Basic Motor Skills of Children With Down Syndrome: Creating a Motor Growth Curve

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Purpose: To create a motor growth curve based on the Test of Basic Motor Skills for Children with Down Syndrome (BMS) and estimate the age of achieving BMS milestones.

Methods: A multilevel exponential model was applied to create a motor growth curve based on BMS data from 119 children with Down syndrome (DS) aged 2 months to 5 years. Logistic regression was applied to estimate the 50% probability of achieving BMS milestones.

Results: The BMS growth curve had the largest increase during infancy with smaller increases as children approached the predicted maximum score. The age at which children with DS have a 50% probability of achieving the milestone sitting was 22 months, for crawling 25 months, and for walking 38 months.

Conclusions: The creation of a BMS growth curve provides a standardization of the gross motor development of children with DS. Physical therapists then may monitor a child's individual progress and improve clinical decisions. (Pediatr Phys Ther 2020;32:375–380)

Key words: Down syndrome, motor development, motor growth curve

INTRODUCTION

Young children with Down syndrome (DS) have delays in gross motor development. Motor milestones are reached at a later age compared with children without a disability[1,2] or children with a mental retardation that is not caused by DS.[3] For example, the mean age for achieving the milestone sitting without support was 10 months (typical development 7 months), measured with the Alberta Infant Motor Scale (AIMS),[4] and 12 months (typical development 6 months), measured with the Bayley Scales of Infant Development (BSID),[5] and for independent walking 26 months (typical development 12 months).[5,6] Not only is their motor development delayed, there is also evidence that they show a different order in which motor milestones are achieved.[7,8] It has been suggested that children with DS have a disorder-specific motor development profile[9] that is due to hypotonia, joint hypermobility, and reduced postural reactions,[7,10,11] resulting in disturbances in postural control and balance. As a result, children with DS develop static and symmetrical movement patterns with a lack of variability that hinder the development of functional motor skills.[12] These "early" motor problems persist in childhood, as evidenced by the lack of motor proficiency of children with DS at school age.[13-15]

There is a need for a standardization of the motor development of children with DS to evaluate their motor development. Gross motor development in children with DS is often assessed with norm-referenced developmental tests (eg, AIMS, BSID, and Test of Infant Motor Performance),[4-6,16] which are less suitable for children with DS because of the disorder-specific motor profile that makes it difficult to justify a reference to typical development. Moreover, such "general" motor developmental tests are probably less sensitive to assess changes in motor function in children with DS as a result of an intervention. As an alternative, comparison of the motor development score of an individual child with DS with the average score of a reference group of children with DS might provide better estimates. For decisions about the need and intensity of motor intervention, it is important to identify children with DS whose gross motor function is delayed relative to the mean expectation for children with DS. This requires a motor growth curve for children with

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TABLE 1

Example of the Subdivision of Test Item 7 "Postural Control in Sitting"

Method of execution	
The child is placed in the sitting-without-support position on a horizontal surface and is encouraged to stretch from the trunk by eliciting reaching upward with the arms and to transfer weight laterally by eliciting sideways reaching out with the arms.	
Developmental step	**Score**
0. The test item has been correctly administered; however the child shows no motor behavior that is described in any of the stage specifications below.	0
1. The child sits independently during stimulation for at least 5 s while supporting the position with 2 hands.	1
2. The child sits independently during stimulation for at least 5 s while supporting the position with 1 hand.	
3. The child sits independently during stimulation for at least 2 s without support from the arms and with a bent back.	
4. The child sits independently during stimulation for at least 2 s without support from the arms with a straight back without lumbar lordosis.	2
5. The child sits independently during stimulation without support from the arms. When stretching the back, a clear lumbar lordosis can be observed for at least 2 s.	
6. The child sits independently during stimulation without support from the arms. When stretching the back and transferring weight to the lateral, a clear lumbar lordosis and a clearly lateral flexed trunk can be observed for at least 2 s.	3

