

GENERAL MOVEMENTS: A WINDOW FOR EARLY IDENTIFICATION OF CHILDREN AT HIGH RISK FOR DEVELOPMENTAL DISORDERS

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Detection of children with a developmental disorder, such as cerebral palsy, at an early age is notoriously difficult. Recently, a new form of neuromotor assessment of young infants was developed, based on the assessment of the quality of general movements (GMs). GMs are movements of the fetus and young infant in which all parts of the body participate. The technique of GM assessment is presented and the features of normal, mildly abnormal, and definitely abnormal GMs discussed. Essential to GM assessment is the Gestalt evaluation of movement complexity and variation. The quality of GMs at 2 to 4 months postterm (so-called fidgety GM age) has been found to have the highest predictive value. The presence of definitely abnormal GMs at this age—that is, GMs devoid of complexity and variation—puts a child at very high risk for cerebral palsy. This implies that definitely abnormal GMs at fidgety age are an indication for early physiotherapeutic intervention. (*J Pediatr* 2004;145:S12-S18)

CHILD'S BRAIN: A CONTINUOUSLY CHANGING SYSTEM

The development of the human brain is a long-lasting process. It is at approximately 30 years of age that the nervous system obtains its adult configuration (Fig 1).^{1,2} Development starts during the early phases of gestation with the proliferation of neurons in the germinal layers near the ventricles. Next, neurons migrate in an orderly fashion to their final places of destination, and they start to differentiate. Neuronal differentiation includes the formation of dendrites and axons, the production of neurotransmitters and synapses, and the elaboration of the intracellular signaling machinery and the complex neural membranes. The process of differentiation is particularly active in the few months before birth and the first postnatal months. However, synapse formation continues throughout life. Besides neural cells, glial cells are generated. The peak of glial cell production occurs in the second half of gestation. Some of the glial cells take care of axonal myelination. Myelination takes place especially between the second trimester of gestation and the end of the first postnatal year. However, it is first completed around the age of 30 years. A remarkable feature of brain development is that it consists not only of the creation of components but also of an elimination of elements. Approximately half of the created neurons die off (apoptosis), in particular during midgestation. Similarly, axons and synapses are eliminated, the latter especially between 18 months of age and the onset of puberty. The shaping of the nervous system by these regressive phenomena is guided by neurochemical processes and neural activity. The neural elements that fit the environment best persist, thus allowing for an adaptation of the brain to its own environment.

This indicates not only that a substantial part of brain development occurs before term age, but also that throughout childhood, the brain is in a continuous process of remodeling. The presence of continuous neurobiological changes during childhood has major clinical consequences. First, the fact that a child has an age-specific nervous system invokes the need for an age-specific neurological assessment—that is, the application of neuromotor evaluation techniques that are adapted to the age-specific characteristics of the nervous system. Second, the age-dependent characteristics affect the way neural dysfunction is expressed. Neurological dysfunction in adults is expressed by means of specific and localized signs—for example, by means of the specific syndrome of a spastic hemiplegia in case of stroke. In contrast, neurological dysfunction in young infants is

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ADHD	Attention deficit hyperactivity disorder	MND	Minor neurological dysfunction
CP	Cerebral palsy	PMA	Postmenstrual age
GM	General movement		

