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The General Movement Optimality Score – a detailed assessment of general movements during preterm and term age

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Abstract

Aim—To explore the appropriateness of applying a detailed assessment of general movements (GMs) and characterise the relationship between global and detailed assessment.

Method—The analysis was based on 783 video-recordings of 233 infants (79 females) who had been videoed from 27 to 45 weeks postmenstrual age. Apart from assessing the global GM categories (normal, poor repertoire [PR], cramped-synchronised [CS] or chaotic GMs), we scored the amplitude, speed, spatial range, proximal and distal rotations, onset and offset, tremulous and cramped components of the upper and lower extremities. Applying the optimality concept, the maximum GM optimality score of 42 indicates the optimal performance.

Results—GM optimality scores differentiated between normal GMs (Median=39; P75=41, P25=37); PR GMs (Median=25; P75=29, P25=22), and CS GMs (Median=12; P75=14, P25=10; $p<0.01$). The optimality score for chaotic GMs (mainly occurring at late preterm age) was similar to those for CS GMs (Median=14; P75=17, P25=12). Short-lasting tremulous movements occurred from very preterm age to postterm age across all GM categories, including normal GMs. The detailed score at postterm age was slightly lower compared to the scores at preterm and term age for both normal ($p=0.02$) and PR GMs ($p<0.01$).

Interpretation—Further research might demonstrate that the GM optimality score provides a solid base for the prediction of improvement vs. deterioration within an individual GM trajectory.

Keywords

Detailed assessment; general movements; preterm infant; neonate; optimality score; video analysis; writhing movements

Abnormal general movements (GMs) are among the most reliable early markers for neurodevelopmental disorders.^{1,2} Recently, Bosanquet et al.³ reviewed various structural and functional assessment techniques for which the accuracy of prediction of cerebral palsy was reported. Compared to cranial ultrasound, magnetic resonance imaging (MRI), and neurological examination, the general movement assessment (GMA) provided best evidence, with a sensitivity of 98% (95% confidence interval: 74-100%) and a specificity of 91% (95% confidence interval: 83-93%).³ Apart from first promising attempts to analyse GMs with the aid of computer-based tools, e.g.^{4,5} GMA is based on visual Gestalt perception. GMs are considered to be normal if the sequence, amplitude, speed, and intensity are variable. Abnormal GMs are characterised by a lack of variability, especially in the movement sequence.^{1,6} Gestalt perception is a powerful tool when it comes to the analysis of complex phenomena. Experienced observers consistently achieved high inter-scorer agreements, ranging from 89% to 93%.⁶

In addition to the global assessment of GM patterns, it can also be worthwhile to look at different aspects and components of GMs, particularly if they are abnormal. By applying the Prechtl optimality concept,⁷ we are able to achieve a semi-quantification of the quality of GMs.⁸ For every movement criterion such as amplitude, speed, range in space, onset and offset of GMs, a score is given whereby a higher score expresses a more optimal performance (see Appendix). The higher the total optimality score the better the quality of GMs.^{7,8} With such a detailed, semi-quantitative approach we can document associations between small changes in the quality of GMs and other clinical parameters, e.g. polygraphical findings.^{9,10} Another potential of such a detailed GMA lies in the evaluation of therapeutic interventions.¹¹

A detailed assessment of GMs at preterm and term age was introduced by Ferrari et al.¹² The first applications were done in infants with brain malformation,¹³ and in infants with Down syndrome¹⁴ – the latter demonstrating that a reduced motor optimality score was associated with more severe motor impairments a few years later.¹⁴ Recently, Hitzert et al.¹¹ reported an association between low-dose dexamethasone in preterm infants at risk for bronchopulmonary dysplasia and higher GM optimality scores. The same research group used the detailed GMA to evaluate the neonatal neurological condition after placenta lesions but did not find any association.¹⁵ The mode of delivery in healthy infants born at term did not have an impact on the detailed GMA.¹⁶ Another group of infants born around term, who were prenatally exposed to selective serotonin reuptake inhibitors, had lower motor optimality scores compared to non-exposed infants.¹⁷

Some 10 years ago we tried to differentiate between infants whose poor repertoire (PR) GMs (for definition, see Method) will have normalised and those whose PR GMs will have

deteriorated, but such a differentiation was not possible.¹⁸ During this analysis we got the impression that some infants had, for example, (i) more rotations in the lower than in the upper extremities; or, (ii) cramped components occurred predominantly in the legs but hardly in the arms. We therefore adapted the original score sheet for detailed GMA at preterm and term age,¹² and scored upper and lower extremities, neck and trunk separately (see Appendix). In order to evaluate its soundness, we (re-)assessed in a multi-centre-study several hundreds of video-recordings of GMs with the aim of comparing global with detailed GMA. We specifically focused on the following questions: (a) Does the GM optimality score (obtained by detailed GMA) differentiate between the global GM categories? (b) How does the detailed assessment contribute to descriptions of the GM categories? (c) Are the results related to the infant's age?