DS. Palisano and colleagues[17] created gross motor growth curves for children with DS aged 1 month to 6 years based on the Gross Motor Function Measure (GMFM). The GMFM was developed specifically for children with cerebral palsy and is considered valid and reliable for evaluating the motor development of children with DS.[18] In the study by Palisano and colleagues,[17] 2 motor growth curves were reported based on the severity of motor impairment (mild or moderate/severe) derived from an overall judgment of muscle tone, strength, range of motion, and motor control. The severity of impairment affected the rate but not the upper limit of gross motor function. With regard to the GMFM items that represent major motor milestones, it was reported that the predicted probability of achieving the milestone "sitting" ranged between 8% at 6 months and 99% at 18 months, for " crawling" between 10% at 6 months and 96% at 48% months, and for "walking" between 14% at 18 months and 92% at 36 months.

Although the creation of motor growth curves based on the GMFM has been a step forward to better assess and evaluate the motor development of children with DS, the GMFM was not specifically developed for children with DS. Based on the disorder-specific disturbances in postural control of children with DS, Lauteslager[12] introduced a physical therapy approach for young children with DS that includes the criterion-referenced instrument "Test of Basic Motor Skills for Children with Down Syndrome" (BMS). The BMS is not only diagnostically useful for determining the motor development level of a child with DS, but is also indicative of the steps to be followed in the further course of the intervention because it makes a distinction between different functional performance levels of a particular basic motor skill. For example, the item "sitting" distinguishes different levels depending on the ability of the child to sit independently with or without support of the arms, or the ability to shift its weight to the lateral side (Table 1).[12] Thus, the BMS appears to be an alternative to the GMFM for measuring the motor development of children with DS, but no BMS development curves have been available to date. The aim of the present study is (1) to create a BMS growth curve that describes the gross motor function of children with DS between the ages of 2 months and 5 years, and (2) to estimate the age at which a child with DS has a 50% probability to achieve particular gross motor skills on the BMS. Such a motor growth curve for children with DS can be used to give information about the level of motor development of an individual child with DS and provides a foundation for goal-oriented motor intervention.

METHODS

Participants

Participants of the present study were 119 children with DS (67 boys and 52 girls) in the age of 0 to 5 years who were recruited via the Dutch Parent Association for children with Down syndrome and the Dutch Association for Pediatric Physiotherapy. Children came from different parts of the Netherlands and were living at home. The BMS data of these 119 children with DS were taken from previous studies (n = 101)[12,19] and supplemented with unpublished BMS data of children with DS who received physical therapy in our clinic (n = 18). According to the Dutch multidisciplinary guideline for the medical supervision of children with Down syndrome, every child with DS is seen by a pediatric physiotherapist in the first year of life.[20] During the period of development of basic motor skills, children with DS in the Netherlands are generally treated by a physiotherapist with a frequency ranging from once a week to once a month. A total of 119 children with DS participated in the current study, resulting in a total of 334 BMS measurements. Characteristics of the children with DS are in Table 2, and Table 3 includes the age distribution by gender.

TABLE 2

Characteristics of Children With Down Syndrome

	n (%)	Range	Mean (SD)
Age at first measurement, mo		1-59	22.0 (15.7)
Gender			
Boys	67 (56.3)		
Girls	52 (43.7)		
Measurements per child, n			
1	50 (42.0)	1-6	2.6 (2.1)
2-4	48 (40.4)		
5-6	21 (17.6)		
Congenital heart disease	36 (30.3)		
Multiple health problems	18 (15.1)		

TABLE 3
Age Distribution by Gender

	Assessments on BMS Test, n	
Age, mo	Boys	Girls
<12	62	52
12-23	74	41
24-35	37	39
36-47	9	12
48-59	4	3
60-72	1	0

Abbreviation: BMS, Test of Basic Motor Skills for Children with Down Syndrome.

