

## Reference Curves for the Gross Motor Function Measure: Percentiles for Clinical Description and Tracking Over Time Among Children With Cerebral Palsy

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**Background and Purpose.** Physical therapists frequently use the 66-item Gross Motor Function Measure (GMFM-66) with the Gross Motor Function Classification System (GMFCS) to examine gross motor function in children with cerebral palsy (CP). Until now, reference percentiles for this measure were not available. The aim of this study was to improve the clinical utility of this gross motor measure by developing cross-sectional reference percentiles for the GMFM-66 within levels of the GMFCS.

**Subjects and Methods.** A total of 1,940 motor measurements from 650 children with CP were used to develop percentiles. These observations were taken from a subsample, stratified by age and GMFCS, of those in a longitudinal cohort study reported in 2002. A standard LMS (skewness-median-coefficient of variation) method was used to develop cross-sectional reference percentiles.

**Results.** Reference curves were created for the GMFM-66 by age and GMFCS level, plotted at the 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th percentiles. The variability of change in children's percentiles over a 1-year interval also was investigated.

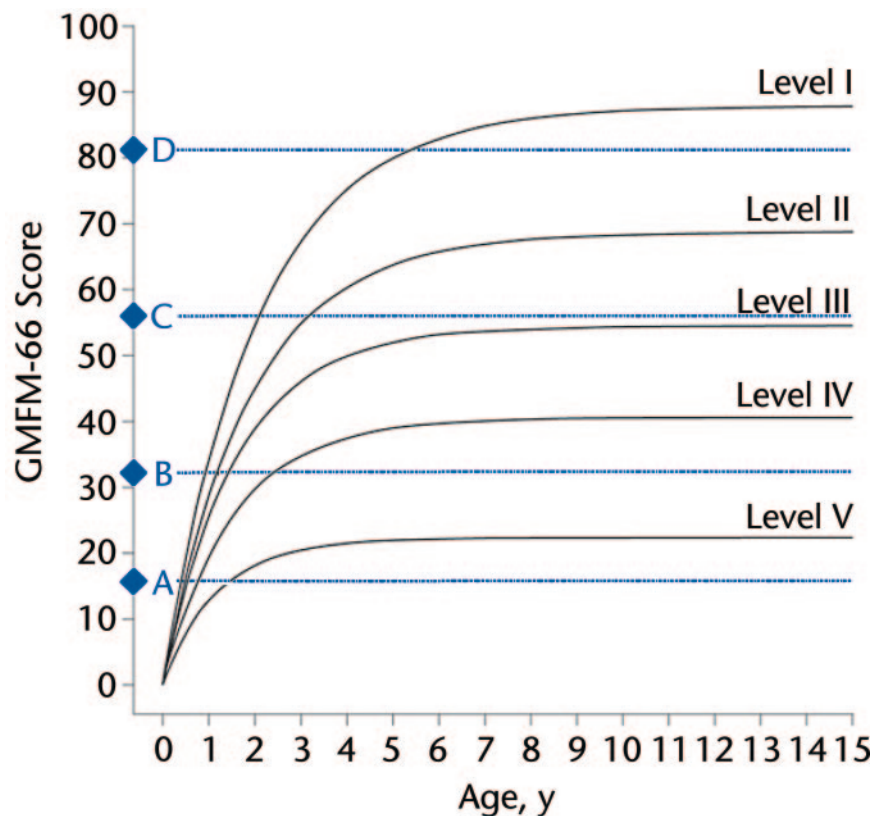
**Discussion and Conclusion.** The reference percentiles extend the clinical utility of the GMFM-66 and GMFCS by providing for appropriate normative interpretation of GMFM-66 scores within GMFCS levels. When interpreting change in percentiles over time, therapists must carefully consider the large variability in change that is typical among children with CP. The use of percentiles should be supplemented by interpretation of the raw scores to understand change in function as well as relative standing.



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Cerebral palsy (CP) is a group of disorders affecting the development of movement and posture and causing activity limitations that are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain.<sup>1</sup> Cerebral palsy occurs in about 2 to 2.5 per 1,000 live births<sup>2</sup> and is the most prevalent childhood neuromuscular condition seen by pediatric rehabilitation practitioners, including physical therapists. The prognosis for gross motor function among children with CP is extremely variable. This variability has been a key challenge for scientific descriptions of motor function as children with CP develop. It is also a fundamental consideration for clinicians who regularly deal with practical issues of examination, prediction, intervention planning, and outcome evaluation<sup>3</sup> when working with children with CP.

In 2002, Rosenbaum and colleagues<sup>4</sup> published a landmark longitudinal cohort study that dramatically improved knowledge of the development of gross motor function among children with CP. Rosenbaum et al<sup>4</sup> used population-based sampling methods to conduct longitudinal assessments of the gross motor function of 657 children over approximately 4 years. Children were stratified by age and by the severity of the condition on the basis of the Gross Motor Function Classification System (GMFCS) for CP.<sup>5</sup> The motor examinations were conducted with the 66-item version of the Gross Motor Function Measure (GMFM-66), an evaluative instrument for use with children with CP.<sup>6-9</sup> The result was a set of 5 motor development curves, corresponding to each of 5 GMFCS levels of severity. The curves describe changes in GMFM-66 motor function scores within strata of severity, in terms of the rate of development and a presumed limit of functional ability (Fig. 1).