Method

Material

We analysed 783 video-recordings of 233 infants (154 males, 79 females; gestational age: Median=34 weeks, P25=32 weeks, P75=39 weeks, range: 26-42 weeks) who had been videoed up to 13 times (Median=1, P25=1, P75=6) from 27 to 45 weeks postmenstrual age (Median=35 weeks, P25=33 weeks, P75=41 weeks). One hundred ten recordings (14%) were performed at the very preterm period (<32 weeks); 166 recordings (21%) at the moderate preterm period (32⁺⁰ to 33⁺⁶ weeks); 230 recordings (30%) at late preterm period (34⁺⁰ to 36⁺⁶ weeks); 102 recordings (13%) at term (37⁺⁰ to 41⁺⁶ weeks); and 175 recordings (22%) at the postterm period (42⁺⁰ to 45 weeks) (Table 1). The infants were recorded for the following reasons: (i) high-risk for neurodevelopmental disorders due to preterm birth or perinatal asphyxia at term; (ii) abnormal findings at paediatric examinations; (iii) parental concerns; or (iv) assignment to a healthy control group. The recordings were conducted at the Medical University of Graz, the Children's Hospital of Fudan University Shanghai, the Medical University of Warsaw, the Carmel Medical Center Haifa, the University Hospital Modena, the Stella Maris Foundation and the Pisa University Hospital, and the Medical University Hospital Groningen. Most of the children had participated in previous studies;^{1,12,19–26} All infants were recorded following the standards of the Prechtl GMA (i.e. infant in supine position, avoiding episodes of crying or fussing, no use of pacifier)⁸ either during active sleep (400 recordings; 51%) or during active wakefulness (383 recordings; 49%). The video clips used for this analysis lasted 1-2.5 minutes and contained at least three GM sequences; 298 recordings (38%) were videoed in one sequence; the remaining 62% (485 recordings) were edited from a longer recording.⁸

All parents gave written informed consent. The ethical boards of all centres involved approved recording and assessment of spontaneous movements for various studies.

Score sheet (Appendix)

The first part of the score sheet refers to the global categories: (a) "normal", i.e., the movement sequence, amplitude, speed, and intensity are variable; (b) "poor repertoire" (PR), i.e., the sequence of movement components is monotonous, and the amplitude, speed, and intensity lack the normal variability; (c) "cramped-synchronised" (CS), i.e., GMs lack the

usual smoothness and appear rigid as the limb and trunk muscles contract almost simultaneously and relax almost simultaneously; and (d) “chaotic”, i.e. the amplitude is large and the speed is fast; movements consistently appear to be abrupt.^{6,8,12} “Hypokinetic” indicates that GMs cannot be observed during the whole recording, but isolated (usually upper) limb movements are present.⁸ In this case, a detailed assessment cannot be carried out. The movement sequence is related to the global GM category: “variable” for normal GMs, “monotonous and/or broken” for PR, “synchronised” for CS, and “disorganised” for chaotic GMs.

The detailed scoring focuses separately on neck and trunk, upper and lower extremities (see Appendix). For each item a description of optimal performance is given and scored with “2” (e.g., cramped components are absent). Less optimal performance is scored with “1” (e.g., cramped components are occasionally present); non-optimal performance is scored with “0” (e.g., cramped components are predominately present). The following five items are only scored with “2” or “1”: (a) the involvement of the neck: we only differentiate if the neck is involved or hardly/not involved in the sequence; (b) the amplitude of upper and lower limb movements; and, (c) the speed of upper and lower limb movements: there is neither an “absence of amplitude” nor an “absence of speed” as long as the infant shows GMs.

Adding the scores of each item within a category (“neck and trunk”, “upper extremity” and “lower extremity”) plus the score for “sequence” gives the GM optimality score with a maximum value of 42, indicating optimal performance. The minimum score (worst performance) is “5”.