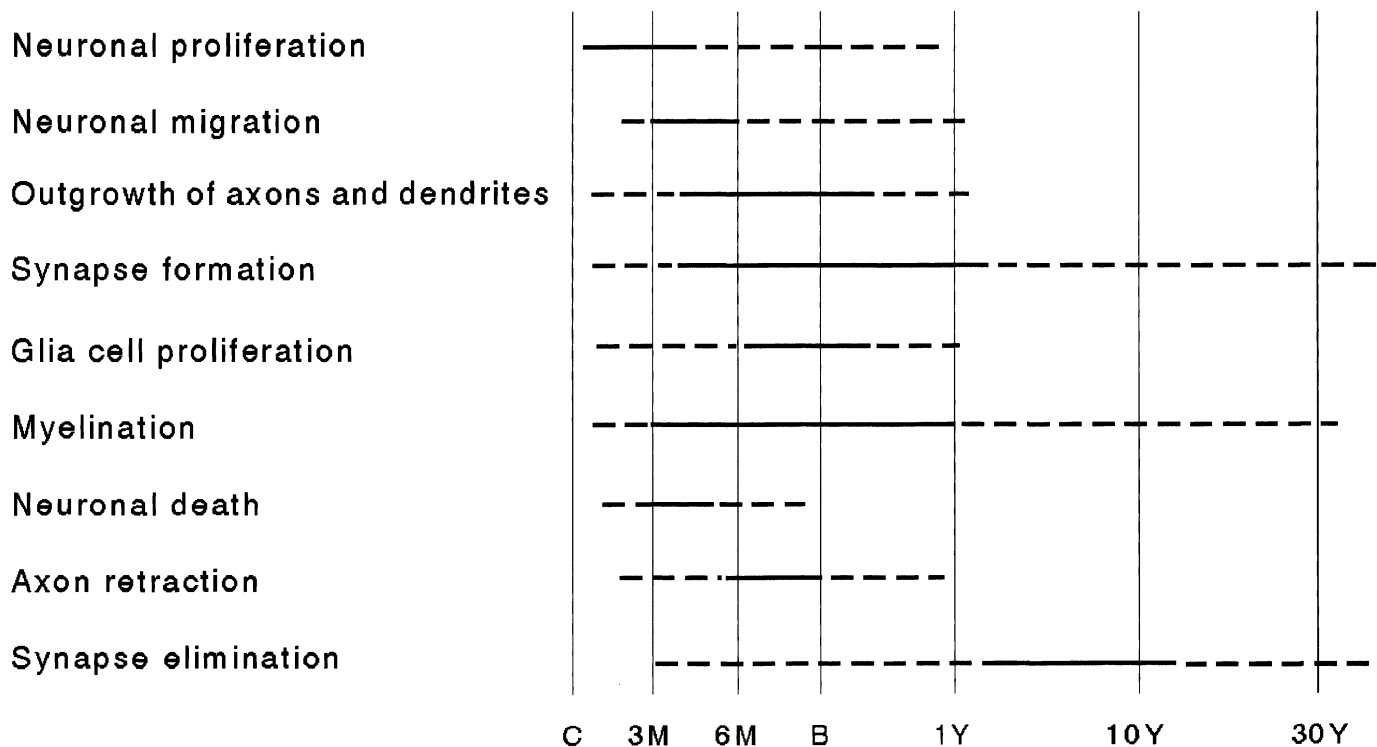


Fig 1. Schematic representation of the age of occurrence of various developmental processes during ontogeny of the human brain. A *bold line* indicates that the process mentioned on the left side is very active, a *broken line* that the process is active but less abundantly. Note that the age axis is drawn in arbitrary units. B, Birth; C, conception; M, months; Y, year.

expressed by means of generalized and aspecific dysfunction. For instance, a preterm infant with a left-sided intraventricular hemorrhage may respond with a generalized hypotonia, a generalized hypertonia, a hypokinesia, or a hyperexcitability syndrome.³ Third, the marked developmental changes of the brain have important implications for the prediction of developmental disorders at early age. The neurodevelopmental changes can induce a disappearance of dysfunctions present at early age. The reverse is also possible: children can be free from signs of dysfunction at early age but grow into a functional deficit with increasing age because of the age-related increase in the complexity of neural functions.^{4,5}

The difficulty in predicting outcome in young infants is reflected by the diversity in techniques available to assess the brain at an early age. The techniques vary from clinical bedside methods requiring no equipment, such as the various forms of neurological assessment, to more or less sophisticated technical assessments, such as brain imaging (ultrasound, magnetic resonance imaging, and computer tomography) and neurophysiological tests, including electroencephalogram recordings and visual or somatosensory evoked potentials. The sensitivities, specificities and accuracies of all these assessment techniques to predict developmental outcome show a large variation.⁶ The heterogeneity in predictive validity points to the need for advanced and more accurately described methods.

