General Movement Optimality Score-Revised (GMOS-R) with General Population-Based Percentile Ranks

Natasha Amery, BSc[1,2], Caroline F. Alexander, PhD[3,4], Alison T. Salt, MSc[1,4,5], Sarah E. Hall, PhD[1,3,4], Catherine Elliott, PhD[3], Catherine Morgan, PhD[6], Alicia J. Spittle, PhD[7], and Jane Valentine, PhD[1,4,5]

Objectives To describe writhing General Movements Assessment (GMA) classification and General Movement Optimality Score–Revised (GMOS-R) profiles in the general population; to explore relationships between GMOS-R scores and GMA classification, age of assessment and infant socio-demographic factors; and to establish the inter-rater reproducibility of writhing age GMA classification and GMOS-R.

Study design A cross-sectional study of 1861 infants recruited from the general population in Perth, Western Australia, including 7.5% born preterm. Parent-recorded videos were collected between 41- and 45-weeks post-menstural age, when writhing movements are typically observed. General movements (GMs) classification and GMOS-R were assessed independently by at least 2 experienced advanced-trained clinicians.

Results The majority of infants' GMs were classified as normal (66.8%) or poor repertoire (33.2%), with one infant's movements classified as cramped synchronized (0.1%). The median GMOS-R score was 33 (interquartile range 27-36). The GMOS-R differentiated GMA classifications. Lower gestational age, any nursery admission, minority ethnicity, and older age at video collection were each associated with a small but statistically significant reduction in GMOS-R scores. GMA classification had excellent inter-rater reliability and agreement. Total GMOS-R had excellent inter-rater reliability and moderate agreement.

Conclusions Although most infants had normal GMs there was a high prevalence of poor repertoire GMs in the general population. GMOS-R scores effectively differentiated movement quality within the poor repertoire classification. This study provides population-based percentile ranks for interpreting individual post-term GM assessments and as a reference for future research. *(J Pediatr 2026;291:114962)*.

General movements (GMs) are age specific, endogenously created, spontaneous movements of the whole body,[1] which are predictive of cerebral palsy[2] and associated with other neurodevelopmental outcomes.[3-5] Present in fetuses and infants, writhing GMs can be observed across the preterm, term and post term period until 45-46 weeks postmenstrual age (PMA). After 45-46 weeks PMA, the character of movements changes and at 9-20 weeks post-term, fidgety age GMs emerge.[6] Prechtl's General Movements Assessment (GMA) is an observational tool used to assess GMs based on pattern recognition by gestalt perception.[7] Although associated with diagnosis of cerebral palsy[8,9] there is emerging evidence that writhing GMA may be also associated with cognitive development[10-15] and other neurodevelopmental disorders.[16,17] It is recommended and routinely used in early assessment of high-risk infants,[18] and there is an increasing interest in the use of the GMA in low-risk populations as an early screening tool for neurodevelopmental outcomes.

Assessment of an infant video at writhing age allows classification as either normal or abnormal, with abnormal movements classified as poor repertoire, cramped synchronized or chaotic.[19,20] Clinical interpretation varies across abnormal writhing GMA classifications. Cramped synchronized movement is strongly associated with abnormal developmental outcomes;[21,22] however, poor repertoire classification alone does not necessarily indicate a poor prognosis.[14,23]

The GM optimality score, a semi-quantified, detailed scoring of writhing age movements may be conducted alongside the GMA classification to provide additional detail and aid clinical interpretation. First proposed by Prechtl,[19] it has undergone several iterations.[24] The current version, the General Movement Optimality Score – Revised (GMOS-R) was published in 2024.[25] The GMOS-R has a total score of 38 with a higher score indicating more optimal writhing

AC_1	Gwet's Agreement Coefficient
GM	General Movement
GMA	General Movement Assessment
GMOS-R	General Movement Optimality Score – Revised
ICC	Intraclass correlation coefficient
PMA	Postmenstrual age

From the [1]Paediatric Rehabilitation, Perth Children's Hospital, Perth, Western Australia, Australia; [2]Physiotherapy, King Edward Memorial Hospital, Perth, Western Australia, Australia; [3]School of Allied Health, Curtin University, Perth, Western Australia, Australia; [4]Kids Rehab Research WA, The Kids Research Institute Australia, Perth, Western Australia, Australia; [5]Paediatrics, UWA Medical School, The University of Western Australia, Perth, Western Australia, Australia; [6]Cerebral Palsy Alliance Research Institute, The University of Sydney, New South Wales, Australia; and [7]Department of Physiotherapy, University of Melbourne, Parkville, Victoria, Australia

https://doi.org/10.1016/j.jpeds.2025.114962

movements. The total GMOS-R score includes the GMA classification itself (normal/poor repertoire/cramped synchronized/chaotic) comprising a maximum of 2 points, with the remaining 36 points made up of neck and trunk movement and 8 detailed scoring components of movement for both upper and lower limbs. Components include amplitude, speed, spatial range, proximal and distal rotations, beginning and end of movements, and stiffness. Each item is scored on a scale of 0-2 with 2 indicating optimal performance, 1 less optimal, and 0 nonoptimal. Optimality scoring at writhing age has been found to have good interrater reliability[6,25] and is increasingly used in both clinical and research settings[17,26] for early detection of risk of cerebral palsy and other neurodevelopmental conditions.

Despite potential application as a screening tool in the general population, most research focuses on infants known to be at high-risk of adverse neurodevelopmental outcomes (such as preterm infants or those with neonatal complications), where the prevalence of abnormal writhing movements is reported to be between 61% and 75%.[13,16,25] Publication of the latest version of the GMOS-R included outcomes from a large international cohort of 1983 infants, the majority of whom were considered high-risk.[25] Results indicate 59% were classified with poor repertoire, 15% cramped synchronized movements, and 1% chaotic movements, which were presented alongside percentile ranks socioeconomically stratified by country of birth. However, there is a lack of research for both writhing classification prevalence and GMOS-R score distributions in the general population, and their relationship with infant and sociodemographic factors. Population based research has the potential to improve early detection and allow early intervention for neurodevelopmental delays in the low-risk, term population and provide a critical point of reference for investigations into these delays in high-risk children.