Procedure

The scoring approach consisted of two steps. First, based on visual Gestalt perception, we re-analysed GMs globally and differentiated between normal and the three abnormal categories, PR, CS or chaotic GMs. The item “sequence” refers to the four global categories and constitutes 4.76% of the total GM optimality score. In a second step, all details (see Appendix) were scored by watching the video as often as necessary. In the majority of cases, it took six reviews to finalise the detailed scoring: (i) neck and trunk; (ii) amplitude and speed, (iii) range in space, (iv) rotations, (v) onset and offset, (vi) tremulous and cramped components. Each video was scored by C.E., and independently by at least a second scorer certified for GMA (P.B.M., J.P., A.S., H.Y., M.S.) with substantial inter-scorer agreement for the detailed assessment (Cohen Kappa: 0.69 to 0.82). In case of disagreements, the video was discussed among at least three scorers until agreement on a final score was reached.

Statistics

Statistical analysis was performed using SPSS version 22.0 (SPSS Inc., Chicago, IL). The Pearson chi-square test was used to evaluate associations between nominal data; the McNemar-Bowker test was used on paired nominal data (i.e. comparison between upper and lower extremities). Nonparametric tests were applied because the data were not normally distributed. The Mann-Whitney-U test and Kruskal Wallis test were used to compare the GM optimality scores between groups. The Wilcoxon signed-rank test was used to compare the subscores of upper and lower extremities within a sample. Spearman rank order

correlations (ρ) were applied to analyse the association between ordinal variables with a monotonic relationship between the two. Throughout the analyses, $p < 0.05$ (two-tailed) was considered to be statistically significant.

Results

Global GMA

We assessed 169 video-recordings (21.6%) as normal GMs; 441 recordings (56.3%) as PR; 160 recordings (20.4%) as CS; and the remaining 13 recordings (1.7%) as chaotic. Table 1 provides the distribution of normal and abnormal GMs for the different age groups. Chaotic GMs occurred predominantly during the late preterm period (11/13).

The association between global and detailed GMA

Table 2 provides the GM optimality scores (Median, 10th, 25th, 75th and 90th percentile rank, minimum and maximum) for each global GM category. The distributions of the GM optimality scores did not differ across CS and chaotic GMs. All other distributions of the optimality scores were significantly different (Table 2). Table 3 provides the age-related GM optimality scores. Again, the distribution of the optimality scores across CS and chaotic GMs did not differ at the late preterm period ($p = 0.09$), whereas all other scores of the detailed GMA significantly differed between the global categories “normal” vs. “PR” vs. “CS” ($p < 0.01$).

Normal GMs assessed in detail

The description is based on 169 assessments. Each optimal criterion is usually met by more than 70% of the GMs assessed as normal (Table 4). The following exceptions were found:

- Thirty-six percent of very preterm infants globally assessed as normal moved their upper extremities in a limited space, and exhibited tremulous arm and leg movements.
- One third of moderate preterm infants with normal GMs ended the GM sequences with minimal fluctuations (37% for upper and 32% for lower extremities, respectively).
- One third of normally-moving late preterm infants showed tremulous arm (29%) and/or leg movements (31%).
- Although globally assessed as normal during postterm age, a considerable number of infants had only “just a few trunk rotations” (47%), “minimal fluctuations” at the end of an upper extremity movement (41%), uni- or bilateral tremulous arm movements (53%), and/or “occasionally present” cramped arm (63%) and/or leg movements (49%).

The following differences were observed between the upper and lower extremities:

- Across all age groups, upper limbs moved more often in a limited space than lower limbs (19% vs. 2%; $p < 0.01$).

- During the postterm period, there were more often “just a few rotations” in the wrists than in the ankles (27% vs. 2%; $p<0.01$).
- Also during the postterm period, both the onset and offset were more often scored as “minimal fluctuation” in the upper limbs than in the lower limbs (27% vs. 10%; $p<0.01$; 41% vs. 14%; $p<0.1$, respectively).
- At term, tremulous movements occurred more often in the legs than in the arms (30% vs. 15%; $p=0.02$), whereas at the postterm period, tremulous movements were more frequent in arms (53%) than in the legs (4%; $p<0.01$).
- At the late preterm period, cramped components were observed in the lower, but not in the upper extremities (20% vs. 0%); at the postterm period the occurrence of cramped components was high both in the upper and lower extremities (63% vs. 49%, $p=0.21$).

The subscores for upper (Median=17, P75=18, P25=15, range: 10–18) vs. lower extremities (Median=17, P75=18, P25=16, range: 11–18) did not differ ($p=0.40$).

Within the global category of normal GMs a slight decrease of the GM optimality score could be observed with age ($\rho=-0.18$; $p=0.02$).