The aim of the current article is to review the possibilities of a new technique of neuromotor assessment of

young infants: the assessment of the quality of general movements.

ASSESSMENT OF THE QUALITY OF GENERAL MOVEMENTS

Normal Development of General Movements

Heinz Prechtl, a pioneer in the field of early neurological development, recognized the significance of spontaneous motor behavior in early life. Prechtl and others^{7,8} realized that self-generated motility during early development plays an important role in survival and adaptation. In addition, Prechtl discovered that the quality of spontaneous motility, especially the quality of general movements (GMs), accurately reflects the condition of the nervous system of the fetus and young infant.⁹

General movements consist of series of gross movements of variable speed and amplitude that involve all parts of the body but lack a distinctive sequencing of the participating body parts.¹⁰ Remarkably, GMs are among the first movements the human fetus develops, and they emerge before isolated limb movements.¹¹ GMs show age-specific characteristics (Table I). Little is known about the developmental changes of GMs during the first two trimesters of pregnancy. From about 28 weeks postmenstrual age (PMA) until 36 to 38 weeks' PMA, GMs are characterized by an abundant variation.¹² At 36 to 38 weeks, the very variable

Table I. Age-specific characteristics of normal GMs^{12,14,15}

GM type	Period of presence in weeks' PMA	Description
Preterm GMs	From \pm 28 wk to 36-38 wk	Extremely variable movements, including many pelvic tilts and trunk movements
Writhing GMs*	From 36-38 wk to 46-52 wk	Something forceful (writhing) has been added to the variable movements. Compared with preterm GMs, writhing GMs seem to be somewhat slower and to show less participation of the pelvis and trunk
Fidgety GMs*	From 46-52 wk to 54-58 wk	Basic motility consists of a continuous flow of small and elegant movements occurring irregularly all over the body, ie, head, trunk, and limbs participate to a similar extent. The small movements can be superimposed by large and fast movements

**Writhing* and *fidgety* are also words used to describe pathological movements. Here the words denote age-specific details of normal GMs. At any GM age, the basic characteristics of normal GMs are participation of all body parts and movement complexity and variation.

preterm GMs change into the forceful writhing GMs. Notably, this transition occurs at the very same age at which fully established behavioral states develop.¹³ A second transition in the form of GMs takes place at the age of 6 to 8 weeks postterm. At this age, the writhing character of the GMs disappears and is replaced by a continuous stream of tiny and elegant movements, the charming dance of fidgety GMs.^{14,15} The finding that the change of writhing GMs into fidgety GMs is much more strongly related to postmenstrual age than to postnatal age suggests that the developmental changes in the form of normal GMs are mainly based on endogenous maturational processes, leaving but a minor role for postnatal experience.¹⁵ The minor contribution of postnatal experience is exemplified by the fact that low-risk preterm infants develop fidgety GMs about 1 week earlier than healthy term infants.¹⁶

Characteristics of Abnormal General Movements

Key words to describe the quality of GMs are *variation* and *complexity* (Fig 2).^{9,12,17-19} Complexity points to the spatial variation of the movements. Complex movements are movements during which the infant actively produces frequent changes in direction of the participating body parts. The changes in movement direction are brought about by continuously varying combinations of flexion-extension, abduction-adduction, and endorotation-exorotation of the participating joints. GM variation represents the temporal variation of the movements. It means that across time, the infant produces continuously new movement patterns. Thus, the primary parameters of GM quality evaluate two aspects of movement variation. This fits with the idea that variation is a fundamental feature of the function of the healthy young nervous system and stereotypy a hallmark of early brain dysfunction.^{23,24}

Four classes of GM quality can be distinguished: two forms of normal GMs, normal-optimal and normal-sub-optimal GMs; and two forms of abnormal GMs, mildly and definitely abnormal GMs (Table II). Normal-optimal GMs are abundantly variable and complex. They are also fluent.