**Figure 1.**

Gross motor development curves representing average development predicted by the Gross Motor Classification System. The diamonds on the vertical axis identify 4 items of the 66-item Gross Motor Function Measure (GMFM-66) that predict when children are expected to have a 50% chance of completing that item successfully. The GMFM-66 item 21 (diamond A) assesses whether a child can lift and maintain his or her head in a vertical position with trunk support by a therapist while sitting, item 24 (diamond B) assesses whether a child can maintain a sitting position on a mat without support from his or her arms for 3 seconds, item 69 (diamond C) measures a child's ability to walk forward 10 steps without support, and item 87 (diamond D) assesses the task of walking down 4 steps by alternating feet with arms free. Reprinted with permission from Rosenbaum PL, Walter SD, Hanna SE, et al. Prognosis for gross motor function in cerebral palsy: creation of motor development curves. *JAMA*. 2002;288:1357-1363. Copyright 2002, American Medical Association. All rights reserved.

These gross motor measures and curves are now widely cited in the clinical and scientific literature<sup>10-12</sup> as useful and valid descriptions of gross motor changes among children with CP. Scientific or clinical questions of prediction can be approached from an initial GMFCS assignment that establishes the appropriate range of functional expectations for an individual child. Evaluating a child's GMFCS severity level is straightforward.<sup>13</sup> Once a child is assigned to a GMFCS level, the cor-

responding motor change curve shows the average pattern of change in GMFM-66 motor scores up to 12 years of age for children at that level. Rosenbaum et al<sup>4</sup> also provided data about the degree of variability in limits of gross motor function expected among children within each level.

With the curves provided by Rosenbaum et al,<sup>4</sup> it is possible to crudely evaluate children's gross motor capability relative to the average for their age and GMFCS level. The user's

**Table 1.**  
Description of Case Examples<sup>a</sup>

Characteristic	David	Jennifer	Hardeep
GMFCS level	I	III	IV
Age at time 1	3 y 2 mo	4 y 9 mo	5 y 2 mo
GMFM-66 score at time 1	57.6	51.6	43.3

<sup>a</sup> Each child had a diagnosis of spastic diplegia. GMFCS=Gross Motor Function Classification System, GMFM-66=66-item Gross Motor Function Measure.

manual for the GMFM-66<sup>8</sup> also provides item maps that aid in criterion-referenced interpretations of scores by relating total GMFM-66 ability scores to the probability of attaining motor tasks such as lying and rolling, sitting, crawling and kneeling, standing, walking, running, and jumping. However, it has been difficult for clinicians to make normative evaluations of children’s motor capability within GMFCS levels because reference percentiles have not been available. In this article, we develop and present reference percentiles for GMFM-66 motor scores by age and GMFCS level. First, we review the clinical utility of the GMFM-66, the GMFCS, and the motor development curves as they pertain to examination, prediction, and intervention planning by using 3 case examples. After presenting the development of the reference percentiles, we revisit these examples to demonstrate how the percentiles can enhance assessment. We discuss the use of the percentiles both for understanding a sin-

gle GMFM-66 assessment and for tracking a child’s motor ability over time.

### Case Examples

We selected real gross motor function data for 3 children from the data set of Rosenbaum et al<sup>4</sup> to use as case examples. Descriptions of the children, with their names changed, are provided in Table 1. Each of these children had a diagnosis of spastic diplegia, although the severity of involvement varied widely (GMFCS levels I, III, and IV), highlighting the variability for children within the classic descriptions of type of motor disorder and distribution of involvement.

### Motor Measures

As shown in Table 1, David, Jennifer, and Hardeep were in GMFCS levels I, III, and IV, respectively. The GMFCS has become the international standard for classifying the severity of CP.<sup>12</sup> Table 2 shows basic descriptions of the gross motor function

abilities expected for children between the ages of 6 and 12 years, according to the 5 GMFCS levels.<sup>5</sup> The GMFCS is straightforward and reliable when used by therapists having minimal contact with children or gaining information from parental reports.<sup>14</sup> Children in level I have the fewest limitations in gross motor function and mobility, and children in level V have the greatest limitations, such that little voluntary movement is possible. The GMFCS levels are assigned on the basis of separate criteria according to age bands (<2 years, 2–4 years, 4–6 years, and 6–12 years). The GMFCS levels can be used to establish broad expectations for motor development and achievement. For instance, we expect that David (level I) will continue to develop in gross motor abilities such that he will be able to perform all of the activities of a 5-year-old child who is developing typically, with minor limitations in speed, balance, and coordination. Jennifer (level III) will be able to walk using a walker or canes on a level surface and will likely use a manual wheelchair for functional mobility. Hardeep (level IV) will need assistance from an adult for transfers and will use either a manual or a powered wheelchair for mobility. This information is useful for realistic goal setting in physical therapy as well as for long-term planning by families with respect to arranging for accessible home, school, and community environments.

The GMFCS also provides a context for interpreting more detailed examinations with the GMFM.<sup>6</sup> The full version of the GMFM contains 88 items (GMFM-88) measuring children’s abilities related to lying and rolling, sitting, crawling and kneeling, standing, walking, running, and jumping, with the most difficult items on the scale representing abilities attained by children developing typically by 5 years of age. Each

**Table 2.**  
Expected Functional Abilities for Children Aged 6 to 12 Years, According to the Gross Motor Function Classification System (GMFCS)

GMFCS Level	Description
I	Walks without restrictions; limitations in more advanced gross motor skills
II	Walks without assistive devices; limitations in walking outdoors and in the community
III	Walks with handheld assistive mobility devices; limitations in walking outdoors and in the community
IV	Self-mobility with limitations; children are transported or use power mobility outdoors and in the community
V	Self-mobility is severely limited even with the use of assistive technology

item is scored by observation on a 4-point ordinal scale. The GMFM-66 was developed and validated by use of Rasch analysis to create a unidimensional motor ability score with interval-level measurement properties.<sup>9</sup> The Rasch model that underlies the GMFM-66 also estimates the difficulties of the items,<sup>7</sup> so that a child's total ability score can be easily related to the probability of attaining common motor milestones. Total possible scores range from 0 to 100.