Previous Studies. In a psychometric study, 42 children with DS (26 boys and 16 girls; mean age 31 months, age range 1-59 months) participated and the BMS was administered once for each child (total: 42 measurements).[12] The age of inclusion was 0 to 4 years. In a second study, the effect of physical therapy on the development of basic motor skills in 18 children with DS (9 boys and 9 girls; mean age at start 7 months, age range 3-11 months) during a period of 14 months was investigated.[12] Each child was assessed 6 times (total: 108 measurements). The age of inclusion was 1 to 11 months. One additional exclusion criterion was applied; children with DS whose parents already knew that they would often have to be admitted to hospital because of health problems were excluded from the study. In a third study, we examined the responsiveness of the BMS in 41 children with DS (19 boys and 22 girls; mean age at start 22 months, age range 3-36 months).[19] Each child was tested 3 times in a period of 16 weeks (total 123 measurements). The age of inclusion was 1 to 36 months.

Instruments

BMS. The BMS is based on the theoretical framework "disturbances in the regulation of postural control,"[9] and consists of 15 basic motor skills items. Each basic motor skill is split up in subdivisions, representing specific developmental steps of motor behavior. For each item a score from 0 to 3 corresponding to the level of motor behavior for that specific motor skill is obtained, giving a total score of 45 points. Disorder-specific aspects resulting from problems in postural control can easily be traced in these subdivisions.[12] For each item, level 1 stands for the first manifestation of motor behavior for that skill, the last level stands for motor behavior with a functional level of postural control for that skill. The subdivisions per item represent the course of development as manifested under the influence of increasing postural control.[12] Depending on the level of motor development, it takes 10 to 30 minutes to administer the BMS.

The interrater and intrarater reliability of the BMS was reported in one of the previous studies and was found to be good (Cohen's kappa was $\kappa = 0.85$ and $\kappa = 0.89$, respectively).[12] Internal consistency of the BMS was good (Cronbach $\alpha = 0.94$). An additional inter- and intrarater reliability analysis was applied on 10 randomly selected children with DS from the group of 18 children with DS whose data were not published. Two experienced pediatric physical therapists who were trained in administering and scoring the BMS test in children with DS scored children's performance on the BMS that were videotaped independently of each other. The interrater reliability was good ($\kappa = 0.89$). After 4 weeks, both assessors scored the BMS again for each of 5 children. The intrarater reliability was good, $\kappa = 0.91$ (MvdH) and $\kappa = 0.92$ (PL).

Test items have good coherence and contribute homogenously to the BMS total score. Construct validity was tested with partial credit model analysis.[21] All items measured the variable "level of postural control" unidimensional. The 15 items were in developmental order and represented an increasing degree of postural control. In addition, there was a significant correlation between age and the BMS score ($r = 0.81$; $P < .001$).[12] Responsiveness of the BMS was investigated by comparing scores on the BMS with scores on the GMFM using Guyatt's Responsiveness Index (GRI).[19] The responsiveness of the BMS was large (GRI = 2.55) and did not significantly differ from the responsiveness of the GMFM. These results support that the BMS is reliable, valid, and responsive to measure (changes in) the gross motor development of children with DS aged 3 to 36 months.

Procedure

Informed consent was obtained and the study has been approved by the ethics committee of 's Heeren Loo. Children could participate in the research regardless of problems in motor behavior, level of mental retardation, or health problems. For all children that participated in one of the studies from which the data were used, the BMS was administered and scored at home or in clinic according to the standard procedure by 3 experienced pediatric physical therapists who were trained in administering and scoring the BMS.

