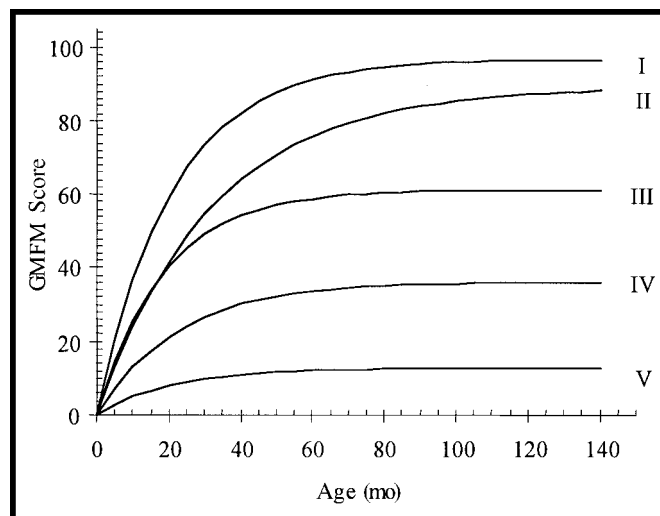$$(12.9 \pm 3.0) \ (1 - \exp[-(.0490 \pm .0652) \times age])$$

The corresponding gross motor function curves are illustrated in Figure 2. The curves are estimates of the average pattern of gross motor function between birth and 12 years of age for children with CP at each of the 5 GMFCS levels. Each curve has the same basic form, characterized by a greater rate of increase in GMFM scores at younger ages and a leveling of the curve as the limit parameter is approached.

To facilitate the interpretation of these curves, the GMFCS was coded to permit pair-wise comparisons between the parameters of adjacent levels (Tab. 5). For each pair-wise comparison, the predicted maximum GMFM score was higher ($P<.05$) the more functional the GMFCS level (level I=96.8, level II=89.3, level III=61.3, level IV=36.1, and level V=12.9) (Tab. 5). The

pair-wise comparisons of the predicted rate of development indicated that children classified at level II approached their maximum GMFM score more slowly than children classified at level I ($P<.05$) and children classified at level III ($P<.05$). Additional pair-wise comparisons indicated that the *rate* parameter of children classified at level III ($t_{(576)}=-.72$, $P=.47$), children classified at level IV ($t_{(576)}=-.22$, $P=.83$), and children classified at level V ($t_{(576)}=-.04$, $P=.97$) do not differ from the *rate* parameter for children classified at level I.

Interpretation of GMFM Total Scores

The GMFM total scores at which children with CP are estimated to have a 50% and 95% probability of achieving selected gross motor functions are presented in Table 3. The results in Table 3 show the relationship between the GMFM total score and achievement of selected items. The results do not predict when a child will attain a particular GMFM total score or achieve a specific gross motor function. The findings for item 69 ("From standing, can walk forward 10+ steps with arms free") will serve to illustrate how to interpret the results in Table 3. Children with a GMFM total score of 70 had a 50% probability of being able to walk 10 steps without support. Children with a GMFM total score of 87 had an 95% probability of being able to walk 10 steps without support. In contrast, a child with a GMFM total score of 61 (the predicted maximum GMFM score for children classified at level III) was estimated to have only a 19.1% probability of being able to walk 10 steps without support (calculation not shown in Tab. 3).

Relationship Between the GMFCS and GMFM

The correlation (r) between the GMFCS levels and GMFM scores was $-.91$ ($P<.0001$). This negative relationship was expected because higher-numbered levels on the GMFCS represent lower function, whereas higher scores on the GMFM represent higher function. The magnitude of the correlation was high, and the negative sign indicates that children with more functional GMFCS levels (ie, level I, level II) had higher GMFM scores. Thus, a therapist's classification of a child's broad level of gross motor function is closely related to the systematic and in-depth quantification of gross motor function, as measured by the GMFM. Age was not correlated to classification level ($r=.02$, $P<.59$). The correlation between the GMFCS levels and GMFM scores was virtually unaffected by adjustment for children's ages ($r=.92$, $P<.0001$). This finding was expected, as criteria for each GMFCS level already consider age and a child's GMFCS level is not expected to change dramatically over time.[20]

Discussion and Conclusions

The results indicate that classification of children with CP based on functional abilities and limitations is pre-

dictive of gross motor function, whereas age alone is a poor predictor of gross motor function. Model 3, in which both the *limit* and *rate* parameters vary with GMFCS level, is able to explain 83% of the variation associated with GMFM scores. The predicted maximum GMFM scores were different for the 5 gross motor function curves. In particular, the differences in predicted maximum GMFM scores between the curves for levels II and III, levels III and IV, and levels IV and V varied from 23 to 28 points. The results of the logistic regressions indicate that differences in GMFM total scores of 23 to 28 points differentiate whether children are likely to able to roll, sit, crawl, stand, walk, and jump. These findings suggest that the distinctions between GMFCS levels are meaningful to the daily activities of children with CP.