Poor repertoire GMs assessed in detail

The description is based on 441 assessments. During the preterm period one third of infants with PR GMs had fluent and elegant trunk rotations; this feature decreased with age ($\rho=-0.24$; $p<0.01$). Shoulder rotations ($\rho=-0.15$; $p<0.01$), fluctuations in the onset of upper ($\rho=-0.25$; $p<0.01$) and lower limb movements ($\rho=-0.15$; $p<0.01$), and fluctuations in the offset of upper limb movements ($\rho=-0.10$; $p<0.05$) also decreased with age (Table 4). The occurrence of tremulous arm movements increased from 35% to 70% with age ($\rho=-0.25$; $p<0.01$), whereas the occurrence of tremulous leg movements decreased from 58% at very preterm age to 11% at postterm age ($\rho=0.28$; $p<0.01$). The occurrence of cramped components increased with age in both the upper (from 10% to 78%; $\rho=-0.48$; $p<0.01$) and the lower limbs (from 29% to 70%; $\rho=-0.31$, $p<0.01$; Table 4).

The following differences were found between the upper and lower extremities:

- Across all age groups, fluent and elegant rotations were more frequent in the shoulders than in the hips (34% vs. 25%, $p<0.01$).
- At the moderate and late preterm periods, fluent and elegant rotations were more frequent in wrists than in ankles ($p<0.01$; Table 4).
- Across all age groups, cramped components were more frequent in the lower than in the upper extremities (51% vs. 31%; $p<0.01$).

The subscores for upper (Median=11, P75=13, P25=10, range: 4–18) vs. lower extremities (Median=11, P75=13, P25=9, range: 3–18) did not differ ($p=0.14$).

Within the global category of PR GMs, the GM optimality score slightly decreased with age ($\rho=-0.21$; $p<0.01$).

Cramped-synchronised GMs assessed in detail

The description is based on 160 assessments. CS GMs did not occur in the very preterm age. Table 4 shows that hardly any CS GMs met an optimal criterion for a particular item; the following exceptions were found:

- Across all age groups, a variable amplitude was relatively more frequent in the upper extremities than in the lower ones (11% vs. 3%, $p<0.01$).
- Almost every second infant with CS GMs showed no tremulous movements (Table 4). Whereas the occurrence of tremulous arm movements was not related to age ($\rho=-0.12$, $p=0.12$), tremulous leg movements decreased with age with an occurrence of only 15% at the postterm period ($\rho=0.23$, $p<0.01$).

The subscores were relatively higher for the upper extremities (Median=6, P75=8, P25=5, range: 2–12) than for the lower extremities (Median=4, P75=5, P25=3, range: 2–10; $p<0.01$), although both were in the lower range.

Within the category of CS GMs, the GM optimality score did not significantly differ with age ($\rho=0.10$; $p=0.19$).

Chaotic GMs assessed in detail

The description is based on 13 recordings; 11 of the chaotic GMs (85%) occurred in the late preterm period (Tables 1 and 4). The subscores for the upper extremities (Median=7, P75=8, P25=5, range: 3–12) did not differ from the subscores for the lower extremities (Median=6, P75=8, P25=5, range: 3–11, $p=0.39$).

Though the GM optimality scores did not significantly differ between chaotic and CS GMs (Table 2), we found the following differences between these two categories across all age groups:

- Whereas the amplitude of the arm movements was predominantly large in chaotic GMs (77%), it was predominantly small in CS GMs (70%; $p=0.02$).
- Whereas the speed of the arm and leg movements was predominantly fast (69%) in chaotic GMs, it was predominately slow (39%) or monotonous (48%) in CS GMs ($p<0.01$).
- Within chaotic GMs, both arms and legs covered the full spatial range in 38%, while this occurred in only 5% (arms) or 2% (legs) of the CS GMs ($p<0.01$).
- While the lower limbs ended a chaotic GM with minimal fluctuations in 69%, 90% of CS GMs ended abruptly ($p<0.01$).
- Whereas 92% of chaotic GMs consisted of upper limb tremulous movements, this was only the case in 58% of CS GMs ($p<0.01$); the same was true of the lower extremities: 92% tremulous leg movements in chaotic GMs vs. 38% in CS GMs ($p<0.01$).

Focusing on the subscores for the extremities, the upper extremities scored similarly in chaotic (Median=7, P75=8, P25=5) and CS GMs (Median=6, P75=8, P25=5; $p=0.89$),

whereas the lower extremities did not: within chaotic GMs, the lower limbs scored slightly higher (Median=6, P75=8, P25=5) than within CS GMs (Median=4, P75=5, P25=3; $p<0.01$).