Each of the 3 children selected as case examples had spastic diplegia. On the initial occasion of measurement, David, a boy who was 3 years 2 months old, was in GMFCS level I and had a GMFM-66 score of 57.6. Both Jennifer and Hardeep were older than David, had more severe limitations, and had lower GMFM-66 scores, 51.6 and 43.3, respectively. These scores, which are clearly not solely related to age, are useful for describing the current motor abilities of individual children, particularly when used with the item maps described earlier.<sup>8</sup> For example, David was able to walk independently but probably could not achieve standing through either left or right half-kneeling, lower himself to sitting on a bench without hand support, pick up an object from the floor without hand support, or walk up or down stairs by holding onto a railing and alternating feet. Jennifer could pull herself to a standing position by using a surface and could cruise to left or right when holding on, but she could not stand without arm support.

Normative and predictive interpretations are facilitated by referencing a child's GMFM-66 score against the average developmental pattern for children in his or her GMFCS level. Such referencing can be done with the motor development curves<sup>4</sup> shown in Figure 1. For instance, the average child in GMFCS level I is ex-

pected to achieve a GMFM-66 score of approximately 88 as he or she approaches adolescence. Rasch item maps from the user's manual for the GMFM-66<sup>8</sup> suggest that such a child has a high probability of being able to perform tasks such as independent walking on a level surface and walking down steps by alternating feet with arms free. However, there is considerable variability within GMFCS levels; therefore, it is clear that the average predicted capability is not the only factor. For instance, Rosenbaum et al<sup>4</sup> reported variability in the ultimate limit of motor capability such that there is only a 50% chance of children in GMFCS level I achieving scores of between 80.1 and 92.3. In addition to the real variability in achievement, there is also measurement error, meaning that no one assessment falls exactly on the true developmental trajectory for a child.

### Normative Percentiles

For a child of 38 months of age, David's GMFM-66 score (57.6) was well below the average score (68.8) predicted from the motor development curve for children of this age in GMFCS level I. Two questions of interpretation immediately arise. First, given the variability in GMFM-66 at this age, is this difference from the average "large"? Second, given that this child's development may be below average for his GMFCS level at age 3, will his development remain below average as he ages?

Clinicians are generally familiar with normative reference percentiles for answering the first question. Reference percentiles are commonly used for interpreting measurements in medicine, such as physical growth,<sup>15</sup> and for defining the normal ranges for a wide variety of laboratory measurements.<sup>16</sup> Many clinical measures in pediatric rehabilitation also provide percentiles to facilitate normative in-

terpretation.<sup>17-19</sup> Reference percentiles are constructed by selecting a clinically appropriate comparison group and developing a statistical summary of the distribution of scores for this group. This summary is transformed to a percentile scale, such that a child's percentile represents the percentage of children in the normative sample that he or she outperforms. Reference percentiles answer questions about function in terms of relative standing.

The question of whether David's motor ability will remain below average relates to issues of both prediction and longitudinal variability or tracking of measurements.<sup>20</sup> It is common for therapists and families to assume that percentile rankings are stable, but in fact they can be highly variable over time.<sup>17</sup> Thus, whenever therapists want to monitor function over time, it will be important to assess the likely degree of variation in percentiles over time. If clinicians do not consider this variation, it can be mistaken for evidence of clinically significant change.

In the present study, we used data from the sample of Rosenbaum et al<sup>4</sup> to construct reference percentiles for GMFM-66 scores within GMFCS levels for children with CP. We also evaluated the degree to which percentile rankings are stable over time, and we discuss how this factor affects the appropriate use of percentiles for clinical monitoring of gross motor function. Our goal was to increase the clinical applicability of the GMFM-66 and GMFCS by providing reference curves in a form familiar to physical therapists and other service providers who work with children with CP.

### Method Subjects

The sample used in the present study was described in detail by Rosenbaum et al.<sup>4</sup> Children with CP and



## Reference Curves for GMFM-66

**Table 3.**

Description of the Sample Used to Create Reference Curves<sup>a</sup>

Characteristic	GMFCS Level					
	I	II	III	IV	V	All Levels
No. of observations	513	269	363	403	392	1,940
No. of children	182	80	119	136	133	650
$\bar{X}$ (SD) age, y <sup>b</sup>	7.5 (2.6)	7.3 (2.8)	7.7 (2.6)	7.6 (2.6)	7.6 (2.5)	7.5 (2.6)
% female	42.9	47.5	47.1	44.1	39.1	43.7

<sup>a</sup> GMFCS=Gross Motor Function Classification System.

<sup>b</sup> Calculated over all observations.

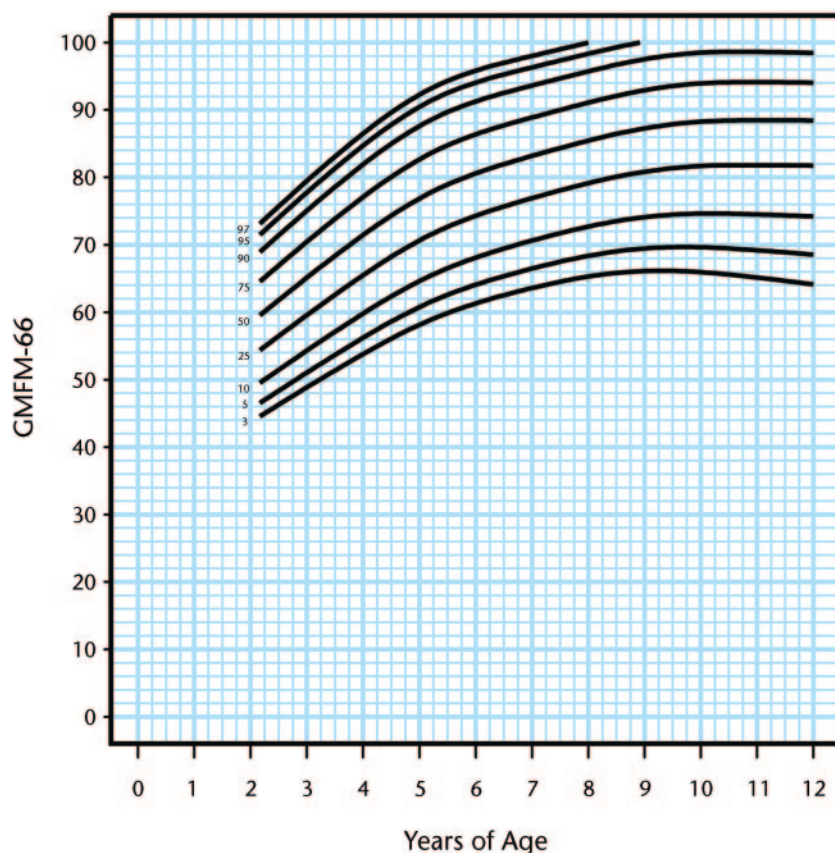
their families were recruited to the study through 19 publicly funded regional ambulatory children's rehabilitation centers in the province of Ontario, Canada, beginning in 1996. These programs provide a range of developmental therapies and services, including physical therapy, occupa-