Normal-optimal movements are relatively rare: only 10% to 20% of 3-month-old term infants show GMs of such a beautiful quality.^{22,23} The majority of infants show normal-suboptimal movements, which are sufficiently variable and complex but not fluent. Mildly abnormal GMs are insufficiently variable and complex and not fluent, and definitely abnormal GMs are virtually devoid of complexity, variation, and fluency. It is best to realize that the classification into four categories of quality is somewhat artificial. In fact, quality of movement is a continuum with, at the one extreme, splendidly complex, variable, and fluent movements, and at the other extreme, very stereotyped movements, such as a repertoire restricted to cramped-synchronized movements.^{12,24} These last movements are characterized by a suddenly occurring en bloc movement, in which trunk and flexed or extended limbs stiffly move in utter synchrony. Actually, the cramped-synchronized movements are the only form of GMs that can be considered pathological. Their presence points to a loss of supraspinal control.²⁵ Thus, the presence of cramped-synchronized GMs implies that the infant shows abnormal GMs. When an infant only occasionally shows a cramped-synchronized GM within a repertoire of movements that mostly exhibit some degree of variation and complexity, GM quality can be classified as mildly abnormal. However, when the infant frequently exhibits the cramped-synchronized pattern, GM quality should be considered definitely abnormal.

Validity of Abnormal General Movements

Various prenatal, perinatal, and neonatal adversities, such as maternal diabetes, intrauterine growth retardation, preterm birth, perinatal asphyxia, neonatal hyperbilirubinemia, and neonatal treatment with dexamethasone can give rise to abnormal GMs.²⁶ Definitely abnormal GMs are specifically but not exclusively related to discernible lesions of the brain.^{12,24,27,28} It has also been demonstrated that movement quality is not a fixed phenomenon. It can change in various ways: movement quality can be transiently affected by illness,²⁹ and movement abnormalities can vanish or

