Gross Motor Function of Children With Down Syndrome: 
Creation of Motor Growth Curves

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Objective: To create gross motor function growth curves for children with Down syndrome (DS) and to estimate the probability that motor functions are achieved by different ages.

Design: Nonlinear growth curve analysis by using a 2-parameter (rate, upper limit) model.

Setting: Early intervention programs, schools, and children’s homes.

Participants: One hundred twenty-one children with DS, ages 1 month to 6 years.

Main Outcome Measures: Gross Motor Function Measure (GMFM) and severity of motor impairment.

Results: The curves for children with mild (n = 51) and moderate/severe (n = 70) impairment were characterized by a greater increase in GMFM scores during infancy and smaller increases as the children approached the predicted maximum score of 85.9 or 87.9. The estimated probability that a child would roll by 6 months was 51%; sit by 12 months, 78%; crawl by 18 months, 34%; walk by 24 months, 40%; and run, walk up stairs, and jump by 5 years, 45% to 52%.

Conclusions: Children with DS require more time to learn movements as movement complexity increases. Impairment severity affected the rate but not the upper limit of motor function. The results have implications for counseling parents, making decisions about motor interventions, and anticipating the time frame for achievement of motor functions.

Key Words: Developmental disabilities; Disabled children; Down syndrome; Motor skills; Rehabilitation.

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Efforts to reduce the cost of health care and funding constraints for early intervention and preschool programs have accentuated the importance of effective use of medical, educational, and rehabilitation services for children with developmental disabilities and their families. Critical to the provision of quality service is the need for families and professionals to identify intervention outcomes that are: (1) consistent with a child’s potential, and (2) important for function at home, in school, and in the community. Outcomes of interventions for developmentally disabled children traditionally have been evaluated by using norm-referenced tests (ie, the Peabody Developmental Motor Scales), which are based on the average performance of children without developmental delays. The validity of this practice has been questioned, particularly when the purpose of testing is evaluating change over time or change in response to an intervention. Norm-referenced tests may not be responsive to small but meaningful changes that children with developmental disabilities are capable of making. A more meaningful and appropriate approach is to make management decisions and to evaluate intervention outcomes based on how well a child performs relative to expectations for children of the same age and disability.

Down syndrome (DS), with a 1.3 incidence per 1000 live births in North America, is a common cause of developmental disability. Children with DS have delays in development of motor function associated with impairments that include low muscle tone, joint hypertensibility, poor postural control, poor balance, and, for some children, congenital heart disease, and obesity. The relatively high incidence of DS and the ability to make a diagnosis at an early age are factors that are conducive to the study of motor development in this population of children.

Motor development of children with DS has been studied primarily by recording the age at which they achieve milestones. Methods of testing and criteria for achieving milestones vary. Historical reports of caregivers and direct observations have been used to collect data. Walking is the milestone that has been reported most frequently: children with DS have been reported to walk as early as 15 months and as late as 74 months. Centerwall and Centerwall and Kugel and Reque compared the age of walking between children with DS living at home and children living in institutions, and reported that children with DS living at home walked at an earlier age. Melyn and White reported that children with DS living at home walked at a mean age of 24 months whereas Carr reported a mean age of 28 months. The percentage of children walking at 2 years of age has been reported as 25% and 44%, and at 3 years as 78% and 82%.

The mean age of achievement of rolling, sitting, and crawling on hands and knees has also been documented for children with DS. The mean age of rolling has been reported as 5 months and 6.4 months. The mean age for independent floor sitting varies between 8.5 months and 11.7 months. The mean age for crawling has been reported as 12.2 months and 17.3 months. Carr found that by 15 months, 72% of the children studied could sit and 37% could crawl: by 24 months, 98% of the children could sit and 93% could crawl.

Quotients based on norms established for children without developmental delays also have been used to describe motor...
development in children with DS. Chen and Woolley\textsuperscript{9} and Piper et al\textsuperscript{17} described the motor development of children with DS by using norm-referenced measures and found that older children had lower motor quotients than younger children. Chen and Woolley\textsuperscript{9} administered the Denver Developmental Screening Test\textsuperscript{18} to 106 children with DS (age range, 2mo-8yr), 45 of whom were tested multiple times. The age at which 50% of children with DS achieved items was compared with test norms to calculate a developmental achievement quotient (age when child with DS achieved item ÷ mean age for Denver × 100). The mean developmental achievement quotient for the sample of children with DS was: 55 for the gross motor domain; 62 for the fine motor-adaptive domain; 65 for the personal-social domain; and 48 for the language domain. The developmental achievement quotient for the gross motor domain decreased from a mean of 59 for infants below the age of 1 year to a mean of 45 for children between the ages of 3 and 8 years. The lower quotient for the older children suggests that the delay in motor development of children with DS increases with age. The sequence in which items were passed by the children with DS, however, was similar to the sequence shown by the sample of children without motor delays.