The primary aim of this study is to describe term-age writhing GMA classification and GMOS-R profiles in the general population. The secondary aims are to explore relationships between GMOS-R scores and GMA classification, age of assessment and infant socio-demographic factors, and to establish the inter-rater reliability and agreement of writhing age GMA classification and GMOS-R.

Methods

This cross-sectional sub-study was part of Early Moves, a large population-based prospective cohort study conducted in Perth, Western Australia.[27,28] Participants were recruited from 2 maternity hospitals: Joondalup Health Campus as a subproject of ORIGINS,[29,30] or St John of God Public and Private Hospitals Midland. Video data collection occurred between November 2019 and March 2024, and video assessment occurred between May 2021 and April 2024. Ethics approval was provided by Ramsay Health Care WA | SA HREC (1902), St John of God Health Care HREC (1767), and WA Child and Adolescent Health Service HREC (4801).

Participants

Any mother intending to give birth or who had recently given birth at one of the study hospitals was eligible to participate with their infant(s) in the Early Moves study. Exclusion criteria included mothers with insufficient English to provide informed consent or infants enrolled in an ORIGINS interventional research study that aims to promote cognitive and language development.[27] All participants with least one scorable writhing video uploaded were included in this study.[28]

Infant clinical and maternal socio-demographic data were extracted from hospital records including standardized data collected by attending midwives for the statewide Western Australia Midwives Notification System.[31] Preterm was defined as per the World Health Organization guidelines (<37 weeks).[32] Admission to special care nursery describes admission to nursery at the primary birth site in full days. Maternal ethnicity was self-reported. Socioeconomic status was measured by the Index of Socio-Economic Advantage and Disadvantage which summarizes information about the economic and social conditions of people and households within an area, including both relative advantage and disadvantage measures.[33] Maternal ethnicity and socioeconomic status are reported to inform generalizability of results and to explore the relationship between sociodemographic factors and outcomes of the GMA, as previously identified in high-risk cohorts.[25] For this exploratory analysis, families residing in the lowest 2 quintiles were classed as having low socioeconomic status. Due to the small number of participants recorded as from minority ethnicities, we grouped these participants into a single category for comparative analysis. This approach was taken to ensure sufficient statistical power and to enable preliminary exploration of potential differences in outcomes between Caucasian and minority ethnic groups. We acknowledge that this category is heterogeneous and may encompass a range of cultural and social backgrounds and results should be interpreted accordingly.

Video Collection and Selection

To increase the likelihood of one scorable video being attained within the writhing period, 2 writhing videos were submitted per participant: Video A was collected between 41.0 and 42.9 weeks and Video B was collected between 43.0 and 44.9 weeks PMA as per published protocol.[27] Recordings were 3 minutes in length and were collected by parents using the Baby Moves research app.[34,35] Videos were not considered scorable if infant or environmental factors or video quality prevented assessment of GMA classification, or if the baby was less than 5 days postnatal age, despite being 41 weeks PMA, as it takes time for the GMs to normalize after birth.[36] Full details on infant, environmental or video factors that are considered to affect scoring have been previously published.[28] If one or more components of GMOS-R were unable to be assessed due to infant, environmental or video factors (eg, distal rotatory components obscured by clothing), full GMOS-R score was not calculated.

A single video per participant was included for analysis. If Video A was scorable for GMA classification and GMOS-R, this was assessed and used for analysis, and Video B was not reviewed. If Video A was not uploaded or uploaded but not scorable for GMA classification and/or GMOS-R, the Video B was assessed and used for analysis. If neither video was scorable for GMOS-R, but both were scorable for GMA classification, data for Video B were used.

General Movement Assessment

Assessors consisted of 7 senior physiotherapists with advanced training in Prechtl's GMA and experience using the GMA with neonates in a tertiary clinical setting. Prior to commencing work with the Early Moves study, project assessors had a mean of 5.2 years (range 3-8 years) experience conducting GMA classification and 1.3 years (range 0-4 years) experience conducting GMOS assessments. All assessors (including those with previous advanced training) completed GMs Advanced Course B in Perth, Western Australia, in May 2021, conducted by the GM Trust [hyperlink: General Movements Trust-The Prechtl General Movement Assessment].

The scorable videos were independently assessed by 2 randomly selected assessors, who were masked to birth history including gestational age and any clinical information. Each video was first assessed for GMA classification using the gestalt assessment. Writhing movements are classified as normal when movements are variable, fluent, and show complex sequences throughout the whole body. Abnormal movements lacking the variability, fluidity and smoothness of normal movements are classified as (1) poor repertoire when movements lack complexity and sequences are monotonous and repetitive, (2) cramped synchronized when movements are characterised by rigidity, simultaneous contraction and relaxation of the limbs and trunk, or (3) chaotic when movements are large amplitude, jerky, and disorganized. Examples of normal and poor repertoire movements are shown in **Video 1**, available at www.jpeds.com and **Video 2**, available at www.jpeds.com. The same 2 assessors independently conducted the full GMOS-R assessment 1 day later to reduce likelihood of gestalt scoring influencing GMOS-R assessment as per recommended guidelines.[25]

As per published protocol,[27] if the 2 independent assessments of each video showed a different GMA classification, or the GMOS-R scores were different by more than 5 points, a third assessor (AJS, CM, or NA), masked to clinical history and previous assessment outcomes, conducted a final assessment. This third assessment was used for the purpose of final analysis. If a third assessment was not conducted due to satisfactory agreement between the first and second assessment, the assessment used for analysis was randomly selected between the 2.

Statistical Analysis

Descriptive statistics, including count and percentage for categorical variables, mean and standard deviation (SD) for normally distributed variables and median and interquartile range (IQR) for non-parametric variables were used. To explore differences in GMOS-R distribution between GMA classifications, infant factors (sex, prematurity, and special care nursery stay), maternal sociodemographic factors (ethnicity, socioeconomic status) and video factors (age at video collection), the Mann–Whitney test was used.