A



B

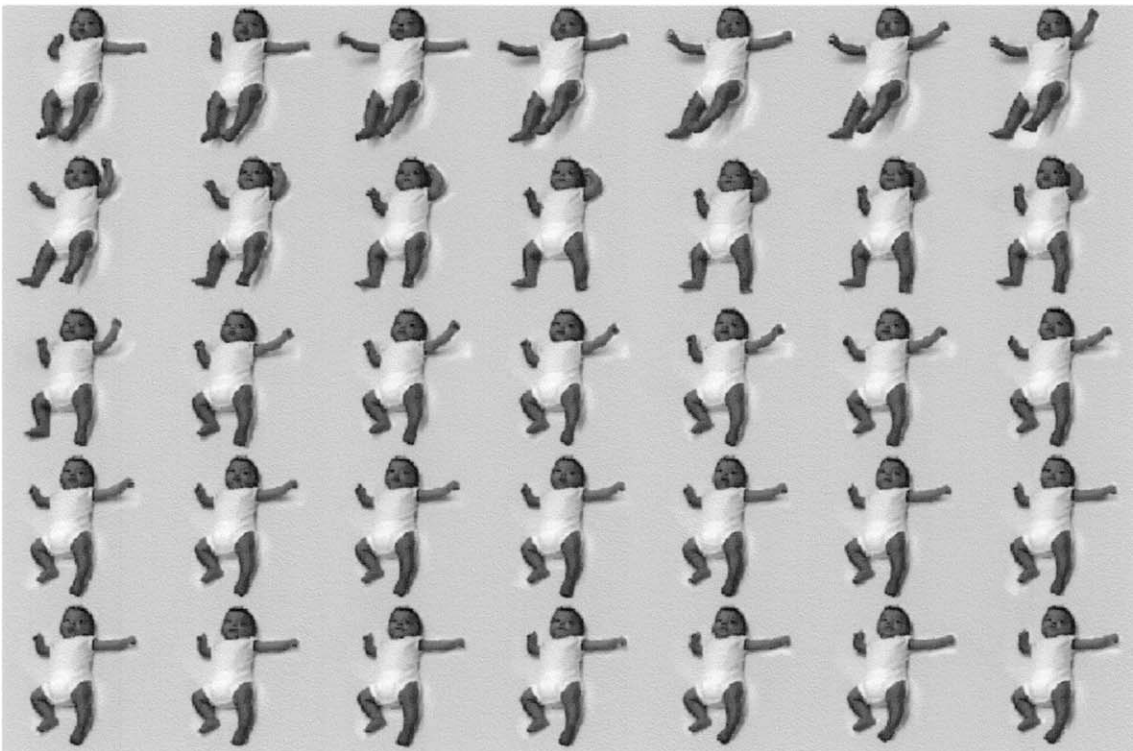


Fig 2. Representation of video frames with GMs of two infants at fidgety GM age. The video recordings start in the left hand upper corner and should be read as the lines in a book. The interval between the video frames is 0.24 seconds. The infant in panel **A** was born at term and shows normal fidgety GMs. The continuously varying positions of the limbs illustrate the rich spatial and temporal variation of normal movements. The infant in panel **B** was born at 28 weeks' PMA. She shows definitely abnormal GMs. The abnormal character of the movement is reflected by the lack of variation, indicated by the virtually identical frames, which induce the false impression that the infant hardly moves. Video recordings made in collaboration with the Department of Developmental and Experimental Clinical Psychology, University of Groningen. Figure published with permission of the parents and the *Nederlands Tijdschrift voor Geneeskunde*.¹⁷

Table II. Classification of the quality of GMs¹⁹

Classification	Complexity	Variation	Fluency
Normal-optimal GMs	+++	+++	+
Normal-suboptimal GMs	++	++	—
Mildly abnormal GMs	+	+	—
Definitely abnormal GMs	—	—	—

Complexity and variation: +++, abundantly present; ++, sufficiently present; +, present, but insufficiently; —, virtually absent or absent.

Fluency (the least important aspect of GM assessment): +, present; —, absent.

become more distinct with increasing age. The majority of changes in GM quality occur in the transitional periods during which normal GMs change in form—that is, between 36 and 38 weeks' PMA and between 6 and 8 weeks postterm.^{19,30} Within the three GM phases (Table I), movement quality is relatively stable.

The predictive validity of GM quality varies with the age at which the GMs are evaluated and with the type of outcome. The best prediction can be obtained by longitudinal series of GM assessments. Infants who persistently show definitely abnormal GMs, even while passing the transformational phases at 36 to 38 weeks' PMA and 6 to 8 weeks postterm, have a high risk (70%-85%) for the development of cerebral palsy (CP).^{24,27} Infants who persistently show cramped-synchronized GMs invariably develop CP.³¹ The prediction of a single GM assessment improves with increasing age. Thus, prediction is best at the age of fidgety GMs—that is, at 2 to 4 months postterm. Studies in populations of infants at risk for developmental disorders reported that the presence of definitely abnormal GMs at fidgety age, which implies a total absence of the elegant, dancing complexity of fidgety movements, predicts CP with an accuracy of 85% to 98%.^{30,32} Recent studies indicate that infants with definitely abnormal GMs at fidgety age who do not develop CP usually show other developmental problems, such as minor neurological dysfunction (MND), attention deficit hyperactivity disorder (ADHD), or cognitive problems.¹⁹ Mildly abnormal GMs at fidgety age are related to the development of MND, ADHD, and aggressive behavior,^{19,30} but the accuracy to predict these minor problems is modest because of the presence of relatively many false positives, resulting in a moderate specificity. The power to predict minor developmental disorders improves considerably when the results of the assessment of GMs are combined with those of the infant neurological examination.¹⁹