Discussion

Prechtl and associates have established a systematic albeit qualitative analysis of GMs as a valid, reliable assessment of the integrity and function of the young central nervous system. 1–3,6,8,12 Quantitative analyses of GMs (i.e. counting the number of GMs per time) have failed to demonstrate significant differences between high-risk and low-risk preterm infants. 12,27 Applying the optimality concept⁷ allowed us to define optimal criteria for the various movement components, and thus semi-quantify the qualitative scoring.^{8,12}

The detailed GMA separated the global categories “Normal” from “PR” and “CS” but not “CS” from “chaotic” GMs

To the best of our knowledge, our study is the first to relate detailed GMA to global GMA in a considerable number of recordings. Across all age groups, GM optimality scores differentiated between normal, PR and CS GMs. Despite these highly significant statistical differences we should be aware of a certain overlap within the scores, e.g., the maximum score within PR GMs corresponds to the Median of normal GMs. Such an overlap demonstrates the basic need to interpret the detailed score within the context of a global assessment. Future research has to demonstrate whether, for example, an infant with PR GMs and a detailed score above the Median (or any cut-off point) is more likely to normalise his/her GMs than an infant with a detailed score below the Median.

Interestingly, the detailed GMA resulted in similar distributions of optimality scores for CS and chaotic GMs. However, our sample of recordings assessed as chaotic GMs was small ($n=13$), with the majority (11/13) occurring at late preterm age. It is well known that chaotic GMs are rather rare, and often precede the development of CS GMs.^{6,8} Apart from the occurrence of chaotic GMs in infants with severe brain injury,⁸ this GM pattern was also reported for anencephalic neonates,¹³ or was related to congenital thyrotoxicosis²⁸. In the latter, chaotic GMs preceded PR GMs that normalised within the first months postterm age. 28 Recently, de Vries and Bos²⁹ described some chaotic features in PR GMs in preterm infants, especially during the first 10 days of life, correlating with hypocalcaemia.

Although the GM optimality scores for chaotic GMs did not differ from CS GMs, the appearance of both patterns is quite different. The detailed GMA confirmed that chaotic GMs are rapid, with large amplitude, covering all spatial planes. By contrast, CS GMs are slow with small amplitude, especially in the upper extremities, and have a limited spatial range. Tremulous limb movements might occur in every second infant with CS GMs, but are present in almost all infants with chaotic GMs. In the detailed GMA, both deviant amplitude and speed are scored as “1”, irrespective of large or small amplitude, high or low speed. This scoring procedure might have contributed to similar distributions of the optimality scores for chaotic and CS GMs.

The contribution of the detailed GMA to the description of the global patterns “normal”, “PR” and “CS”

Because optimal is not synonymous with normal, we did not expect that all recordings globally assessed as normal would be distributed in the upper 10% of the scoring list. Whereas normal is defined by the absence of abnormality (often synonymous with pathology), an optimal condition is more restricted and more narrowly defined. For example, the delivery of a primigravida is certainly within the realm of normality but is not considered to be optimal because of the increased mortality rate as compared to the second and third delivery.⁷

The most surprising result was the relatively high rate of occurrence of tremulous – albeit short-lasting – movements across all global GM categories. By contrast, GMs classified as “chaotic” are characterised by long-lasting and predominant tremulous movements superimposed on large-amplitude limb movements.

Although the variability of the sequence indicated normal GMs, very preterm infants had short-lasting tremulous arm and leg movements, along with small-amplitude arm movements that did not cover the full spatial range. Short, tremulous limb movements also occurred in one third of normally-moving, late preterm infants, and even more frequently after term. Apart from tremulous movements, every second infant at postterm age had cramped and stiff arm/or leg movements, although the movement sequence was variable, indicating a global score of normal GMs. Tremulous and cramped movement components along with a reduction in the amount of wrist rotations were the most common reason for a slightly lower optimality score (for normal GMs) during postterm age compared to term and preterm age.

Short-lasting tremulous arm movements (increasing with age) and tremulous leg movements (decreasing with age) were also a common feature of PR GMs. Apart from the dominant lack of variability in the sequence, the majority of PR GMs did not show variable amplitude or speed, did not cover the full range in space, and had no smooth and fluent beginning and ending. At least during preterm age, the absence of cramped components was similar to infants with normal GMs, and was – in addition to tremulous components – not a feature to distinguish between normal and PR GMs.

CS GMs met almost no optimal criteria, apart from the absence of tremulous movements. Similar to PR or normal GMs, tremulous leg movements in CS GMs were rare during postterm age. The clinical impression that the abnormal features of CS are more often expressed in the legs than in the arms was confirmed by a lower score for the lower extremities as compared to the upper extremities.

The age-dependency of the results

It was surprising to see that the optimality scores for both normal and PR GMs were lower after term compared to preterm and term age. Future research should consider the postnatal age of the infant videoed at postterm age, as previous observations revealed that preterm infants approaching term-equivalent age might have fewer rotations and more jerky movements than infants born at term.³⁰ But also the fading out of writhing movements at the end of the first month postterm could cause a less optimal GM performance after term.