Piper\textsuperscript{17} studied the longitudinal development of 32 infants with DS enrolled in an early intervention program. Development was assessed by using the Griffiths Developmental Scale.\textsuperscript{19} Mean developmental quotients at 6 months varied between 87 for the locomotor domain and 75 for the speech and hearing domain. Mean developmental quotients at the age of 2 years were lower in all domains and varied between 68 for the personal-social domain and 56 for the speech and hearing domain. The decline in developmental quotient was greatest for the locomotor domain where the mean quotient changed from 87 at 6 months to 59 at the age of 2 years. Piper\textsuperscript{17} suggested that compared with other domains of development, the locomotor and hearing and speech domains may represent developmental areas that are more genetically determined and less likely to be influenced by environmental stimulation.

The studies reviewed suggest that young children with DS achieve gross motor functions at an average age that is almost twice the mean age of children without motor delays. The studies, however, varied in method of data collection and were conducted before the widespread availability of early intervention programs. Studies that have used tests normed on children without motor delays have reported that motor development quotients of children with DS decrease with age.\textsuperscript{9,20,21} This finding suggests that differences in motor development quotients between children with DS and children without motor delays become more pronounced over time. Developmental quotients, however, are not intended to measure change over time but rather are intended to compare a child with the average performance of children of the same age without motor delays. In our experience, developmental quotients do not provide parents with information that helps them understand their child’s motor development nor do they address what constitutes typical motor development for children with DS.

Determining whether the motor function of a child with DS is advanced, age appropriate, or delayed according to expectations for children with DS of the same age and degree of motor impairment is important to decision making, including identification of a child’s strengths and needs. This perspective is advocated by Cronk et al\textsuperscript{22} who developed physical growth curves for children with DS. We believe that this assessment approach enables parents and professionals to make management decisions and evaluate intervention outcomes more effectively than making decisions based on findings from developmental assessments normed on children without motor delays.

The purposes of the present study were to examine the motor function of a large sample of children with DS prospectively by means of a standardized criterion-referenced measure, and to apply these data: (1) to create motor growth curves that describe motor function of children with DS between the ages of 1 month and 6 years; (2) to compare the rate of improvement and upper limit of function between children with mild motor impairment and children with moderate or severe motor impairment; and (3) to estimate the probability by different ages that a child with DS is able to perform these actions: roll to prone, sit on a mat with arms free, crawl forward on hands and knees, stand alone, walk, run, walk up steps without holding onto a railing, and jump forward.

METHODS

Participants

One hundred thirty-three children with DS, 1 month to 6 years of age, who were or had been clients of early intervention programs in southern Ontario, Canada, were enrolled in a study that examined the validity of the Gross Motor Function Measure (GMFM)\textsuperscript{23} for evaluating change in children with DS.\textsuperscript{24} The data from the initial GMFM assessment were further analyzed to meet the objectives of the present study. Informed consent of a parent or guardian was obtained for each subject. Ten subjects who did not complete the study and 2 additional subjects for whom motor impairment was not determined were excluded from data analysis. The sample of 121 subjects consisted of 65 boys and 56 girls. The subjects’ ages varied between 1.7 and 72 months (mean ± standard deviation, 28.9 ± 20.7mo). The age distribution of subjects is in table 1.

The subjects had the following types of DS: trisomy 21 (80%), translocation type (5%), mosaic type (2.5%), mixed type (0.8%), and unknown (11.6%). The most common health problems identified by parents were heart conditions (54%), hearing impairments (28%), visual impairments (21%), feeding difficulties (16%), thyroid dysfunction (7%), seizures (4%), and “other congenital” problems (16%). After enrollment in the study, 51 children were classified as having mild motor impairment, 64 as having moderate motor impairment, and 6 as having severe motor impairment according to the criteria described in the Instruments subsection and in table 2. We combined the moderate and severe groups because the number of children with severe motor impairment (n = 6) was too small for analysis. The GMFM total score for these 6 children ranged from 13 to 50 (mean, 36.1 ± 12.8). The GMFM total score for the 64 children with moderate motor impairment ranged from 4 to 91 (mean, 53.1 ± 28.2).