Practical Issues on the Assessment of General Movements

The assessment of the quality of GMs focuses on the amount of movement variation and complexity exhibited by the infant (Fig 2). These parameters can be appreciated by

Table III. Effect of behavioral state on normal GMs³³

Behavioral state*	Complexity and variation	Fluency
2, Active sleep or REM sleep	Normal	Reduced
4, Actively awake	Normal	Normal
5, Crying	Reduced	Reduced
Nonnutritive sucking	Reduced	Normal

REM, Rapid eye movement.

*Behavioral states (numbers according to Prechtl³⁴) are fully established only from 36 to 38 weeks' PMA onward.¹³

means of Gestalt perception of the observer.⁹ Gestalt perception allows the evaluation of the repertoire of movement patterns displayed by all parts of the body and does not pay special attention to particular behavior of specific body parts (eg, fisting). GM evaluation also includes the evaluation of movement fluency (Table II). However, this is the least important aspect of the assessment. Regrettably, our visual system has an innate sensitivity to spot a loss of movement fluency, and this visual propensity for the detection of abnormalities in movement fluency, such as jerkiness, tremulousness, and stiffness, interferes to some extent with the assessment of the major components of the GMs: movement complexity and variation.

The evaluation of movement complexity and variation is demanding and requires offline assessment by means of a video recording. Assessment of the movements in real life introduces errors and should be avoided.²³ The video also offers the opportunity of movement replay at high speed, which facilitates the evaluation of movement complexity and variation. A high-speed replay produces an effect comparable with the effect produced by the video frame sampling procedure of Figure 2.

General movements are affected by the behavioral state of the infant.³³ The optimal state for GM analysis is active wakefulness, or Prechtl³⁴ state 4. In this state, the splendid variation and fluency of normal GMs is expressed best. During other behavioral states, normal GMs have features reminiscent of abnormality, implying that a nonoptimal state interferes with movement classification. The effects of behavioral state on normal GMs are summarized in Table III. Practically, this means that GMs preferably are assessed in state 4. When a video recording contains GMs only during state 2 (or state 2-like conditions), the primary parameters of GM analysis—complexity and variation—still can be evaluated. GMs should not be assessed during crying or nonnutritive sucking.³³

The basic principles of GM assessment can be learned in 2 days. Further practice with approximately 100 GM recordings is required to become a skilled observer.²³ Various studies reported that the intraobserver and interobserver agreement of GM assessment of skilled observers is high (κ values approximately 0.80, implying an excellent interrater and test-retest reliability).^{19,30}

CONCLUSIONS

The assessment of the quality of GMs is a sensitive tool to evaluate brain function in young infants. It has a function complementary to the traditional neurological examination. Prediction of developmental outcome on the basis of longitudinal series of GM assessment is best. Second best is prediction on the basis of an assessment at fidgety age. European experience indicates that a single GM assessment at fidgety age can be implemented relatively easily into clinical practice.

The presence of definitely abnormal GMs at fidgety age puts a child at such a high risk for CP that it warrants physiotherapeutic intervention. It is unlikely that the intervention will prevent the development of CP, but animal data³⁵ suggest that early intervention could improve the child's later functional abilities. Of course, this is an issue begging for further exploration and research, because until now, studies have failed to prove a consistent positive effect of early intervention on long-term motor development.³⁶

The clinical implications of the information that a child shows mildly abnormal GMs at fidgety age are less clear. It could be surmised that mildly abnormal GMs point to the presence of a nonoptimally wired brain, which puts the infant at risk for the development of problems like MND, ADHD, and aggressive behavior. However, the effect of the risk needs to be determined by future investigations in the general population.

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