For categorical variables (GMA classification and GMOS-R items) inter-rater reliability was assessed using Gwet's Agreement Coefficient 1 (AC_1),[37] whereas inter-rater agreement was assessed using percentage agreement with 95% confidence intervals (CIs). Reliability and agreement for categorical outcomes were interpreted using definitions of slight (0.00-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80) and almost perfect (0.81-1.00).[38] For the total GMOS-R assessment, intraclass correlation coefficient (ICC) using a two-way random effects model for absolute agreement inter-rater reliability was analyzed and interpreted using definitions of poor (<0.4), weak (0.4-0.54) moderate (0.55-0.69), good (0.70-0.84) and excellent (>0.85).[39] Inter-rater agreement was assessed using limits of agreement.[40] Clinically acceptable limits of agreement were set a priori as $\pm$ 5 points.[27] All statistical analysis was conducted in Stata v16 (StataCorp, Texas USA).[41]

Results

Writhing videos were uploaded for 2165 participants, of which 1861 were scorable for GM classification and included for analysis. More detailed exploration of video quality and factors influencing video upload have been reported elsewhere.[28] Of infants with a scorable video, 1722 were born at term and 139 were born preterm. Infants had a mean gestational age of 39.0 weeks (SD 1.6, range 26.3-42.9) and mean birthweight of 3354g (SD 530, range 811 – 4940). Participant characteristics are presented in **Table I**. Average age of infants at video collection was 42.9 weeks PMA (SD 1.1) with 462 (24.8%) recordings completed during the term period – by 41.9 weeks – and 1399 (75.2%) recorded during the post-term period – after 42 weeks. Average postnatal age at video collection was 3.9 weeks (SD 1.9, range 0.6-14.9).

GMA Classification

The majority of infants (n = 1243; 66.8%) were classified with normal GMs, and almost a third (n = 617; 33.2%) were classified with poor repertoire GMs. One infant (0.1%) was classified as having cramped synchronized GMs, and no infants had chaotic GMs.

GMOS-R Scores

Videos were of sufficient quality for GMOS-R scoring for 1703 infants (91.5%). Median GMOS-R was 33, with an IQR of 27 to 36 (see **Table II**) and total range of 14 to 38. Sub scores were similar for the lower and upper extremity with both showing a mean of 14 and IQR of 12 to 15. As shown in **Figure 1**, infants classified with normal writhing movements scored significantly higher (Z = 33.45,

Table I. Participant characteristics

Characteristics	Participants n = 1861 n (%)
Infant characteristics	
Sex, male	990 (53.2)
Plurality, twins	41 (2.2)
Estimated gestation, wks	
<28	3 (0.2)
28 + 0-31.9	8 (0.4)
32 + 0-36.9	128 (6.9)
37 + 0-40.9	1606 (86.3)
≥41.0	116 (6.2)
Birth weight, g	
<1000	1 (0.1)
1000-1499	7 (0.4)
1500-2499	95 (5.1)
≥2500	1751 (94.4)
SCN stay at the primary site, d	
None	1487 (80.6)
1-3	262 (14.2)
4-7	41 (2.2)
≥8	56 (3.0)
Sociodemographic characteristics	
Maternal ethnicity	
African	14 (0.8)
Asian	123 (6.7)
Caucasian	1492 (81.7)
Indian (sub-continent)	50 (2.7)
Indigenous Australian	12 (0.7)
Māori or Polynesian	7 (0.4)
Other	129 (7.1)
Socio-economic status	
Lowest quintile	96 (5.2)
Lower middle quintile	185 (10.0)
Middle quintile	460 (24.8)
Upper middle quintile	776 (41.8)
Upper most quintile	340 (18.3)

$P < .001$) and had a smaller range (range = 11 points; 27-38) than those classified with poor repertoire writhing movements (range = 18 points; 14-32). The single infant with cramped synchronized movements had a GMOS-R of 14.

Within the category of normal writhing movements, each optimal criterion (ie, score of 2) was met by more than 70% of infants, with the exception of upper and lower extremity distal rotatory components, which was observed in 62% and 69% of infants respectively (Table III). Among infants with normal writhing movements, sub scores were similar for the lower and upper extremity with both showing a mean of 15 and IQR of 14 to 16.

Within the category of poor repertoire writhing movements, each optimal criterion was met by 20-65% of infants, with the exception of the trunk (6%) (Table III). Among infants with poor repertoire writhing movements, sub scores were similar for the lower and upper extremity with both showing a mean of 11, and IQR of 9 to 12 for lower extremity, and 10 to 12 for upper extremity.

Table II. Population-based GMOS-R percentile ranks for all infants, and according to the different general movement classifications assessed during the post-term period (41.0 to 44.9 weeks postmenstrual age)

Percentile	Normal n = 1142	Poor repertoire n = 560	Total group n = 1703
P90	38	29	37
P75	36	27	36
P50	35	25	33
P25	33	23	27
P10	32	20	24
P5	30	19	22
P1	29	15	17

GMA and Infant Factors

In infants born at term, 32.5% were classified as having poor repertoire movements, compared with 40.6% of infants born preterm, though this difference did not reach statistical significance ($\chi^2 = 3.69$, $P = .055$). As shown in Figure 2A, gestational age had a small statistically significant effect on GMOS-R scores, with term-born infants having higher GMOS-R scores than infants born preterm ($Z = 2.66$, $P = .008$). Gestational age was also associated with a small statistically significant reduction in GMOS-R scores amongst those classified as normal ($Z = 1.97$, $P = .049$), but there was no effect among those classified with poor repertoire ($Z = 0.61$, $P = .545$).

No statistically significant difference was found in GMA classification between male infants (34.7% poor repertoire) compared with female infants (31.3% poor repertoire; $\chi^2 = 3.35$, $P = .187$). As shown in Figure 2B, infant sex had no effect on GMOS-R scores in the overall group ($Z = -1.10$, $P = .27$), among those classified with normal GMs ($Z = 0.63$, $P = .532$), or poor repertoire ($Z = -0.61$, $P = .541$).