Instruments

Motor development was assessed by means of the GMFM, a criterion-referenced measure constructed specifically to evalu-
Table 2: Motor Impairment Rating Scale

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Mild</td>
<td>Movement patterns at a similar stage of motor development are similar to those of children without DS. The child shows sufficient muscle tone, strength, and voluntary control to initiate, adapt, and sustain movements during play.</td>
</tr>
<tr>
<td>Moderate</td>
<td>The child is able to initiate, adapt, and sustain movements during play, but movement patterns are less efficient than those of children without DS. The child’s movements are characterized by excessive motion in some weight-bearing joints, a wide base of support, reduced balance, and compensatory movements when muscle tone and strength are not adequate to meet the demands of a task.</td>
</tr>
<tr>
<td>Severe</td>
<td>The child has difficulty initiating, adapting, and sustaining movements during play. Frequency of movement and physical endurance may be limited. Movement patterns are inefficient and characterized by compensations that reflect low muscle tone, reduced strength, and limitations in voluntary control of movement.</td>
</tr>
</tbody>
</table>

Data Analysis

We examined how well a 2-parameter exponential model describes the motor function of children with DS as a nonlinear function of age. Previously, we developed and applied the model to describe motor function of children with CP.24 The model uses a function that increases over time, more rapidly at the beginning and then leveling off as children approach the upper limit of motor function. The 2 parameters are a rate and an upper-limit parameter. The model equation used to calculate the motor growth curves was

\[
\text{GMFM} = \theta(1 - e^{-\lambda t})
\]

where \( \theta \) is the limit parameter, \( e \) the base of natural logarithms, \( \lambda \) the rate parameter, and \( t \) the age. The limit parameter (\( \theta \)) is an estimate of the maximum GMFM score of children with DS as they get older. The higher the limit parameter, the higher the height of the curve. The rate parameter (\( \lambda \)) is an estimate of how fast children with DS approach their maximum GMFM score. The higher the rate parameter, the faster children approach their maximum score.

The following criteria were used to identify a satisfactory fit of the model to data by using nonlinear regression methods: (1) visual agreement between the observed GMFM scores and the predicted GMFM scores from the regression model; (2) a random pattern of residuals; (3) small number of extreme outlier scores; (4) interpretation of the parameter estimates, including comparison of estimates between the 2 groups; (5) a low mean squared error (variance of the difference between the observed and predicted scores); and (6) a high (pseudo) \( R^2 \) value, indicating the overall fit of the model.

The probability that a child with DS is able to perform gross motor functions by different ages was estimated by using logistic regression. We selected 8 items on the GMFM to represent motor functions that are important in early childhood and provide information that is useful to parents (table 3). Scores for each item were recoded as “achieved” or “not achieved” based on criteria presented in table 3. For each item, a logistic regression was performed. Achievement of the motor function was the dependent variable and age was the independent variable.

Data were analyzed by using the Biomedical Data Program (BMDP), version 7.4 and SPSS, version 6.14.9

RESULTS

The plots of the observed GMFM scores and the motor growth curve for children with mild motor impairment are in figure 1, and those for children with moderate or severe motor impairment are in figure 2. The curves represent the average scores predicted by the model. Both curves are characterized by an improvement in GMFM scores with age with the largest change during infancy and smaller increases as children get older and approach the upper limit parameter (maximum GMFM score predicted by the model). Observed scores cluster close to the predicted scores during the first year and then are
more variable. The (pseudo) $R^2$ is .848 for the curve for children with mild motor impairment and .818 for the curve for children with moderate or severe motor impairment. These findings indicate that the 2-parameter model has a good overall fit.

The rate parameter (estimate of the proportional rate of increase of GMFM scores) is .054 (95% confidence interval [CI] = .041–.067) for the curve for children with mild impairment and .044 (95% CI = .013–.075) for the curve for children with moderate or severe impairment. Children with mild impairment have approximately 25% faster improvement in GMFM scores compared with children who have moderate or severe impairment. The upper limit parameter (maximum GMFM score) is 87.9 (95% CI = 80.2–95.6) for the curve for children with mild impairment and 85.9 (95% CI = 65.3–100) for the curve for children with moderate or severe impairment. The upper limit parameter for the 2 curves is qualitatively similar. The GMFM scores predicted by the model at ages 1, 3, and 5 years are in table 4.

