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

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ABSTRACT. Palisano RJ, Walter SD, Russell DJ, Rosenbaum PL, Gémus M, Galuppi BE, Cunningham L. Gross motor function of children with Down syndrome: creation of motor growth curves. Arch Phys Med Rehabil 2001;82:494-500.

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.

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[1]), which are based on the average performance of children without developmental delays.[2-4] 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.[5] 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.[6] Children with DS have delays in development of motor function associated with impairments that include low muscle tone, joint hyperextensibility, poor postural control, poor balance, and, for some children, congenital heart disease, and obesity.[7-10] 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 motor 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[11] and as late as 74 months.[10] Centerwall and Centerwall[12] and Kugel and Reque[13] 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[10] reported that children with DS living at home walked at a mean age of 24 months whereas Carr[14] reported a mean age of 28 months. The percentage of children walking at 2 years of age has been reported as 25%[14] and 44%,[12] and at 3 years as 78%[12] and 82%.[15]

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[9] and 6.4 months.[10] The mean age for independent floor sitting varies between 8.5 months[9] and 11.7 months.[10] The mean age for crawling has been reported as 12.2 months[10] and 17.3 months.[11] Carr[14,16] 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

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development in children with DS. Chen and Woolley[9] and Piper et al[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[9] administered the Denver Developmental Screening Test[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[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.[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[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 developmental delays have reported that motor development quotients of children with DS decrease with age.[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[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)[23] for evaluating change in children with DS.[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 1: Age Distribution by Gender

Boys ($n = 65$)	n	Girls ($n = 56$)	n
5–6yr	9	5–6yr	4
4–5yr	9	4–5yr	6
3–4yr	10	3–4yr	9
2–3yr	9	2–3yr	5
1–2yr	13	1–2yr	14
<1yr	15	<1yr	18

Table 2: Motor Impairment Rating Scale

Rating	Description
Mild	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.
Moderate	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.
Severe	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.

ate change in gross motor function in children with motor disabilities.[23-25] Criterion-referenced measures are designed to assess a child's ability in a particular domain and to evaluate change over time without regard to the distribution of scores achieved by other children of the same age.[26] The GMFM consists of 88 items that are grouped into 5 dimensions: lying and rolling (17 items); sitting (20 items); crawling and kneeling (14 items); standing (13 items); and walking, running, and jumping (24 items). Items are measurable by observation and scored on a 4-point ordinal scale. Scores for each dimension are expressed as a percentage of the maximum score for that dimension. The total score is obtained by adding the scores for each dimension and dividing by 5 (the number of dimensions), so each dimension contributes equally to the total score. The total score varies from 0 to 100. The GMFM is reliable, valid, and responsive (ability to measure change) for children with cerebral palsy[25] (CP) and DS.[24]

Motor impairment was rated as mild, moderate, or severe by using criteria developed for the present study (table 2). The rating represented the assessor's overall judgment of muscle tone, strength, range of motion, motor control, efficiency of movement, and quality of movement.

Procedure

Each child was administered the GMFM and rated on degree of motor impairment by 1 of 18 service providers (9 physical therapists, 8 occupational therapists, 1 psychometrist). Seventeen assessors had 5 or more years of experience with infants and young children and 14 had 5 or more years experience working with children with DS. All assessors were tested to ensure they had reached the minimally acceptable level of interrater reliability for scoring the GMFM (weighted $\kappa >$ .80).[27] Criterion test scores of individual assessors ranged from a kappa value of .87 to .99, indicating excellent agreement.

The assessments were administered at community early intervention programs, health care facilities, schools, or children's homes. The standard procedure for administration of the GMFM requires that the assessor score only the motor behaviors actually performed by the child during the assessment. Because some concern was raised in previous reports[28] about how much a GMFM score is affected by the young child's ability or willingness to comply with the assessor's requests, the assessors also asked the child's parents for information regarding typical performance on items that the child regularly showed at home but failed to perform during the assessment. The information obtained by parent report was included when calculating a child's GMFM score. At least 1 reported item was included in 81 of the 121 (67%) GMFM assessments. The frequency of inclusion of reported scores across cases ranged from 1 to 32 items (mean, 8 ± 6.9).

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.[29] 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 θ is the limit parameter, e the base of natural logarithms, λ the rate parameter, and t the age. The limit parameter (θ) 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 (λ) 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,[a] and SPSS, version 6.14.[a]

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

Table 3: Criteria for Achievement of Gross Motor Functions

Function	GMFM Item	Passing Score	Description
Rolling	8	3	Rolls to prone over side from lying in supine
Sitting	24	3	Sits on floor at least 3s, arms free
Crawling	45	3	Crawls reciprocally forward at least 6ft (1.82m) on hands and knees
Standing	56	≥2	Stands with arms free and no support for at least 3s
Walking	69	3	Walks forward 10 steps with arms free and no support
Running	77	3	Runs 15ft (2.74m), stops, and returns
Jumping	81	≥2	Jumps forward at least 2in (5.08cm), both feet simultaneously
Climbing stairs	86	≥1	Walks up at least 2 steps from the base of the stairs, alternating feet, without holding on

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:

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

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% ([.40 − .14]/[1 − .14] = .26/.86 = .30) and by 30 months is 70% ([.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.