tional therapy, speech-language therapy, and recreational therapy. Because these centers are publicly funded and each program serves the majority of eligible children in its treatment area, Rosenbaum et al<sup>4</sup> argued that the sample was closely representative of the population of children with CP in On-

tario. Children were included in the study if they had received a diagnosis of CP or if they had neuromotor findings consistent with CP, such as spasticity or reflex abnormalities. Children were excluded if they had other neuromotor conditions, such as spina bifida or muscle diseases. They also were excluded if they had ever received botulinum toxin in the lower limbs or dorsal rhizotomy or were currently receiving intrathecal baclofen. The sample was stratified by GMFCS severity level and age and, therefore, was not necessarily representative with respect to those factors.

From 936 randomly selected children and families who were eligible and after refusals to participate (n=217; 23%), other losses of contact, and later exclusions because of reevaluation of eligibility, 657 children were included in the original motor development analyses. Children under 6 years of age were assessed every 6 months, and older children were assessed every 9 to 12 months. This protocol yielded a total of 2,632 GMFM-66 assessments, with an average of approximately 4 observations per child.

The method used to create percentiles (see section on data analysis below) required that the observations be treated as cross-sectional rather than longitudinal. To minimize the effects of the longitudinal design, while still including as many data as



**Figure 2.**

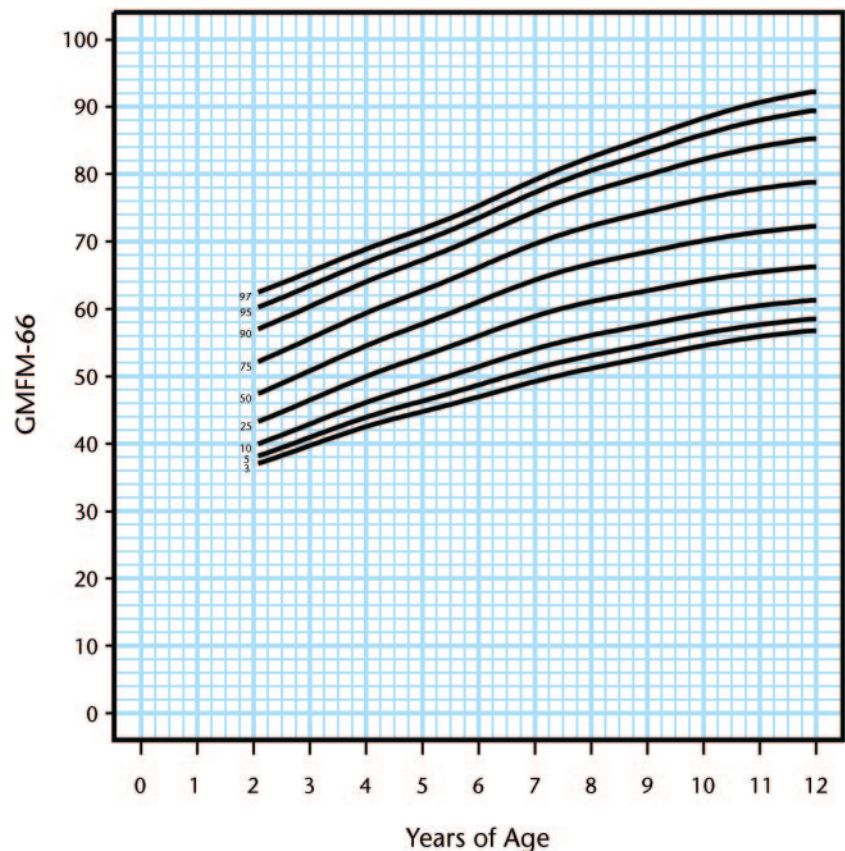
Gross Motor Function Classification System level I percentiles. GMFM-66=66-item Gross Motor Function Measure. Figure 2 may not be used or reproduced without written permission from the authors.

possible, we selected a subsample from the original 2,632 observations to avoid multiple observations from a child occurring close in time. To accomplish this, we established ten 1-year age bands from 2 years up to and including 12 years of age. Observations were selected so that there was no more than one observation per child per 1-year age band. As a result, statistical smoothing operations used to create the percentiles gave substantial weight to only one observation for each child at a given age. It is important to note that these age bands were used only for creating the subsample and were not used for fitting the percentiles. Observations were included only for ages from 2 to 12 years, restricting inferences to ages for which large amounts of data were available. This sampling also is consistent with the appropriate use of the GMFCS, which is currently applicable to children up to 12 years of age.