Data Analysis

Motor growth curves were constructed by modeling the total BMS scores as a function of age, taking into account the dependency structure in the data. The available measurement points were not balanced; that is, the number of measurements and the time (age) of measurement differ per participant. Therefore, an analysis is required that treats the repeated measurements as hierarchical data, with measurement occasions nested within individuals. In this case, motor growth curves can be constructed by means of multilevel analyses.[22]

The multilevel model used is a 2-parameter exponential model. The use of an exponential function creates a model that increases over time more rapidly at the beginning and then levels off as children approach the upper limit of motor function. The 2 parameters of the model are the growth rate (λ) and the upper limit (θ).

The multilevel exponential model equation is given by

$$BMS = (\theta_{00} + u_0)\left(1 - \exp\left\{-\exp\{\lambda_{10} + u_1\}\,Age\right\}\right)$$

where θ_{00} is the average limit parameter (across individuals), exp is the base of the natural logarithm, and λ_{10} is the average rate parameter (across individuals). *Age* is given in weeks. The terms u_0 and u_1 are random error terms representing individual

differences in the limit parameter and rate parameter, respectively. The limit parameter is an estimate of the maximum BMS score of children with DS (upper boundary). The higher the limit parameter, the higher the curve. The rate parameter is an estimate of how fast children with DS approach their maximum total BMS score. The higher the rate parameter, the faster a child approaches its maximum score.

The probability of a child demonstrating specific motor behavior at a certain age can be predicted using multilevel logistic regression analysis.[23] As developmental steps were scored between 0 and 3 for each test item, predictions could be made for the different levels of motor development per test item. The probability that a child demonstrates the last and most advanced level of motor behavior on a certain test item (score = 3) was obtained for the ages of 3 to 72 months. Again, multilevel models are required to take the hierarchical nature of the data into account. For each test item, the multilevel logistic regression equation that models the achievement of the motor function with age is given by

$$\text{Logit}(\varphi) = \gamma_{00} + \gamma_{10}Age + u_0$$

where φ represents the probability of passing an item, γ_{00} is the average intercept (across individuals), γ_{10} is the regression coefficient of *Age*, and u_0 is again a random error term representing individual differences in the intercept of children.

Data were analyzed using R version 2.7.2, the R-package "Nonlinear Mixed-Effects Models,"[24] and SPSS version 16.0.

RESULTS

There were no significant differences between boys and girls in either the rate (95% confidence interval [CI] males, 46.87 to 56.63; 95% CI females, 41.43 to 52.68) or the limit parameter (95% CI males, −4.92 to −4.63; 95% CI females, −4.80 to −4.42). Therefore, the analyses reported here include all participants, and no gender differentiation was made. The Figure graphs the observed total BMS scores and the estimated motor development curve. The solid line represents the average scores predicted by the model while the dotted lines represent the upper and lower boundary of the 95% CI around the mean. The curve is characterized by an increase in total BMS score with age, with the largest change occurring during infancy, and smaller increases as children get older. The estimate of the upper limit parameter is 51.75 (95% CI, 46.85 to 56.64). The rate parameter is estimated to be 0.0084 (95% CI, 0.0073 to 0.0098). The data can also be used to construct the 95% predictive interval. That is the range within which 95% of the predicted total BMS scores fall. The dashed lines in the Figure denote this interval. Table 4 shows the average predicted BMS total score per period of 3 months.

The predicted probabilities that a child demonstrates the last and most advanced step of motor behavior (score = 3) on a certain test item at a certain age were obtained using multilevel logistic regression analysis. This resulted in a probability (expressed in percentage) for each period of 3 months. To present these predicted probabilities in a way that is meaningful to both health care professionals and parents, we have listed in Table 5 the age (in months) at which the predicted probability exceeds 50%, per test item. For example, children reach a 50% probability to achieve the most advanced step for the milestone of independent sitting at 22 months, crawling at 25 months, and independent walking at 38 months. The predicted probability results show that most children with DS will reach all items of the BMS by the age of 60 months, except for the items "sitting up" (later than 72 months) and "standing up" (67 months).