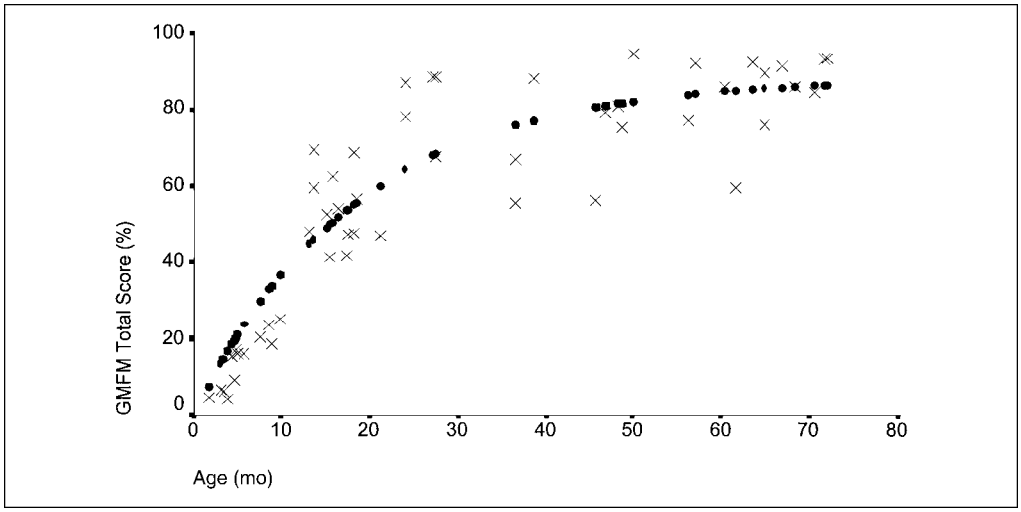

Fig 1. Gross motor function growth curve: children with mild motor impairment (*n* = 51). X, observed values; ●, predicted values nonlinear regression.

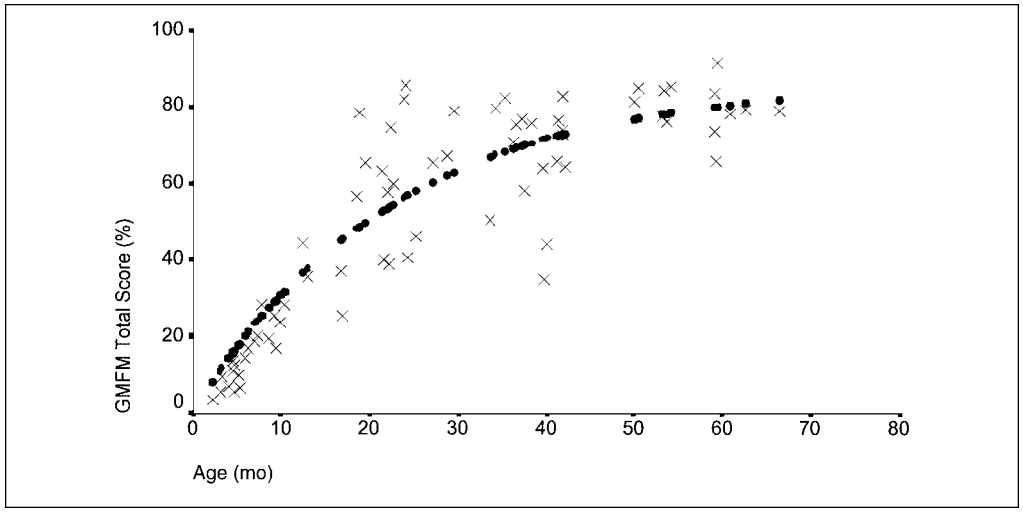

Fig 2. Gross motor function growth curve: children with moderate or severe motor impairment ($n = 70$). X, observed values; ●, predicted values nonlinear regression.

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 of the motor impairment rating scale. Furthermore, it is not clear whether only a small percentage of children with DS met our definition of severe motor impairment or whether children with severe impairment were not adequately represented in our 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.

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

	Predicted GMFM Scores		
Motor Impairment Group	1yr	3yr	5yr
Mild	41.2	75.2	84.4
Moderate/severe	35.4	69.5	79.9

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[12,14,15] 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,[11] Centerwall and Centerwall,[12] and Hall[15] who reported that children with DS may walk as early as 15 to 18 months, and also to those of Melyn and White[10] and Carr[14] 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%),

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

Millestone	Predicted Probability (%) of Achieving Motor Milestone								
	Age (mo)								
	6	12	18	24	30	36	48	60	72
Rolling	51	64	74	83	89	93	97	99	100
Sitting	8	78	99	100	100	100	100	100	100
Crawling	10	19	34	53	71	84	96	99	100
Standing	4	14	40	73	91	98	100	100	100
Walking	1	4	14	40	74	92	99	100	100
Running	1	2	3	5	8	12	25	45	67
Climbing step	0	0	1	1	3	5	18	46	77
Jumping forward	0	0	0	1	2	5	18	52	84

whereas 12 months is a time frame by which children have a high probability of walking (conditional probability, 70%). We suggest that the results be used in conjunction with other relevant information when making decisions for individual children. This suggestion is consistent with evidence-based practice where the best available knowledge and research is used to guide clinical decision making within the context of the individual client.[30]

The finding that the motor growth curves begin to level off above the age of 3 years has implications when determining the needs of preschool and primary school age children with DS. The estimated probability that children with DS will: (1) run 15 feet, stop, and return; (2) walk up a minimum of 2 steps without holding a railing; and (3) jump forward with both feet by the age of 5 years ranges from 45% to 52%. These abilities are associated with motor activities common to the play and recreation of young children. Maximizing the play and recreation abilities of children with DS may enhance self-esteem, contribute to social interactions, and increase participation in inclusive settings.[31,32]

The results also have implications for decisions about motor interventions such as physical and occupational therapy. Children whose motor function is age appropriate or advanced relative to expectations for children with DS may successfully achieve motor goals through play and structured developmental activities; and interventions may appropriately be directed to other areas of development. Conversely, children whose gross motor function is delayed relative to expectations for children with DS may be less likely to achieve goals without therapy intervention. We believe that this approach to assessment will enable 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.

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.

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