We could confirm the clinical impression that neither CS nor chaotic GMs occurred during very preterm age; chaotic GMs were predominantly observed during the late preterm period.

Limitations and a note of caution

Firstly, our sample is not representative of the normal population, and consists of cross-sectionally and longitudinally acquired data of at-risk populations. Secondly, detailed assessment is much more time-consuming than global GMA. Thirdly, we would like to point out that detailed GMA interferes with the ability to globally assess GMs. Gestalt perception/pattern recognition has its limitations when the observer focuses on details. We strongly advise the scorer to chronologically separate global from detailed GMA. In this context we would like to stress that the item “sequence” is related to the global GMA. Therefore, a possible limitation of our study could be that this item has an impact to the results although it constitutes only 4.76% of the total GM optimality score.

Conclusion and further implications

The clinical significance of this detailed GMA lies in a better description of the global categories, which certainly has implications for less experienced GM scorers to comprehend the underlying parameters of the GM classification system. Another benefit might lie in documenting subtle changes caused by (early) intervention, with the potential of evaluating various therapeutic approaches. Perhaps more importantly, detailed GMA might provide a solid base for the short-term prediction of improvement vs. deterioration within an individual GM trajectory.

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References

1. Prechtl HFR, Einspieler C, Cioni G, Bos AF, Ferrari F, Sontheimer D. An early marker for neurological deficits after perinatal brain lesions. *Lancet*. 1997; 349:1361–3. [PubMed: 9149699]
2. Hadders-Algra M. General movements: a window for early identification of children at high risk for developmental disorders. *J Pediatr Suppl*. 2004; 145:S12–8.
3. Bosanquet M, Copeland L, Ware R, Boyd R. A systematic review of tests to predict cerebral palsy in young children. *Dev Med Child Neurol*. 2013; 55:418–26. [PubMed: 23574478]
4. Adde L, Helbostadt JL, Jensenius AR, Taraldsen G, Støen R. Using computer-based video analysis in the study of fidgety movements. *Early Hum Dev*. 2009; 85:541–7. [PubMed: 19464127]
5. Marcroft C, Khan A, Embleton ND, Trenell M, Plötz T. Movement recognition technology as a method of assessing spontaneous general movements in high risk infants. *Frontiers Neurol*. 2015; 5(284):1–9.
6. Einspieler C, Prechtl HFR. Prechtl's assessment of general movements: a diagnostic tool for the functional assessment of the young nervous system. *Ment Retard Dev Disabil Res Rev*. 2005; 11:61–7. [PubMed: 15856440]
7. Prechtl HFR. The optimality concept. *Early Hum Dev*. 1980; 4:201–5. [PubMed: 7418634]