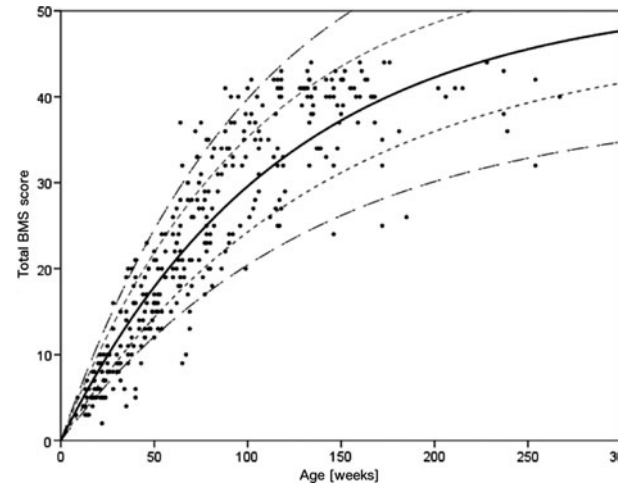

Fig. BMS growth curve: total BMS score as a function of age. Dots represent scores of individual children. The solid line represents the average scores predicted by the model while the dotted lines (- - -) represent the upper and lower boundary of the 95% confidence interval around the mean. The 95% predictive interval is denoted by the dash-dotted lines (- —- -), and represents the range within which 95% of the predicted total BMS scores fall. BMS indicates Test of Basic Motor Skills for Children with Down Syndrome.

TABLE 4

Average Predicted BMS Total Score per Period of 3 Months

Age, mo	BMS Score
3	5.38
6	10.2
9	14.51
12	18.38
15	21.85
18	24.96
21	27.74
24	30.24
27	32.47
30	34.47
33	36.27
36	37.88
39	39.32
42	40.61
45	41.77
48	42.8
51	43.73
54	44.57
57	45.31
60	45.98

Abbreviation: BMS, Test of Basic Motor Skills for Children with Down Syndrome.

TABLE 5

Predicted Probability of Achieving Motor Function

Test Item	Motor Behavior Corresponding to BMS Score of 3 (Most Advanced Step)	Age[a], mo
1. Raising legs when supine	Raises legs from the ground, flexes the trunk, and tilts pelvis backward	6
2. Reaching when supine	Reaches out with arms and tracks sideways	8
3. Raising head when supine	Raises the head, flexes the cervical spinal column, and pulls up	12
4. Elbow support when prone	Functional elbow support, reaches out with 1 arm	13
5. Rolling from prone to supine	Rolls over and rotates the trunk	19
6. Rolling from supine to prone	Sits unsupported, transfers weight to the side, and laterally flexes the trunk	15
7. Sitting	Sits unsupported, transfers weight to the side, and laterally flexes the trunk	22
8. Moving forward over the floor	Crawls forward using asymmetrical arm and leg activity	25
9. Walking with support	Crosses over from one to another table	24
10. Standing with support	Stands with support of table, transfers weight laterally, laterally flexes the trunk	29
11. Standing up with support	Stands up via half-kneeling posture with support of table	25
12. Standing without support	Stands unsupported, transfers weight laterally, laterally flexes the trunk	41
13. Sitting up	Sits up with active trunk, no arm support, lateral flexion, clear side-sitting	>72
14. Walking without support	Walks without support with trunk rotation, dynamic stabilized knees	38
15. Standing up without support	Stands up via half-kneeling posture without support	67

Abbreviation: BMS, Test of Basic Motor Skills for Children with Down Syndrome.
[a]The age at which children have a 50% probability of mastering the last and most advanced step of a particular test item on the BMS.

DISCUSSION

The aim of the present study was to construct a gross motor growth curve for young children with DS and to estimate the age at which children with DS have a 50% predicted probability to master each of the 15 motor skills in the BMS. The motor growth curve showed that the largest increase in BMS score occurred during infancy with smaller increases as children approached the predicted maximum score. The average age at which children with DS reached a 50% predicted probability to achieve the milestone sitting was 22 months, for crawling 25 months, and for walking 38 months.