As a result of this subsampling, a total of 1,940 observations from 650 children were available for creating cross-sectional reference curves. The distribution and characteristics of this sample within 5 levels of GMFCS severity are shown in Table 3.

### Outcome Measures

The severity of CP was classified with the GMFCS. The GMFCS is a reliable and valid system that classifies children with CP on the basis of the major age-appropriate gross motor activities that they can typically accomplish, with particular emphasis on functional mobility.<sup>5,13</sup> The use of the GMFCS requires familiarity with the child but does not require formal training. Interrater reliability is good for children aged 2 to 12 years ( $\kappa=.75$ ) and not so strong for children under 2 years of age ( $\kappa=.55$ ). Although the GMFCS was recorded at each observation, we followed the protocol of Rosenbaum et al<sup>4</sup> in relying on the first



**Figure 3.**

Gross Motor Function Classification System level II percentiles. GMFM-66=66-item Gross Motor Function Measure. Figure 3 may not be used or reproduced without written permission from the authors.

available GMFCS assignment for the children in the present study. Doing so ensured correspondence with previous research and reflects typical clinical goals, in which an initial classification with the GMFCS frames subsequent intervention planning and outcome evaluation.

Gross motor function was examined with the GMFM-66.<sup>8</sup> The validity of the GMFM-66 was established in several ways. Face validity was established by examining the hierarchy of items by use of Rasch analysis.<sup>7</sup> Sensitivity to change was determined by demonstrating that children who were younger changed more than children who were older and that more change occurred in children in GMFCS levels I and II than in those in

the other levels.<sup>7</sup> Reliability was initially established with trained raters, who obtained intraclass correlation coefficients of .99 for both interrater reliability and test-retest reliability.<sup>7</sup> In the study of Rosenbaum et al,<sup>4</sup> all examining therapists were trained on the administration and scoring of the GMFM.

### Data Analysis

The LMS method of Cole and Green<sup>21</sup> was used to construct reference percentiles. The method summarizes the changing distribution of GMFM-66 scores as a function of age in terms of 3 curves representing the skewness (L), the median (M), and the coefficient of variation (S). Smooth, nonlinear fitting of the 3 LMS curves is accomplished with cu-



bic splines by use of a penalized likelihood criterion. Assuming that the original data are skew-normal, the resulting curves approximate a standard normal distribution at any given age and thus can be combined to produce percentiles. The degree of smoothness for each of the 3 LMS functions is controlled by selecting smoothness parameters, often expressed as expected degrees of freedom (edf), for each curve. In turn, the smoothness of the resulting percentile curves depends on the smoothness of the LMS curves. Higher values for edf allow for more complexity and less smoothing with respect to each of the components of the curve—skewness (L), median (M), and variability (S)—with the goal being to select the simplest

model (ie, with lower values for edf) that preserves clinically plausible details in the percentile curves. The LMS method is a standard method for constructing cross-sectional reference percentiles. Unlike many ad hoc methods, it produces smooth curves that incorporate the changing variability and skewness in the sample and does not require the arbitrary binning of subjects into crude age bands.

Determining the appropriate degree of smoothness for the LMS curves is necessarily a balance of smoothing out irregularities arising from sampling error without eliminating features of real clinical interest. For assistance in identifying the appropriate degree of smoothness, changes in edf were evaluated as likelihood

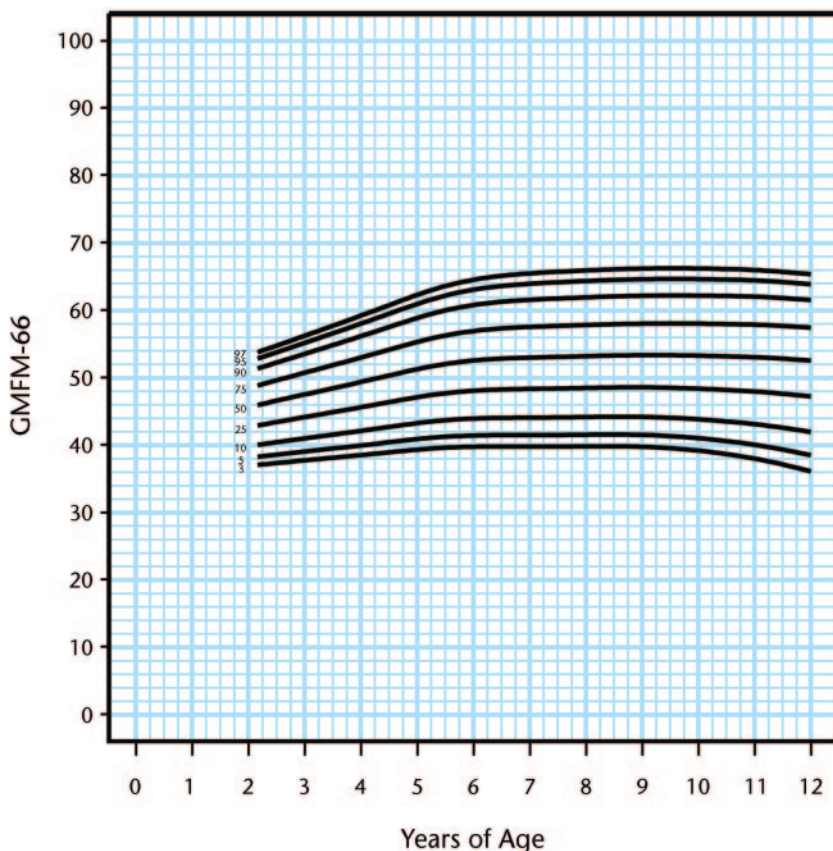
ratio tests based on changes in the penalized likelihood.<sup>21</sup> In a well-fitting model for the percentiles, the observations should conform to a standard normal distribution at any given age after LMS transformation. Thus, the goodness of fit for candidate models was evaluated by use of Kolmogorov-Smirnov tests of normality for the transformed data and by inspection of Q-Q plots of the estimated percentiles.<sup>21</sup>

The LMS percentiles were constructed separately for each GMFCS level by use of the statistical routines provided by Carey,<sup>22</sup> implemented in the R statistical programming language.<sup>23</sup> Separate curves were not considered for boys and girls because of sample size and because Rosenbaum et al<sup>4</sup> found that gender was not a significant predictor of gross motor function trajectories in the sample studied.