The predicted probabilities that children with DS are able to perform gross motor functions by particular ages are listed in table 5. Rolling is the only movement children are likely to have achieved by the age of 6 months. The probability that children with DS will sit by 12 months is 78%; by 18 months the probability is 99%. The probability of crawling forward on hands and knees and standing without support by 18 months is 34%; by 24 months the probability is greater than 50%. The probability that a child with DS will walk by 24 months is 40%; by 30 months the probability is 74%, and by 36 months the probability is 92%. The probability of running, walking upstairs, and jumping forward by the age of 4 years ranges from 18% to 25%. The probability of running, walking upstairs, and jumping forward by the age of 5 years ranges from 45% to 52%; by the age of 6 years, the probability ranges from 67% to 84%.

The conditional probability that a child who is unable to perform a gross motor function at a particular age ($T_1$) will achieve a gross motor function by a particular age ($T_2$) can be determined from table 5 by using the following proportion:

$$ \text{Probability at } T_2 = \frac{\text{Probability at } T_1}{1 - \text{Probability at } T_1} $$

For example, for a child who is 18 months old and unable to walk, the conditional probability that the child will walk by 24 months is 30% ($\frac{.40 - .14}{1 - .14} = .26/.86 = .30$) and by 30 months is 70% ($\frac{.74 - .14}{1 - .14} = .60/.86 = .70$).

**DISCUSSION**

The relationship between age and gross motor function in children with DS during the first 6 years of life is represented by motor growth curves in which scores improve the fastest at younger ages, then level off as the predicted upper limit of gross motor function is approached. The difference rate and upper limit parameters for the curves suggest that motor impairment has a discernable effect on rate of improvement but only a slight effect on ultimate achievement of gross motor function during early childhood. The upper limit parameters (GMFM scores, 85.9, 87.9) also showed that, on average, children with DS did not achieve all the gross motor functions included on the GMFM by the age of 6 years.

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**Table 3: Criteria for Achievement of Gross Motor Functions**

<table>
<thead>
<tr>
<th>Function</th>
<th>GMFM Item</th>
<th>Passing Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling</td>
<td>8</td>
<td>3</td>
<td>Rolls to prone over side from lying in supine</td>
</tr>
<tr>
<td>Sitting</td>
<td>24</td>
<td>3</td>
<td>Sits on floor at least 3s, arms free</td>
</tr>
<tr>
<td>Crawling</td>
<td>45</td>
<td>3</td>
<td>Crawls reciprocally forward at least 6ft (1.82m) on hands and knees</td>
</tr>
<tr>
<td>Standing</td>
<td>56</td>
<td>≥2</td>
<td>Stands with arms free and no support for at least 3s</td>
</tr>
<tr>
<td>Walking</td>
<td>69</td>
<td>3</td>
<td>Walks forward 10 steps with arms free and no support</td>
</tr>
<tr>
<td>Running</td>
<td>77</td>
<td>3</td>
<td>Runs 15ft (2.74m), stops, and returns</td>
</tr>
<tr>
<td>Jumping</td>
<td>81</td>
<td>≥2</td>
<td>Jumps forward at least 2in (5.08cm), both feet simultaneously</td>
</tr>
</tbody>
</table>
| Climbing stairs   | 86        | ≥1             | Walks up at least 2 steps from the base of the stairs, alternating feet, without holding on stairs, and jumping forward by the age of 4 years ranges from 18% to 25%. The probability of running, walking upstairs, and jumping forward by the age of 5 years ranges from 45% to 52%; by the age of 6 years, the probability ranges from 67% to 84%.

**Fig 1.** Gross motor function growth curve: children with mild motor impairment ($n = 51$). X, observed values; -, predicted values nonlinear regression.
The rate of improvement in gross motor function predicted by the model suggests that children with DS require more time to learn movements as movement complexity increases. The motor control requirements for posture, weight support, muscle force production, and balance increase as children progress from floor mobility to walking, to the ability to perform movements used during play and recreation such as running and jumping. During infancy, when GMFM scores improve the fastest, children with DS are developing the ability to sit and move on the floor. Between the ages of 18 months and 3 years, most children with DS are learning to stand alone and to walk. The slower improvement in scores during this period may correspond to the increased motor control required to move when standing where the center of gravity is higher and the base of support smaller and less stable compared with creeping and crawling. Between the ages of 3 and 6 years, most children with DS are learning to run, walk up and down stairs, and jump. This period corresponds to the portion of the curve where there is the smallest improvement in GMFM scores and may reflect the increased motor control required for limb coordination, speed, and balance. For some children, changes in the ratio of muscle to lean body mass and a reduced level of fitness may also constrain development of the muscle strength and endurance that a child needs to perform movements used in play and recreation.