In infants admitted to a special care nursery, 35.6% were classified as having poor repertoire movements, compared with 32.4% of infants without nursery admission, though this difference did not reach statistical significance ($\chi^2 = 5.45$, $P = .066$). As shown in Figure 2C, admission to a special care nursery had a small statistically significant effect on GMOS-R scores overall ($Z = 1.98$, $P = .047$), but was unrelated to GMOS-R among those classified as normal ($Z = 1.41$, $P = .157$) or poor repertoire ($Z = -0.31$, $P = .753$).

GMA and Maternal Socio-Demographic Factors

Infants residing in low socioeconomic areas were more likely to be classified as having poor repertoire movement (35.2%) compared with those in higher socioeconomic areas (32.7% poor repertoire; $\chi^2 = 6.34$, $P = .042$). As shown in Figure 2D, GMOS-R scores were not significantly different between infants residing in low and high socioeconomic areas overall ($Z = 0.76$, $P = .447$), among those classified as normal ($Z < 0.01$, $P = .997$) or poor repertoire ($Z = -0.26$, $P = .796$).

Infants of mothers from minority ethnicities were more likely to be classified with poor repertoire movements (40.6%) than infants of Caucasian mothers (30.8%; $\chi^2 = 12.06$, $P = .002$). As shown in Figure 2E, maternal ethnicity had a small statistically significant effect on

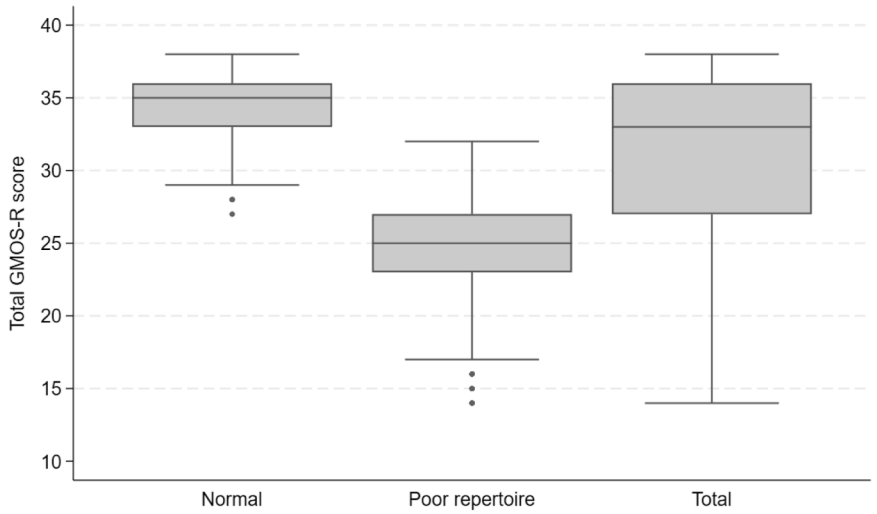

Figure 1. Distribution of the General Movements Optimality Score - Revised (GMOS-R) of normal general movements (GMs), poor repertoire GMs, and all GMs. The boxes represent the 25th to 75th percentiles, with the horizontal line indicating the median score. The whiskers represent the upper and lower adjacent values (1.5 IQR) and the markers denote statistical outliers.

GMOS-R scores overall (Z = −2.56, P = .010), but no effect within those classified as normal (Z = −0.27, P = .784) or poor repertoire (Z = 0.54, P = .591).

GMA and Video Factors

Infants assessed at post-term age (42.0-45.9 weeks PMA) were more likely to be classified with poor repertoire movements (35.6%) than those assessed at term age (25.8%; χ^2 = 15.52, P < .001), with significantly lower GMOS-R scores overall (Z = 2.96, P = .003), but not among those classified as normal (Z = 0.39, P = .694) nor among those classified with poor repertoire (Z = −0.52, P = .604), as shown in **Figure 2**F.

GMA Inter-rater Reliability and Agreement

Of the 1861 videos assessed, 187 (10%) went to third review due to difference in GMA classification (n = 90), difference in

Table III. Optimal criteria n (%) met within each category of GMs, and inter-rater reliability and agreement for each criterion

Criterion	Normal n = 1142 n (%)	PR n = 560 n (%)	Total n = 1703 n (%)	Inter-rater reliability Gwets AC_1 (95% CI)	Inter-rater agreement % agreement (95% CI)
Neck	933 (82)	146 (26)	1079 (63)	0.66 (0.62-0.69)	0.73 (0.71-0.76)
Trunk	834 (73)	35 (6)	869 (51)	0.55 (0.52-0.59)	0.68 (0.65-0.71)
Upper extremity					
Amplitude	1034 (91)	280 (50)	1314 (77)	0.78 (0.75-0.82)	0.81 (0.78-0.84)
Speed	1085 (95)	366 (65)	1452 (85)	0.79 (0.76-0.82)	0.81 (0.78-0.83)
Spatial range	865 (76)	129 (23)	994 (58)	0.67 (0.64-0.71)	0.75 (0.73-0.78)
Proximal rotatory component	1055 (93)	277 (50)	1333 (78)	0.70 (0.67-0.73)	0.75 (0.72-0.78)
Distal rotatory components	707 (62)	161 (29)	869 (51)	0.45 (0.41-0.49)	0.60 (0.57-0.63)
Beginning	933 (82)	152 (27)	1085 (64)	0.58 (0.55-0.62)	0.68 (0.65 – 0.71)
End	984 (86)	180 (32)	1164 (68)	0.68 (0.65-0.71)	0.75 (0.72-0.78)
Stiffness	857 (75)	327 (59)	1184 (70)	0.60 (0.56-0.63)	0.69 (0.66-0.72)
Lower extremity					
Amplitude	1062 (93)	294 (53)	1356 (80)	0.76 (0.74-0.79)	0.79 (0.76-0.82)
Speed	1072 (94)	349 (62)	1421 (84)	0.79 (0.76-0.82)	0.81 (0.78-0.84)
Spatial range	875 (77)	119 (21)	994 (58)	0.67 (0.64-0.71)	0.75 (0.72-0.78)
Proximal rotatory components	967 (85)	198 (35)	1165 (69)	0.66 (0.62-0.69)	0.71 (0.68-0.74)
Distal rotatory components	784 (69)	174 (31)	958 (56)	0.51 (0.48-0.55)	0.66 (0.61-0.67)
Beginning	860 (75)	127 (23)	987 (58)	0.54 (0.50-0.58)	0.65 (0.62-0.68)
End	892 (78)	155 (28)	1047 (62)	0.59 (0.55-0.62)	0.68 (0.66-0.71)
Stiffness	876 (77)	285 (51)	1161 (68)	0.57 (0.54-0.61)	0.67 (0.64-0.70)