To examine the degree of stability of GMFM-66 percentiles over time, we exploited the longitudinal aspect of the original data. A subsample of the observations used in constructing the reference percentiles was selected such that 2 GMFM-66 observations from each child were contributed to the sample. Children for whom only one observation was available were excluded. For children with more than 2 available measurements, the earliest 2 measurements were selected. The resulting sample contained pairs of measurements for 570 children. For each pair of observations, estimated percentiles were extracted, and the means and standard deviations of the differences were calculated for each GMFCS level.

**Results**  
**Reference Curves for Gross Motor Function**

Figures 2, 3, 4, 5, and 6 show the estimated reference curves for each GMFCS level, plotted at the 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th,



**Figure 4.** Gross Motor Function Classification System level III percentiles. GMFM-66=66-item Gross Motor Function Measure. Figure 4 may not be used or reproduced without written permission from the authors.

and 97th percentiles. Note that the reference curves begin at the earliest observed age in each data set, which varies slightly by GMFCS level.

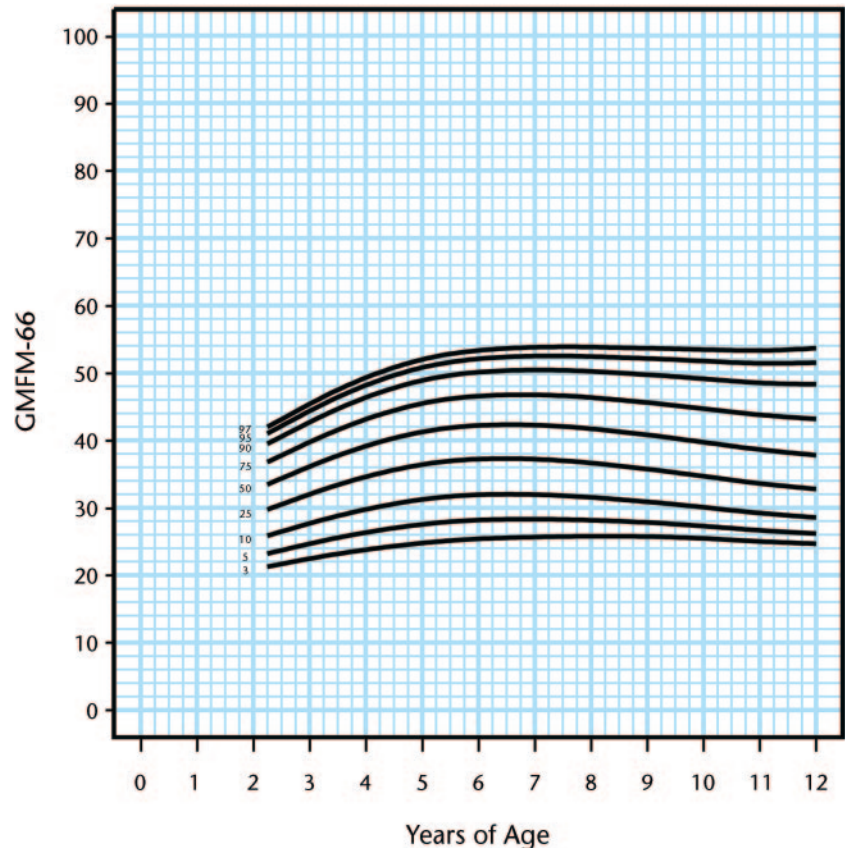
For GMFCS levels I to IV, well-fitting percentiles were obtained at edf of 3, 5, and 3 for the L, M, and S curves, respectively. For level V, there were numerical problems in estimating an L parameter for adjusting skewness; therefore, the L parameter was set to 1.0 to yield no adjustment for skewness, with edf of 4 and 4 for the M and S curves, respectively.

Kolmogorov-Smirnov tests of normality within each level were not significant, indicating that the percentiles conform to the expected normal distribution and that the model used in constructing the percentiles fits the data well. To assess fit at particular age ranges, the data for each level were split into 5 age bands of equal width, and Kolmogorov-Smirnov tests were applied within each age band. None of these tests were significant at any age band, within any GMFCS level, indicating a good fit at all ages. In addition, inspection of Q-Q plots yielded no evidence that the percentiles fit poorly at particular ages.

An approximate percentile can be obtained by consulting the figure for a child's GMFCS level and finding the percentile curve nearest the intersection of the child's age and the GMFM-66 score. For most clinical purposes, it will be sufficiently accurate to visually interpolate between adjacent percentile curves (eg, half-way between the 10th and the 5th percentiles). If greater accuracy is desirable, tabulated percentiles are available online<sup>24</sup> or by contacting the corresponding author.

### Longitudinal Stability of Percentiles

The means and standard deviations of the changes in percentiles by GMFCS level are shown in Table 4.



**Figure 5.**

Gross Motor Function Classification System level IV percentiles. GMFM-66=66-item Gross Motor Function Measure. Figure 5 may not be used or reproduced without written permission from the authors.

The median time between observations for each child was 1.0 year for each level, and neither time difference nor baseline age was correlated significantly with the amount of change in percentiles.