In contrast to the findings for the *limit* parameter, the findings for the predicted *rate* parameter for the gross motor function curves did not differ from each other, with the exception of the findings for the rate parameter for level II. Children classified at level II approached the limit of their gross motor function at a slower rate than children classified at level I and level III. Thus, the distinctions between the curves for level I and level II are unique. First, the predicted maximum GMFM scores for level I (96.8) and level II (89.3) differed by only 7.5 points, compared with 23 to 28 points for the comparisons among the other curves. Second, the *rate* parameter of the curve for level II was less than the *rate* parameter for the curve for level I. Children at level II are predicted not only to take longer to approach the limit of their gross motor function but also ultimately to achieve slightly lower gross motor function compared with children classified at level I.

For all 5 gross motor function curves, the predicted rate of increase in GMFM scores was greatest during infancy and early childhood. The slopes for the 5 curves began to flatten at 3 to 4 years of age and, with the exception of the curve for level II, have almost reached a plateau by 7 years of age. This finding suggests that by middle childhood, children with CP do not make substantial changes in the gross motor abilities measured by the GMFM. Measures of disability and participation that focus on successful performance of gross motor functions within the context of daily routines (eg, ability to transfer into and out of the bathtub at home, ability to walk between classrooms at school), amount of caregiver assistance, and use of assistive technology are likely to be more responsive than the GMFM to changes made by children with CP who are older than 6 years of age.

Our results suggest that outcomes of intervention should be based on expectations for children with CP of the same age and gross motor function rather than on

norms established for children without developmental delays.[31–33] Previously, the GMFM scores of 61 children without motor delays were used to construct a gross motor function curve using the 2-parameter nonlinear model used in our study.[26] The curve had a *rate* parameter of .064 (95% CI=.014) and a *limit* parameter of 100. In our study, the mean *rate* parameters ranged from .0316 to .0541. The *limit* parameter was 96.8 (95% CI=94.2–99.4) for children with CP classified at level I and 89.3 (95% CI=83.8–94.8) for children with CP classified at level II. Children classified at levels I and II, therefore, are predicted to approach, but not attain, a GMFM score of 100. The predicted maximum GMFM scores of children with CP at levels III, IV, and V not only differed from each other but also were considerably lower than scores of children with CP at levels I and II.

The high correlation between GMFCS levels and GMFM scores ($r=-.91$) provides further evidence of the construct validity of the GMFCS scores. Classification of children's broad levels of gross motor function on the GMFCS is closely related to the systematic and in-depth examination of specific gross motor abilities measured in detail by the GMFM. Level I represents the continuum between children with neuromuscular and musculoskeletal impairments whose functional limitations are not pronounced and children who have traditionally been diagnosed as having CP of minimal or mild severity. The predicted maximum GMFM percentage score of 96.8 is consistent with the description for level I. At the other end of the continuum, children classified at level V have multiple impairments that restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. The predicted maximum GMFM percentage score of 12.9 fits this description.

Clinical Implications

The GMFCS provides a standardized method of classifying gross motor function of children with CP. The terms "functional related groups," "severity of disability," "case-mix complexity," and "risk adjustment" have been used to describe methods of grouping patients on the basis of functional limitation and disability rather than medical diagnosis.[34] The results of our study provide evidence that the GMFCS scores are valid for classifying the gross motor abilities and limitations of children with CP. The therapists and pediatricians who participated in the nominal group process and Delphi survey consensus methods indicated that the GMFCS has applications for clinical practice, research, teaching, and administration.[18] We believe that use of the GMFCS can improve communication among parents and professionals, decisions regarding utilization of medical and rehabilitation services, and evaluation of intervention outcomes for program evaluation and clinical research.