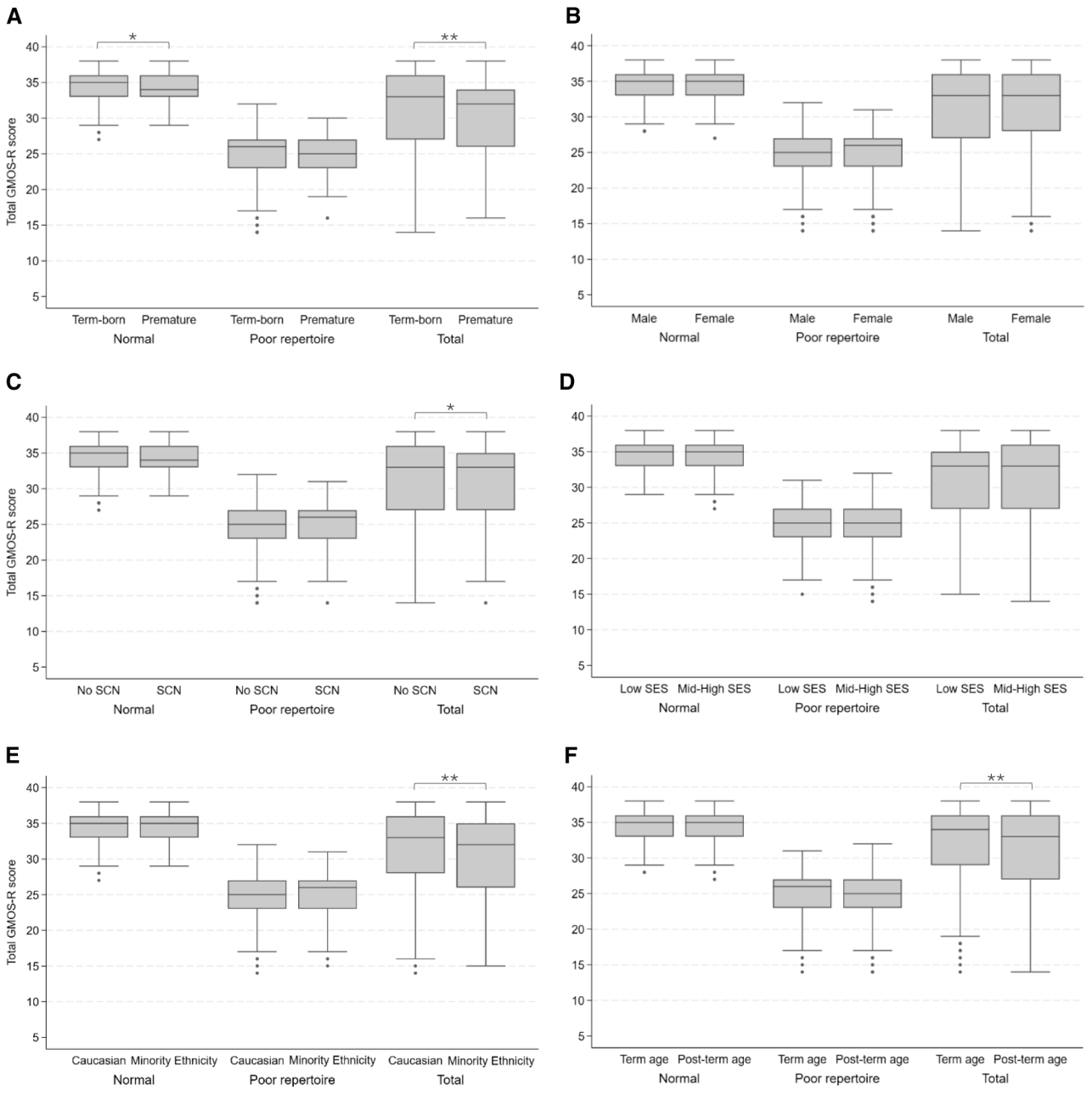

Figure 2. Comparison of distribution of the General Movements Optimality Score - Revised (GMOS-R) of normal general movements (GMs), poor repertoire GMs, and all GMs by **A**: gestational age, **B**: infant sex, **C**: admission of at least 1 day to special care nursery (SCN), **D**: socioeconomic status (SES), **E**: maternal ethnicity and **F**: age at video collection. The boxes represent the 25th to 75th percentiles, with the horizontal line indicating the median score. The whiskers represent the upper and lower adjacent values (1.5 IQR) whereas the markers denote statistical outliers. * = statistically significant difference at $P = \leq.05$, ** = statistically significant difference at $P = \leq.01$.

GMOS-R of more than 5 points with agreement on GMA classification (n = 30), or difference in GMA classification and GMOS-R score of more than 5 points (n = 67).

Inter-rater reliability for GMA classification was excellent with Gwet's AC_1 of 0.903 (95% CI 0.877-0.928) and almost perfect agreement of 92.4% (95% CI 90.1-94.8).

Inter-rater reliability for the GMOS-R was excellent, with ICC = 0.88 (95% CI 0.87-0.89), whereas inter-rater agreement was moderate with limits of agreement of ± 5.2 points. As shown in Figure 3, the Bland-Altman plot indicates poorer agreement was seen when the mean score was within the range of 22 to 32. Substantial inter-rater reliability was found for the lower extremity (ICC = 0.77, IQR 0.75-0.79) and upper extremity (ICC = 0.77, IQR 0.75-0.79). Inter-rater agreement was moderate with limits of agreement of ± 3.3 points for lower and ± 3.0 points for upper extremity.