Table 4 shows intervals of expected change between 2 percentile measurements, corresponding to 20%, 50%, and 80% coverage probabilities. Thus, for a child in GMFCS level III, a second percentile measurement has about an 80% chance of being within  $\pm 15.9$  of the first measurement but only a 50% chance of being within  $\pm 8.4$ . As shown in Table 4, the expected within-child variability in percentiles was substantial for all GMFCS levels, with the largest

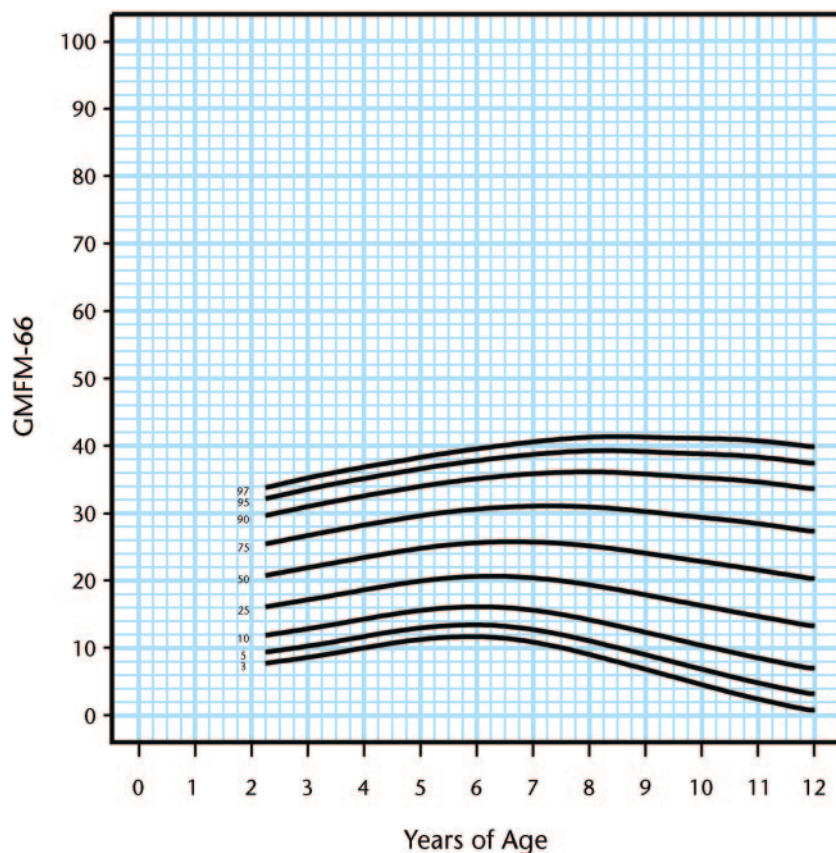
variability being observed for levels I and II.

### Discussion and Conclusion

By using the GMFCS, GMFM-66, and motor development curves (Fig. 1), physical therapists have had clinical instruments to assist with examination, prediction, intervention planning, and outcome evaluation for children with CP. However, percentile norms within GMFCS levels have not been available to assist with the interpretation of relative standing or change over time. In this article, we provide GMFM-66 percentile reference curves that are useful additional tools when therapists want to understand a child's capability in the context of the usual development of



## Reference Curves for GMFM-66



**Figure 6.**

Gross Motor Function Classification System level V percentiles. GMFM-66=66-item Gross Motor Function Measure. Figure 6 may not be used or reproduced without written permission from the authors.

**Table 4.**

Mean Changes in Percentiles Over 2 Assessments, With Probability Intervals<sup>a</sup>

Parameter	GMFCS				
	I	II	III	IV	V
No. of children	147	78	107	121	117
Mean change	3.0	-0.8	3.3	2.5	3.6
SD for change	15.6	15.5	12.4	11.8	13.2
Probability $\hat{b}$	Interval of Change in Percentiles Between Assessments				
20%	±4.0	±3.9	±3.1	±3.0	±3.3
50%	±10.5	±10.5	±8.4	±8.0	±8.9
80%	±20.0	±19.9	±15.9	±15.1	±16.9

<sup>a</sup> GMFCS=Gross Motor Function Classification System. The median time between assessments was 1 year.  $\hat{b}$ =probability that observed change falls within the corresponding interval.

other children with CP who are classified at the same functional level. Next, using the case examples, we illustrate the application of these percentiles (Tab. 1), and then we discuss some general issues of use and interpretation.

The reference curves are straightforward for use in evaluating a child's relative capability at a single point in time. The percentiles for the case examples are shown in Table 5. They were obtained at this level of precision from the LMS output, but in a real application, tabulated percentiles or visual interpolation from Figures 2, 3, 4, 5, and 6 would normally be sufficient. On the first occasion of measurement (time 1), David, Jennifer, and Hardeep had percentile rankings of 14.9, 54.6, and 60.7 relative to other children in GMFCS levels I, III, and IV, respectively. David had the highest GMFM-66 score of the 3 children but, nonetheless, had a much lower percentile ranking. This inconsistency between capability and percentile rankings occurred because the 3 children were of different ages and in different GMFCS levels. In transforming scores to percentiles, the clinical meaning of original scores in relation to functional criteria is set aside in favor of relative ranking. Clinicians and families must adjust their interpretations accordingly. This is especially obvious for the GMFM-66 reference curves, because children's percentiles depend on both age and GMFCS level. As another example, a 6-year old child who scores 52 on the GMFM-66 is near the 95th percentile if she is in level IV but is near the 50th percentile if she is in level III. Her motor capability is the same in either case. Nonetheless, if expectations and intervention planning are being based on the GMFCS, it may be of interest to know that she is a very highly functioning child in level IV. In contrast to measures that derive their interpretation entirely from norm

referencing, such as many intelligence tests, users of the GMFM-66 now have access to both functional and percentile interpretations; it is likely that many examinations will rely on both.