The age at which children with DS in the present study have a 50% probability to achieve the milestone of crawling at 25 months seems comparable with that reported in the study by Palisano et al,[17] that is a 53% probability at 24 months. However, the age at which children with DS in the present study reached the milestone of sitting and walking (22 and 38 months, respectively) seems to occur at a later age compared with those reported by Palisano and colleagues.[17] They found a 78% probability that children reached the milestone sitting at the age of 12 months, and for the milestone walking a 40% probability at the age of 24 months and 74% at 30 months, whereas the present study found a 50% probability for sitting at 22 months, and for walking at 38 months. Also, achievement of the milestone sitting unsupported, and crawling (50% predicted probability: respectively, 22 months and 25 months) in the present study occurred at a later age compared with the achievement of the milestone sitting without arm support and reciprocal crawling (median: respectively, 10 months and 12 months) as reported by the study of Pereira and colleagues.[4] A possible explanation is the way in which the milestones are scored. In the study by Pereira et al,[4] the AIMS was assessed: the (spontaneous) motor behavior of the infant is observed in supine, prone, sitting, and standing positions, and when, for example, the item "sitting without arm support" is observed the item is scored. This item of the AIMS is maybe comparable with the BMS item "sitting unsupported" as defined on "level 1," which requires the child to "sit unsupported for 5 seconds." This latter BMS item is also comparable with the item sitting in the GMFM, which requires the child "to sit unsupported for 3 seconds." However, the more advanced levels of the BMS (level 2 and 3) require a *qualitative* evaluation of the basic motor skills in terms of *postural control and balance*. In the BMS, sitting "level 3" requires the child "to sit unsupported with the ability to transfer weight to the side and with lateral flexion of the trunk," which means that the child should be able to maintain its balance when moving toward the borders of the support plane when reaching out for a toy. The use of these more advanced levels might explain the age difference in attainment of the milestone sitting as measured with the AIMS or GMFM and the BMS. In a similar way, the difference in attainment of the milestones rolling, standing, and walking can be explained. With regard to crawling the item "crawling on hands and knees" from the GMFM corresponds already with the item crawling "level 3" from the BMS, resulting in comparable attainment of this milestone. It should be noticed that the qualitative evaluation of the developmental steps of a particular motor skill, such as sitting, gives indications for subsequent steps in treatment based on increasing levels of postural control. From the perspective of treatment of the specific motor problems of children with DS, the BMS seems better suited to apply than the GMFM.

The results underline the problems in postural control of young children with DS during the development of basic motor skills. Especially postural control during dynamic motor activities defying gravity proves to be difficult. For instance, sitting up from prone (test item 13) and standing up using a half-kneeling position (test item 15) are very demanding and require an adequate level of stabilizing posture and keeping balance. This might be the reason why the predicted probability of these items showed that most children would probably not achieve these BMS items at the age of 60 months.

Clinical Implications

The BMS growth curve offers the opportunity to compare the basic motor skills of a young child with DS to the average

performance of a reference group of young children with DS that can be used for clinical decision-making. Young children with DS that are relatively more delayed in their motor development compared with the BMS motor growth curve may need special attention for further diagnosis and for more intense treatment. For example, children that are considerably late with standing and walking might need more intensive physical therapy, or they might benefit from special treatment, such as treadmill training,[25] or wearing special DS pressure pants.[26]

Limitations of the Study and Recommendation for Future Research

Our sample contained relatively few children older than 3 years, which may have led to less accuracy in the motor growth curve for this age range. With regard to the above-mentioned application of the motor growth curve as a clinical tool, this means that some caution is required in the application of this motor growth curve for children with DS older than 3 years. Collecting further data in this age range may improve the accuracy of the fit of the BMS growth curve.

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