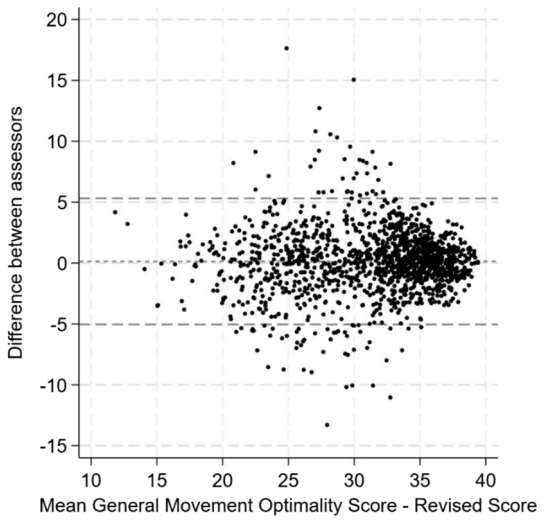

Figure 3. Bland-Altman plot of agreement between the 2 assessors from the General Movement Optimality Score -Revised.

Inter-rater reliability for individual GMOS-R criteria was weak to substantial, with Gwet's AC_1 ranging from 0.45 (for upper limb distal rotatory components) to 0.79 (upper and lower limb speed). Inter-rater agreement for individual GMOS-R criteria was moderate to substantial with percentage agreement ranging from 0.60 (upper limb distal rotatory components) to 0.81 (upper limb amplitude, and upper and lower limb speed).

Discussion

This study presents general population-based percentile charts for writhing age GMA classification and GMOS-R. A high prevalence of normal writhing movements was observed among the predominantly healthy and mostly term-born population. Only one infant was found to have cramped synchronized movements and no infants had chaotic movements. Although the prevalence of poor repertoire writhing movements in our cohort was lower than what has been reported among high-risk infants,[16,25] poor repertoire writhing was observed in one third of the general population.

This study presents general population-based percentile charts for GMOS-R, irrespective of GMA classification, finding a median GMOS-R of 33, with 5% of infants scoring 22 or less, and 1% scoring 17 or below. These normative data represent the range of performance on the GMOS-R that may be expected in a general population, providing a reference group against which an individual's results can be compared as a starting point for the interpretive process.

When considering GMOS-R scores within GMA classifications, infants classified with normal writhing movements in this population-based cohort had similar median, IQR and range of GMOS-R scores to high-risk infants classified as having normal writhing movements.[25] However, among infants classified as having poor repertoire writhing, infants in this population-based cohort had similar range scores, but higher median and IQR GMOS-R scores compared with reported scores from high-risk infants.[25] This indicates that infants in the general population tend to display more optimal movements within the classification of poor repertoire and suggests the GMOS-R is capable of differentiation of movement quality within the classification of poor repertoire, which may aid interpretation of GMA outcomes.

Inter-rater reliability and agreement for GMA classification were found to be excellent replicating previous work.[42,43] GMOS-R inter-rater reliability was also found to be excellent however the inter-rater agreement was only considered moderate. In particular, it is noted that poorer GMOS-R inter-rater agreement is observed within the range of 22-32, where the classification of normal and poor repertoire score ranges overlap.

Gestational age, infant sex and admission to a special care nursery were found to have a small but significant influence on GMA classification and GMOS-R scores in this population-based cohort, aligning with known risk factors for adverse developmental outcomes in a term born population.[44] Only one previous study has explored the relationship between GMOS-R and gestational age or sex, finding no association. However, this previous study was of high-risk infants and therefore may be explained by low variance and high risk of confounders.[25]

Sociodemographic variables were not related to GMOS-R scores within GMA classifications, suggesting that recently published differences in GMOS-R scores by socioeconomic status of the country of birth[25] are not replicated at a local level in a high-income country. However, infants residing in low socioeconomic areas and infants of mothers from minority ethnicities were more likely to receive a poor repertoire classification, with maternal ethnicity showing a significant association with GMOS-R scores overall. The group of infants of mothers from minority ethnicities is heterogeneous, including participants from many different cultural and social backgrounds. Future studies with larger and more diverse samples are needed to explore outcomes by specific ethnicities and cultures to better understand potential differences and ensure appropriate development of relevant stratified percentile ranks to aid clinical interpretation.

This study's strengths lie in its use of a very large population-based sample from a birth cohort previously reported as representative of the local birthing population in terms of infant risk factors.[28] The standardization of data collection processes, including substantial support to ensure high-quality recordings and double-scored videos, enhanced the quality of data collected.

Generalizability to lower-income or diverse health care settings may be limited by the metropolitan setting in a high-income country. Further, only one infant was identified to have a cramped synchronized movement pattern which is more strongly associated with cerebral palsy than poor repertoire.[21] This limited the study's ability to explore the relationship between GMOS-R and cramped synchronized classification. Although we asked families to record the

videos in both the term and the post term period, if the first video was not uploaded, the second video was scored. As families were not randomly allocated into timing of videos, there is potential bias due to external factors such as less settled infants influencing when a family managed to complete their first video, which may explain the association between age at video collection and GMA outcome.

This study demonstrates that the poor repertoire classification is relatively common within a general population sample, though within this classification infants tend to have higher GMOS-R scores compared with high-risk cohorts. This finding underscores the value of reporting a GMOS-R score alongside a GMA classification, to support clinical interpretation. Further research examining the relationship between GMA classification and GMOS-R scores and developmental outcomes across both high- and low-risk infant populations is required to understand predictive utility of the GMA classification and GMOS-R, and aid in setting appropriate cut off scores for monitoring and intervention.