The appropriate use of reference percentiles relies on a wise choice of reference group. Percentiles derived from the scores of children developing typically may be useful for screening but are of extremely limited value for examining function among children with CP and other chronic disabling conditions.<sup>25</sup> Such tests will generally fail to detect meaningful variations in capability among children in a clinical population who all fall below the extreme lowest percentiles of the typical development reference distribution. Furthermore, such a measure is incongruent with the usual goals of service provision, which have little relevance to achieving “normal function.” The GMFM-66 percentiles have important advantages in this regard. The 5 GMFCS levels define clinically meaningful subpopulations that are already widely used by therapists to organize examination and intervention planning.<sup>12</sup>

These percentiles are based on a large data set that, within GMFCS levels, is likely to be representative of the population of children with CP that most therapists in Europe and North America will serve. This is a key requirement for the effective interpretation of normative comparisons and is an important strength of the present study. Rosenbaum et al<sup>4</sup> did not control therapeutic interventions during their study; therefore, the sample was representative of children who received a range of accepted medical, orthopedic, and developmental therapy services. Children receiving dorsal rhizotomy, botulinum toxin, and intrathecal baclofen prior to their study were excluded. At the time, these were

**Table 5.**

Changes in 66-Item Gross Motor Function Measure (GMFM-66) and Percentiles for Case Examples

Case Example and Parameter	Time 1	Time 2
David (level I)		
Age, y	3.2	4.4
GMFM-66 score	57.6	66.0
Percentile	14.9	19.6
Jennifer (level III)		
Age, y	4.8	5.4
GMFM-66 score	51.6	49.9
Percentile	54.6	37.5
Hardeep (level IV)		
Age, y	5.2	6.0
GMFM-66 score	43.3	47.1
Percentile	60.7	77.8

newer therapies with largely unknown effects, and they were not readily available in Ontario. In any event, as Rosenbaum et al<sup>4</sup> pointed out, these interventions are used only in highly selective subgroups of children and would have little effect on the estimated distribution of GMFM-66 scores as a whole.

Cross-sectional percentiles are most easily applied when therapists wish to evaluate relative standing at a single point in time. Therapists routinely use them to evaluate longitudinal change in standing as well, although this use is not strictly valid without consideration of the typical stability of percentiles. For example, a therapist who may be alarmed upon finding that a child in level I has dropped from the 50th percentile to the 40th percentile upon re-examination should consult Table 4 and consider that changes at least this large are quite common. For instance, for level I, 80% of re-examinations are expected to change by up to 20 percentile points in either direction, meaning that 20% of changes are larger than this. The reference curves require additional information to assist with the inter-

pretation of change over time, as illustrated next.

Table 5 shows outcome data on David, Jennifer, and Hardeep after a period of approximately 1 year. For David, who was in GMFCS level I, the GMFM-66 score changed from 57.6 to 66.0, a change of 8.4 points. This change translates to a percentile ranking of 14.9 at the beginning of the year and a ranking of 19.6 at the end of the year, an increase of 4.7. An examination of Table 4 shows that this amount of change means that David is developing as might be expected; his change is well within the interval within which 80% of children change.

In contrast, for Jennifer, classified in level III, the GMFM-66 score changed from 51.6 to 49.9 (a decrease of 1.7 points). This change represents little or no loss of function but translates to a change in percentile ranking from 54.6 to 37.5 over 1 year, a decrease of 17.1. Table 4 shows that this amount of change is relatively uncommon in level III; there is an 80% chance that the percentile will remain within 15.9 points of the initial ranking on retesting 1 year later.

Jennifer is not far outside this range, but the results may suggest that she is falling behind the developmental trajectory expected for children in level III.

The example for Jennifer shows how the percentiles can be helpful in revising goals and interventions over the subsequent time period to ensure that further unexpected changes do not occur. However, this example also illustrates that interpretations of changes in percentile rankings should be tempered by knowledge of the child's clinical situation, and we emphasize the hazards of overinterpreting longitudinal comparisons. For Jennifer, an uncommonly large decrease in percentile ranking resulted from a decrease of only 1.7 points in GMFM-66 scores, a finding that may have little importance in functional terms. Indeed, such a small raw score change may not be statistically significant given the standard error of the measure; if not, one cannot be confident that any functional change has occurred. A large downward percentile change arises nonetheless, because the distribution of scores is changing; Jennifer may not be changing, but other children are, and she is falling behind. However, "falling behind" is not the same as losing function. When large changes in percentiles occur, we encourage therapists to consider the functional meaning of the raw scores by using interpretative aids in the user's manual for the GMFM-66.<sup>8</sup>

Finally, for Hardeep, classified in level IV, the GMFM-66 score changed from 43.3 to 47.1, a modest increase of 3.8 points. This change translates to a change in percentile ranking from 60.7 to 77.8, an increase of 17.1. Table 4 shows that there is an 80% chance that percentiles for children in level IV will not change more than 15.1 points on retesting after 1 year. For Hardeep, one can conclude that his develop-

ment was better than expected over the preceding year.

These examples illustrate how to use the reference curves to approximately interpret changes in percentiles. The results shown in Table 4 suggest that large changes in percentile rankings over 1 year are quite common at all levels of the GMFCS. This suggestion is consistent with the findings for gross motor development among children developing typically.<sup>17,26</sup> Our approach to approximately quantifying the longitudinal stability of GMFM-66 percentiles will be useful for interpreting changes. We are presently developing a longitudinal approach that will further improve the prediction of changes in GMFM-66 percentiles. In the meantime, the cross-sectional percentiles presented here are important new tools for the clinical assessment of motor function among children with CP.

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Dr Russell, as one of the authors of the *Gross Motor Function Measure (GMFM-66 and GMFM-88) User's Manual*, receives royalties, which are deposited into a research account and not taken for personal use.

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