8. Einspieler, C., Prechtl, HF., Bos, AF., Ferrari, F., Cioni, G. Prechtl's Method on the Qualitative Assessment of General Movements in Preterm, Term and Young Infants. London: MacKeith Press, distributed by Cambridge University Press; 2004. (incl. CD-ROM).
9. Einspieler C. Abnormal spontaneous movements in infants with repeated sleep apnea. *Early Hum Dev.* 1994; 36:31–48. [PubMed: 8026363]
10. Yuge M, Marschik PB, Nakajima Y, et al. Movements and postures of infants aged 3 to 5 months: to what extent is their optimality related to perinatal events and to the neurological outcome. *Early Hum Dev.* 2011; 87:231–7. [PubMed: 21295927]
11. Hitzert MM, Benders MJNL, Roescher AM, van Bel F, de Vries L, Bos AF. Hydrocortisone vs. dexamethasone treatment for bronchopulmonary dysplasia and their effects on general movements in preterm infants. *Pediatr Res.* 2012; 71:100–6. [PubMed: 22289857]
12. Ferrari F, Cioni G, Prechtl HFR. Qualitative changes of general movements in preterm infants with brain lesions. *Early Hum Dev.* 1990; 23:193–231. [PubMed: 2253580]
13. Ferrari F, Prechtl HFR, Cioni G, et al. Posture, spontaneous movements, and behavioural state organisation in infants affected by brain malformations. *Early Hum Dev.* 1997; 50:87–113. [PubMed: 9467696]
14. Mazzone L, Mugno D, Mazzone D. The general movements in children with Down syndrome. *Early Hum Dev.* 2004; 79:119–30. [PubMed: 15324992]
15. Roescher AM, Timmer A, Hitzert MM, et al. Placental pathology and neurological morbidity in preterm infants during the first two weeks after birth. *Early Hum Dev.* 2014; 90:21–5. [PubMed: 24331826]
16. Ploegstra WM, Bos AF, de Vries NK. General movements in healthy full term infants during the first week after birth. *Early Hum Dev.* 2014; 90:55–60. [PubMed: 24231002]
17. De Vries NK, van der Veere CN, Reijneveld SA, Bos AF. Early neurological outcome of young infants exposed to selective serotonin reuptake inhibitors during pregnancy: results from the observational SMOK study. *PloS One.* 2013; 8:e64654. [PubMed: 23785389]
18. Nakajima Y, Einspieler C, Marschik PB, Bos AF, Prechtl HFR. Does a detailed assessment of poor repertoire general movements help to identify those infants who will develop normally? *Early Hum Dev.* 2006; 82:53–9. [PubMed: 16153788]
19. Bruggink JLM, Einspieler C, Butcher PR, Stremmelaar EF, Prechtl HFR, Bos AF. Quantitative aspects of the early motor repertoire in preterm infants: do they predict minor neurological dysfunction at school age? *Early Hum Dev.* 2009; 85:25–36. [PubMed: 18691834]
20. Bruggink JLM, Einspieler C, Butcher PR, Van Braeckel KNJA, Prechtl HFR, Bos AF. The quality of the early motor repertoire in preterm infants predicts minor neurological dysfunction at school age. *J Pediatr.* 2008; 153:32–9. [PubMed: 18571531]
21. Butcher PR, van Braeckel K, Bouma A, Einspieler C, Stremmelaar EF, Bos AF. The quality of preterm infant's spontaneous movements: an early indicator of intelligence and behavior at school age. *J Child Psychol Psychiatr.* 2009; 50:920–30.
22. Prechtl HFR, Ferrari F, Cioni G. Predictive value of general movements in asphyxiated fullterm infants. *Early Hum Dev.* 1993; 35:91–120. [PubMed: 8143572]
23. Bos AF, van Loon AJ, Hadders-Algra M, Martijn A, Okken A, Prechtl HFR. Spontaneous motility in preterm, small-for-gestational age infants. II. Qualitative aspects. *Early Hum Dev.* 1997; 50:131–47. [PubMed: 9467698]
24. Cioni G, Bos AF, Einspieler C, et al. Early neurological signs in preterm infants with unilateral intraparenchymal echodensity. *Neuropediatr.* 2000; 31:240–51.
25. Einspieler C, Cioni G, Paolicelli PB, et al. The early markers for later dyskinetic cerebral palsy are different from those for spastic cerebral palsy. *Neuropediatr.* 2002; 33:73–8.
26. Ferrari F, Cioni G, Einspieler C, et al. Cramped synchronised general movements in preterm infants as an early marker for cerebral palsy. *Arch Pediatr Adolesc Med.* 2002; 156:460–7. [PubMed: 11980551]
27. Bos AF, van Loon AJ, Martijn A, van Asperen RM, Okken A, Prechtl HFR. Spontaneous motility in preterm, small-for-gestational age infants. I. Quantitative aspects. *Early Hum Dev.* 1997; 50:115–29. [PubMed: 9467697]

28. Gaboli M, Aguilera S, Azcona C, Alzina V, Narbona J. Normal neurological outcome after congenital thyrotoxicosis: prognostic value of observation of general movements. *Neuropediatr.* 2008; 39:351–3.
29. de Vries NKS, Bos AF. The quality of general movements in the first ten days of life in preterm infants. *Early Hum Dev.* 2010; 86:225–9. [PubMed: 20488635]
30. Cioni G, Prechtl HFR. Preterm and early postterm motor behavior in low-risk premature infants. *Early Hum Dev.* 1990; 23:159–91. [PubMed: 2253579]

What this paper adds

- The general movement optimality score, applied from birth to 5 weeks postterm age, differentiates between normal, poor repertoire and cramped-synchronised general movements.
- Short-lasting tremulous movements occurred from very preterm age to postterm age across all GM categories including normal GMs.
- The detailed score at postterm age was slightly lower compared to the scores at preterm and term age for both normal and PR GMs.