In summary, this study has provided general population-based percentile ranks from the largest population-based dataset of writhing GMA. The percentile ranks offer a critical reference point for the initial interpretation of individual post-term writhing GMA results, and a valuable resource for future research. ■

CRediT authorship contribution statement

Natasha Amery: Writing – original draft, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Caroline F. Alexander:** Writing – review & editing, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Alison T. Salt:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Sarah E. Hall:** Writing – review & editing, Project administration, Formal analysis, Conceptualization. **Catherine Elliott:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Catherine Morgan:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Alicia J. Spittle:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Jane Valentine:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

Early Moves is funded by Curtin University's Faculty of Health Sciences and School of Allied Health; National Health and Medical Research Council (NHMRC) clinical trials and cohort study grant; Perth Children's Hospital Foundation project grant with The Channel 7 Telethon Trust and Mineral Resources Limited; Cerebral Palsy Alliance Research Foundation project grant; WA Child Research Foundation project grant. A.J.S. has received funding from the NHMRC Investigator Grant. A.J.S. and C.M. are licensed tutors of the General Movements Trust. A.J.S. reports a relationship with General Movements Trust that includes: speaking and lecture fees and travel reimbursement. C.M. reports a relationship with General Movements Trust that includes: speaking and lecture fees and travel reimbursement. Given A.J.S.'s role on the editorial board for the Journal of Pediatrics, she had no involvement in the peer review of this article and no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Early Moves is conducted on Whadjuk Noongar Country and is only possible because of the commitment of all the families involved. We would like to thank the GM assessors (A Coenen, J Moore, N Hanlin, N Smith, A Pratten, and E Stanton) for the substantial contribution to the data collection for this work, along with the full Early Moves project team. We would also like to acknowledge and thank the ORIGINS project team, Community Reference and Participant Reference Groups, Clinical Reference Group, and Research Interest Groups and Scientific Committee.

Submitted for publication Jul 1, 2025; last revision received Oct 17, 2025; accepted Dec 12, 2025.

Reprint requests: Caroline F Alexander, PhD, School of Allied Health, Curtin University, Kent Street, Bentley, Western Australia 6102, Australia. E-mail: caroline.alexander@curtin.edu.au

Data Statement

Data sharing statement available at www.jpeds.com.

References

1. Einspieler C, Prechtl HF. 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.
2. Burger M, Louw QA. The predictive validity of general movements – a systematic review. Eur J Paediatric Neurol 2009;13:408-20. https://doi.org/10.1016/j.ejpn.2008.09.004
3. Bennema AN, Schendelaar P, Seggers J, Haadsma ML, Heineman MJ, Hadders-Algra M. Predictive value of general movements' quality in low-risk infants for minor neurological dysfunction and behavioural problems. Early Hum Dev 2016;94:19-24. https://doi.org/10.1016/j.earlhumdev.2016.01.010
4. Einspieler C, Bos AF, Libertus ME, Marschik PB. The general movement assessment helps us to identify preterm infants at risk for cognitive dysfunction. Mini review. Front Psychol 2016;22:406. https://doi.org/10.3389/fpsyg.2016.00406
5. Hadders-Algra M, Groothuis AMC. Quality of general movements in infancy is related to neurological dysfunction, ADHD, and aggressive behaviour. Dev Med Child Neurol 1999;41:381-91. https://doi.org/10.1017/S0012162299000845
6. Ustad T, Evensen KAI, Bertoncelli N, Frassoldati R, Ferrari F. Validity of the general movement optimality list in infants born preterm. Pediatr Phys Ther 2017;29:315-20. https://doi.org/10.1097/pep.0000000000000445
7. Lorenz K. Gestalt perception as fundamental to scientific knowledge. Gen Syst 1962;7:37-56.