Our ability to assess the impact of motor impairment was limited by the small number of children classified as having severe motor impairment and by potential measurement error. Because only 6 subjects had severe motor impairment, they were grouped for analysis with children rated as having moderate impairment. Combining subjects reduced the variability in the ratio of muscle to lean body mass and a reduced level of fitness may also constrain development of the muscle strength and endurance that a child needs to perform movements used in play and recreation.

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Table 4: Predicted GMFM Scores at Selected Ages by Motor Impairment Group

<table>
<thead>
<tr>
<th>Motor Impairment Group</th>
<th>1yr</th>
<th>3yr</th>
<th>5yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>41.2</td>
<td>75.2</td>
<td>84.4</td>
</tr>
<tr>
<td>Moderate/severe</td>
<td>35.4</td>
<td>69.5</td>
<td>79.9</td>
</tr>
</tbody>
</table>

Sample. Measurement error is another potential confounding factor. The reliability and validity of the motor impairment rating scale have not been examined. Poor interrater reliability or inaccurate definitions for mild, moderate, and severe impairment, or both, could have reduced differences in motor function between the groups. Further study, taking account of the difficulties outlined earlier, is needed to provide a more definitive understanding of how motor impairment affects development of gross motor function.

An apparent difference between the results of the present study and what was previously reported for children with DS is the upper age of walking. In the present study, the estimated probability of walking by 36 months was 92%. The percentage of children reported to walk at 36 months in 3 earlier studies varies from 78% to 82%. Our findings that the probability of walking by 18 months is 14%, by 24 months is 40%, and by 30 months 73% compares favorably with the findings of Fishler et al, Centerwall and Centerwall, and Hall who reported that children with DS may walk as early as 15 to 18 months, and also to those of Melyn and White and Carr who reported the mean age of walking as 24 and 28 months, respectively. In contrast to the children in the present study who had received or were receiving early intervention, the studies cited were conducted before the widespread availability of early intervention services. Perhaps early intervention by parents and professionals does not lower the age of walking in children with DS below constraints imposed by maturation of the nervous and musculoskeletal systems. Rather, early intervention services may promote more efficient walking and earlier walking in children with health problems such as heart conditions and those with moderate or severe motor impairments. These issues were not explored in the present study.

The present study’s results provide an evidence-based resource to assist parents and professionals to set intervention goals and outcomes that have a high probability of being achieved. The motor growth curves show the average pattern of development of children with DS based on cross-sectional data. One cannot assume that all children with DS will follow the average predicted by the model. The motor growth curves and the results of the logistic regression, however, can be used to help anticipate when a child is likely to acquire a motor function. For example, the results suggest that for most 18-month-old children with DS who are unable to walk, 6 months is too short a time frame (conditional probability, 30%).
Conclusions

The present study contributes to the understanding of gross motor function of children with DS by providing evidence about the rate of improvement and upper limit of motor function during the first 6 years of life. The results indicate that children with DS require more time to learn movements as movement complexity increases and that, on average, children with DS did not completely achieve by the age of 6 years the motor abilities measured by the GMFM. The results should prove useful in describing gross motor function of children with DS at specific ages. The results also have implications for making decisions about if and when motor interventions such as physical and occupational therapy are needed and in setting goals for intervention.

Longitudinal data from a larger sample of children with DS is necessary to determine the extent to which individual children follow the average pattern predicted by the model: at least 3 GMFM assessments performed at 3- to 6-month intervals is recommended. The greater the number of observations per subject and the longer the period of time that is represented by each child’s data, the greater the precision in fitting a curve that represents the rate, upper limit of motor function, and variability among children with DS. Similarly, estimation of the probability that a child with DS will have achieved a motor function by a specific age would be improved by multiple GMFM assessments of the same child over time.

Table 5: Predicted Probability of Achieving Gross Motor Functions Across Ages for Children With DS Based on Logistic Regression

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Predicted Probability (%) of Achieving Motor Milestone</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Rolling</td>
<td>51</td>
</tr>
<tr>
<td>Sitting</td>
<td>8</td>
</tr>
<tr>
<td>Crawling</td>
<td>10</td>
</tr>
<tr>
<td>Standing</td>
<td>4</td>
</tr>
<tr>
<td>Walking</td>
<td>1</td>
</tr>
<tr>
<td>Running</td>
<td>1</td>
</tr>
<tr>
<td>Climbing step</td>
<td>0</td>
</tr>
<tr>
<td>Jumping forward</td>
<td>0</td>
</tr>
</tbody>
</table>

References


Supplier
a. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.