Table 1

Distribution of normal and abnormal GM patterns according to the different age groups

	Normal GMs	PR GMs	CS GMs	Chaotic GMs	Total
Very preterm period	14	93	0	0	110
Moderate preterm period	19	118	31	1	166
Late preterm period	65	105	49	11	230
Term period	20	42	39	1	102
Postterm period	51	83	41	0	175
Total	169	441	160	13	783

Key: GMs = general movements; PR = poor repertoire; CS = cramped-synchronised

Table 2

GM optimality scores according to the different categories of GM quality

GM optimality score	Normal GMs (<i>n</i> =169)	PR GMs (<i>n</i> =441)	CS GMs (<i>n</i> =160)	Chaotic GMs (<i>n</i> =13)
Maximum	42	39	19	25
P90	42	33	17	17
P75	41	29	14	17
Median	39	25	12	14
P25	37	22	10	12
P10	35	19	7	8
Minimum	30	13	5	8
p-Values	$p<0.01^a$		$p<0.01^a$	
	$p<0.01^a$			$p<0.09^a$
	$p<0.01^a$			
	$p<0.01^a$			

Key: P = percentile rank; GMs = general movements; PR = poor repertoire; CS = cramped-synchronised

^aIndependent-Samples Mann-Whitney U Test

Table 3
Age-specific GM optimality scores according to the different categories of GM quality

	Very preterm period			Moderate preterm period			Late preterm period			Term period			Postterm period		
	N	PR	N	PR	CS	N	PR	CS	Ch	N	PR	CS	N	PR	CS
<i>n</i>	14	93	19	118	31	65	105	49	11	20	42	39	51	83	41
Max	42	37	42	39	19	42	38	18	25	42	37	18	42	33	19
P90	42	34	42	34	18	42	32	15	25	42	33	16	41	31	17
P75	41	30	41	32	15	41	28	14	16	42	29	14	40	26	15
Median	39	26	40	27	12	40	25	11	14	40	25	11	37	23	13
P25	37	23	35	23	10	37	22	9	11	39	20	9	35	21	11
P10	34	19	35	20	8	36	20	7	8	36	18	7	35	18	9
Min	31	13	30	14	5	30	15	5	8	32	13	6	32	16	6

Key: P = percentile rank; N = normal general movements; PR = poor repertoire; CS = cramped-synchronised; Max = maximum score; Min = minimum score

Table 4

Optimal criteria (in %) met within each category of GMs according to the different age groups

Optimal criterion	Normal GMs (n=169)						PR GMs (n=441)						CS GMs (n=160)						Chaotic GMs (n=13)						
	VP	M	LP	T	PT	VP	M	LP	T	PT	VP	M	LP	T	PT	VP	M	LP	T	PT	VP	M	LP	T	PT
Number of recordings	14	19	65	20	51	93	118	105	42	83	0	31	49	39	41	0	1	11	1	0					
Neck involved in the sequence	79	84	89	80	76	30	30	34	31	27		7	18	10	15										
Fluent and elegant trunk rotations	86	74	86	75	53	33	34	21	14	5		0	0	0	0										
Upper extremities	93	90	89	80	98	40	33	33	41	37		7	18	15	3										
Variable amplitude	71	84	80	85	94	26	26	26	41	23		3	2	10	5										
Variable speed																									
Full space variably used	64	84	80	85	82	26	32	29	24	17		10	8	2	0										
Fluent and elegant proximal rotations	79	94	91	90	84	37	47	32	36	17		0	0	0	5										
Fluent and elegant distal rotations	86	79	85	75	73	31	39	28	36	30		0	0	0	5										
Smooth and fluctuating onset	71	95	91	100	73	33	27	19	17	6		0	0	0	0										
Smooth and fluctuating offset	79	63	80	100	59	10	10	7	7	1		0	0	0	0										
No tremulous movements	64	79	71	85	47	65	60	65	41	30		48	46	41	32										
No cramped components	93	84	100	100	37	90	82	81	45	22		0	0	0	0										
Lower extremities	93	95	100	90	99	44	40	33	31	27		0	10	0	0										
Variable amplitude																									
Variable speed	93	84	85	95	90	27	28	27	31	27		3	2	0	0										
Full space variably used	99	100	95	99	99	28	38	32	29	30		7	2	0	0										
Fluent and elegant proximal rotations	93	79	82	85	92	28	36	15	19	22		0	0	0	0										
Fluent and elegant distal rotations	100	74	79	85	98	20	25	11	21	30		0	0	0	2										
Smooth and fluctuating onset	79	100	92	100	90	26	24	16	14	6		0	0	0	0										
Smooth and fluctuating offset	86	68	82	100	86	1	8	2	7	1		3	0	0	0										
No tremulous movements	64	79	69	70	96	42	53	49	62	89		52	57	54	85										
No cramped components	93	84	80	90	51	71	64	30	38	30		0	0	0	0										

Key: GMs = general movements; PR = poor repertoire; CS = cramped-synchronised; VP = very preterm; M = moderate preterm; LT = late preterm; T = term; PT = postterm