8. Wang T, Zheng B, Yang H, Liu H, Zhou Y, Wen Z, et al. Predictive value and ranking of writhing and fidgety movements for cerebral palsy: a meta-analysis based on the superiority index. Medicine 2025;104:e43813.
9. Kwong AKL, Fitzgerald TL, Doyle LW, Cheong JLY, Spittle AJ. Predictive validity of spontaneous early infant movement for later cerebral palsy: a systematic review. Dev Med Child Neurol 2018;60:480-9. https://doi.org/10.1111/dmcn.13697
10. Vallamkonda N, Bandyopadhyay T, Marcia A. A study of general movement assessment and its association with neurodevelopmental outcome at age 12 to 15 months among term neonates with hyperbilirubinemia. Pediatr Neurol 2024;153:77-83. https://doi.org/10.1016/j.pediatrneurol.2023.12.030
11. Kepenek-Varol B, Çalışkan M, İnce Z, Tatlı B, Eraslan E, Çoban A. The comparison of general movements assessment and neurological examination during early infancy. Turkish J Pediatr 2016;58:54-62. https://doi.org/10.24953/turkjped.2016.01.008
12. George JM, Colditz PB, Chatfield MD, Fiori S, Pannek K, Fripp J, et al. Early clinical and MRI biomarkers of cognitive and motor outcomes in very preterm born infants. Nature 2021;90:1243-50. https://doi.org/10.1038/s41390-021-01399-5
13. Spittle AJ, Spencer-Smith MM, Cheong JLY, Eeles AL, Lee KJ, Anderson PJ, et al. General movements in very preterm children and neurodevelopment at 2 and 4 years. Pediatrics 2013;132:e452-8. https://doi.org/10.1542/peds.2013-0177
14. Beccaria E, Martino M, Briatore E, Podestà B, Pomero G, Micciolo R, et al. Poor repertoire general movements predict some aspects of development outcome at 2 years in very preterm infants. Early Hum Dev 2012;88:393-6. https://doi.org/10.1016/j.earlhumdev.2011.10.002
15. Kodric J, Sustersic B, Paro-Panjan D. Assessment of general movements and 2.5 year developmental outcomes: pilot results in a diverse preterm group. Eur J Paediatric Neurol 2010;14:131-7. https://doi.org/10.1016/j.ejpn.2009.04.012
16. Yildirim C, Asalioğlu A, Coşkun Y, Acar G, Akman İ. General movements assessment and Alberta infant motor scale in neurodevelopmental outcome of preterm infants. Pediatr Neonatal 2022;63:535-41. https://doi.org/10.1016/j.pedneo.2022.06.002
17. Barbosa VM, Einspieler C, Smith E, Bos AF, Cioni G, Ferrari F, et al. Clinical implications of the general movement optimality score: beyond the classes of rasch analysis. J Clin Med 2021;10:1-12. https://doi.org/10.3390/jcm10051069
18. Novak I, Morgan C, Adde L, Blackman J, Boyd RN, Brunstrom-Hernandez J, et al. Early, accurate diagnosis and early intervention in cerebral palsy: advances in diagnosis and treatment. JAMA Pediatr 2017;171:897-907. https://doi.org/10.1001/jamapediatrics.2017.1689
19. 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. https://doi.org/10.1016/s0140-6736(96)10182-3
20. Einspieler C, Prechtl HFR, Bos A, Ferrari F, Cioni G. Clinics in developmental medicine, Prechtl's method on the qualitative assessment of general movements in preterm, term and young infants167. London, UK: Mac Keith Press; 2004.
21. Ferrari F, Cioni G, Einspieler C, Roversi MF, Bos AF, Paolicelli PB, et al. Cramped synchronized general movements in preterm infants as an early marker for cerebral palsy. Arch Pediatr Adolesc Med 2002;156:460-7. https://doi.org/10.1001/archpedi.156.5.460
22. Einspieler C, Marschik PB, Bos AF, Ferrari F, Cioni G, Prechtl HFR. Early markers for cerebral palsy: insights from the assessment of general movements. Future Neurol 2012;7:709-17. https://doi.org/10.2217/fnl.12.60
23. 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. https://doi.org/10.1016/j.earlhumdev.2005.07.010
24. Einspieler C, Marschik PB, Pansy J, Scheuchenegger A, Krieber M, Yang H, et al. The general movement optimality score: a detailed assessment of general movements during preterm and term age. Dev Med Child Neurol 2016;58:361-8. https://doi.org/10.1111/dmcn.12923
25. Einspieler C, Bos AF, Spittle AJ, Bertoncelli N, Burger M, Peyton C, et al. The general movement optimality score-revised (GMOS-R) with socio-economically stratified percentile ranks. J Clin Med 2024;13:2260. https://doi.org/10.3390/jcm13082260
26. Barbosa VM, Smith EV, Bos A, Cioni G, Ferrari F, Guzzetta A, et al. Psychometric properties of the general movements optimality score using rasch measurement. J Appl Meas 2020;21:17-37.
27. Elliott C, Alexander C, Salt A, Spittle AJ, Boyd RN, Badawi N, et al. Early moves: a protocol for a population-based prospective cohort study to establish general movements as an early biomarker of cognitive impairment in infants. BMJ Open 2021;11:1-9. https://doi.org/10.1136/bmjopen-2020-041695
28. Alexander CF, Hall SE, Salt A, Spittle AJ, Morgan C, Grisbrook T, et al. Implementation fidelity of population-based smartphone application for general movement assessment: the early moves study. J Pediatr 2025;285:114710.
29. Davey B, Billingham W, Davis J, Gibson L, D'Vaz N, Prescott SL, et al. Data resource profile: the ORIGINS project databank: a collaborative data resource for investigating the developmental origins of health and disease. Int J Popul Data Sci 2023;8:2388.
30. Silva DT, Hagemann E, Davis JA, Gibson LY, Srinivasjois R, Palmer DJ, et al. Introducing the ORIGINS project: a community-based interventional birth cohort. Rev Environ Health 2020;35:281-93. https://doi.org/10.1515/reveh-2020-0057
31. Government of Western Australia Department of Health. Data from: midwives notification system. Perth, Western Australia: Government of Western Australia; 2024.
32. World Health Organsiation. WHO: recommended definitions, terminology and format for statistical tables related to the perinatal period and use of a new certificate for cause of perinatal deaths. Modifications recommended by FIGO as amended October 14, 1976. Acta Obstet Gynecol Scand 1977;56:247-53.
33. Australian Bureau of Statistics. Socio-Economic Indexes for Areas (SEIFA): Technical Paper, 2021. Published on ABS Website April 2023. Accessed October 3, 2025. https://www.abs.gov.au/statistics/detailed-methodology-information/concepts-sources-methods/socio-economic-indexes-areas-seifa-technical-paper/2021
34. Kwong AKL, Eeles AL, Olsen JE, Cheong JLY, Doyle LW, Spittle AJ. The baby moves smartphone app for general movements assessment: engagement amongst extremely preterm and term-born infants in a state-wide geographical study. J Paediatrics Child Health 2018;55:1-7. https://doi.org/10.1111/jpc.14240
35. Spittle AJ, Olsen JE, Kwong AKL, Doyle LW, Marschik PB, Einspieler C, et al. The baby moves prospective cohort study protocol: using a smartphone application with the general movements assessment to predict neurodevelopmental outcomes at age 2 years for extremely preterm or extremely low birthweight infants. BMJ Open 2016;6:e013446. https://doi.org/10.1136/bmjopen-2016-013446
36. 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. https://doi.org/10.1016/j.earlhumdev.2010.03.004
37. Gwet KL. Inter-rater reliability: dependency on trait prevalence and marginal homogeneity. Stat Methods Inter Rater Reliability Assess Ser 2002;2:9.
38. Landis RJ, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74. https://doi.org/10.2307/2529310
39. Schober P, Mascha EJ, Vetter TR. Statistics from A (agreement) to Z (z score): a guide to interpreting common measures of association, agreement, diagnostic accuracy, effect size, heterogeneity, and reliability in medical research. Anesth Analgesia 2021;133:1633-41. https://doi.org/10.1213/ane.0000000000005773
40. Bland MJ, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;327:307-10.
41. StataCorp. Stata statistical software16. College Station, TX: StataCorp LLC; 2019.
42. Bernhardt I, Marbacher M, Hilfiker R, Radlinger L. Inter- and intra-observer agreement of Prechtl's method on the qualitative assessment

of general movements in preterm, term and young infants. Early Hum Dev 2011;87:633-9. https://doi.org/10.1016/j.earlhumdev.2011.04.017

43. Valencia A, Viñals C, Alvarado E, Balderas M, Provasi J. Prechtl's method to assess general movements: inter-rater reliability during the preterm period. PLoS One 2024;19:e0301934. https://doi.org/10.1371/journal.pone.0301934

44. Bölte S, Neufeld J, Marschik PB, Williams ZJ, Gallagher L, Lai M-C. Sex and gender in neurodevelopmental conditions. Nat Rev Neurol 2023;19:136-59.