The gross motor function curves can assist parents and health care professionals to make evidence-based management decisions more effectively than relying solely on personal experience or findings from developmental assessments normed on children without motor delays. The gross motor function curves also could assist in determining whether a child's gross motor function is comparable to expectations for children with CP of the same age and GMFCS level. For example, the curves presented in Figure 2 indicate that a 24 month-old child classified at level III who achieves a GMFM score of 28 is functioning near the predicted average for children of the same age and GMFCS level. In contrast, a 40-month-old child classified at level III who achieves a GMFM score of 38 is functioning lower than the average score predicted for children of the same age and GMFCS level. The gross motor function curves also provide information on the average change in gross motor function as children become older. This information may be useful in anticipating change over time, but should not be used to predict the future gross motor function for an individual child. We recommend that the gross motor function curves be used in conjunction with other relevant information when making decisions. This suggestion is consistent with evidence-based practice, where the best available information and research are used to guide decision making within the context of the individual client.[35]

The model used to construct the gross motor function curves was examined in this study using cross-sectional data. Validation and refinement of the model await the completion of the longitudinal phase of data collection. To date, 689 children are enrolled in the study. Children are being classified using the GMFCS, and the GMFM is administered to them every 6 months (for children less than 6 years of age) or every 9 to 12 months (for children 6 years of age and older) with the intent of completing 4 to 6 assessments for each child. The longitudinal data will allow us not only to estimate the average curve within each GMFCS level, but also to examine individual variability in patterns of development of gross motor function. The longitudinal data also will provide information on whether GMFCS levels are stable over a 2- to 3-year period. Estimating the likelihood for change in gross motor function in children with CP is a complex process. Curves that have been validated for this purpose would assist in determining the extent to which an intervention improves a child's gross motor function compared with expectations for change in children with CP of the same age and GMFCS level.

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Appendix.
Gross Motor Function Classification System[18,a]

Introduction and User Instructions:

The Gross Motor Function Classification System for Cerebral Palsy is based on self-initiated movement with particular emphasis on sitting (truncal control) and walking. When defining on a 5-level classification system, our primary criterion was that the distinctions in motor function between levels must be clinically meaningful. Distinctions between levels of motor function are based on functional limitations, the need for assistive technology including mobility devices (such as walkers, crutches, and canes) and wheeled mobility, and, to a much lesser extent, quality of movement. Level I includes children with neuromotor impairments whose functional limitations are less than what is typically associated with cerebral palsy and children who have traditionally been diagnosed as having "minimal brain dysfunction" or "cerebral palsy of minimal severity." The distinctions between levels I and II, therefore, are not as pronounced as the distinctions between the other levels, particularly for infants less than 2 years of age.

The focus is on determining what level best represents the child's present abilities and limitations in motor function. Emphasis is on the child's usual performance in home, school, and community settings. It is therefore important to classify on ordinary performance (not best capacity), and not to include judgements about prognosis. Remember the purpose is to classify a child's present gross motor function, not to judge quality of movement or potential for improvement.

The descriptions of the 5 levels are broad and are not intended to describe the function of individual children. For example, an infant with hemiplegia who is unable to crawl on hands and knees, but otherwise fits the description of level I, would be classified in level I. The scale is ordinal, with no intent that the distance between levels be considered equal or that children with cerebral palsy are equally distributed among the 5 levels. A summary of the distinctions between each pair of levels is provided to assist in determining the level that most closely resembles a child's current gross motor function.

The title for each level represents the highest level of mobility that a child will achieve between 6–12 years of age. We recognize that classification of motor function is dependent on age, especially during infancy and early childhood. For each level, therefore, separate descriptions are provided for children in several age bands. The functional abilities and limitations for each age interval are intended to serve as guidelines, are not comprehensive, and are not norms. Children below age 2 should be considered at their correct age.

An effort has been made to emphasize children's function rather than their limitations. Thus, as a general principle, the gross motor function of children who are able to perform the functions described in any particular level will probably be classified at or above that level; in contrast, the gross motor function of children who cannot perform the functions of a particular level will likely be classified below that level.

Gross Motor Function Classification System
LEVEL I—Walks without restrictions; limitations in more advanced gross motor skills.

Before 2nd birthday: Infants move in and out of sitting and floor sit with both hands free to manipulate objects. Infants crawl on hands and knees, pull to stand and take steps holding onto furniture. Infants walk between 18 months and 2 years of age without the need for any assistive mobility device.

From age 2 to 4th birthday: Children floor sit with both hands free to manipulate objects. Movements in and out of floor sitting and standing are performed without adult assistance. Children walk as the preferred method of mobility without the need for any assistive mobility device.

From age 4 to 6th birthday: Children get into and out of, and sit in, a chair without the need for hand support. Children move from the floor and from chair sitting to standing without the need for objects for support. Children walk indoors and outdoors, and climb stairs. Emerging ability to run and jump.

From age 6 to 12: children walk indoors and outdoors, and climb stairs without limitations. Children perform gross motor skills including running and jumping but speed, balance, and coordination are reduced.

LEVEL II—Walks without assistive devices; limitations walking outdoors and in the community.

Before 2nd birthday: Infants maintain floor sitting but may need to use their hands for support to maintain balance. Infants creep on their stomach or crawl on hands and knees. Infants may pull to stand and take steps holding onto furniture.

From age 2 to 4th birthday: Children floor sit but may have difficulty with balance when both hands are free to manipulate objects. Movements in and out of sitting are performed without adult assistance. Children pull to stand on a stable surface. Children crawl on hands and knees with a reciprocal pattern, cruise holding onto furniture and walk using an assistive mobility device as preferred methods of mobility.

From age 4 to 6th birthday: Children sit in a chair with both hands free to manipulate objects. Children move from the floor to standing and from chair sitting to standing but often require a stable surface to push or pull up on with their arms. Children walk without the need for any assistive mobility device indoors and for short distances on level surfaces outdoors. Children climb stairs holding onto a railing but are unable to run or jump.

From age 6 to 12: children walk indoors and outdoors, and climb stairs holding onto a railing but experience limitations walking on uneven surfaces and inclines, and walking in crowds or confined spaces. Children have at best only minimal ability to perform gross motor skills such as running and jumping.

Distinctions between levels I and II:

Compared with children in level I, children in level II have limitations in the ease of performing movement transitions; walking outdoors and in the community; the need for assistive mobility devices when beginning to walk; quality of movement; and the ability to perform gross motor skills such as running and jumping.

LEVEL III—Walks with assistive mobility devices; limitations walking outdoors and in the community.

Before 2nd birthday: Infants maintain floor sitting when the low back is supported. Infants roll and creep forward on their stomachs.

From age 2 to 4th birthday: Children maintain floor sitting often by "W-sitting" (sitting between flexed and internally rotated hips and knees) and may require adult assistance to assume sitting. Children creep on their stomach or crawl on hands and knees (often without reciprocal leg movements) as their primary methods of self-mobility. Children may pull to stand on a stable surface and cruise short distances. Children may walk short distances indoors using an assistive mobility device and adult assistance for steering and turning.

From age 4 to 6th birthday: Children sit on a regular chair but may require pelvic or trunk support to maximize hand function. Children move in and out of chair sitting using a stable surface to push on or pull up with their arms. Children walk with an assistive mobility device on level surfaces and climb stairs with assistance from an adult. Children frequently are transported when travelling for long distances or outdoors on uneven terrain.

From age 6 to 12: children walk indoors or outdoors on a level surface with an assistive mobility device. Children may climb stairs holding onto a railing. Depending on upper limb function, children propel a wheel

chair manually or are transported when traveling for long distances or outdoors on uneven terrain.

Distinctions between levels II and III:
Differences are seen in the degree of achievement of functional mobility. Children in level III need assistive mobility devices and frequently orthoses to walk, while children in level II do not require assistive mobility devices after age 4.

LEVEL IV—Self-mobility with limitations; children are transported or use power mobility outdoors and in the community.

Before 2nd birthday: Infants have head control, but trunk support is required for floor sitting. Infants can roll to supine and may roll to prone.

From age 2 to 4th birthday: Children floor sit when placed, but are unable to maintain alignment and balance without use of their hands for support. Children frequently require adaptive equipment for sitting and standing. Self-mobility for short distances (within a room) is achieved through rolling, creeping on stomach, or crawling on hands and knees without reciprocal leg movement.

From age 4 to 6th birthday: Children sit on a chair but need adaptive seating for trunk control and to maximize hand function. Children move in and out of chair sitting with assistance from an adult or a stable surface to push or pull up on with their arms. Children may at best walk short distances with a walker and adult supervision but have difficulty turning and maintaining balance on uneven surfaces. Children are transported in the community. Children may achieve self-mobility using a power wheelchair.

From age 6 to 12: Children may maintain levels of function achieved before age 6 or rely more on wheeled mobility at home, school, and in the community. Children may achieve self-mobility using a power wheelchair.

Distinctions between levels III and IV:
Differences in sitting ability and mobility exist, even allowing for extensive use of assistive technology. Children in level III sit independently, have independent floor mobility, and walk with assistive mobility devices. Children in level IV function in sitting (usually supported), but independent mobility is very limited. Children in level IV are more likely to be transported or use power mobility.

LEVEL V—Self-mobility is severely limited even with the use of assistive technology.

Before 2nd birthday: Physical impairments limit voluntary control of movement. Infants are unable to maintain antigravity head and trunk postures in prone and sitting. Infants require adult assistance to roll.

From age 2 to 12: Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. At level V, children have no means of independent mobility and are transported. Some children achieve self-mobility using a power wheelchair with extensive adaptations.

Distinctions between levels IV and V:
Children in level V lack independence even in basic antigravity postural control. Self mobility is achieved only if the child can learn how to operate an electrically powered wheelchair.

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