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Identifying determinants of 12-month gross motor development in high-risk infants: A multivariate analytical study

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Abstract
Background: Gross motor development during the first year of life reflects early brain maturation and neuromotor pathway integrity. High-risk infants, especially those exposed to prenatal, perinatal, or neonatal complications, are more likely to demonstrate delayed milestone acquisition. Factors such as birth asphyxia, neonatal seizures, meconium aspiration, small-for-gestational-age (SGA) status, prolonged oxygen support, low Apgar scores, multiple gestation, consanguinity, and periventricular leukomalacia (PVL) are known contributors to early motor impairment. Early prediction of motor outcomes enables timely physiotherapy intervention and improved developmental surveillance.
Objective: To identify significant prenatal, perinatal, and neonatal predictors of 12-month gross motor development in high-risk infants and to develop a regression-based predictive model.
Methodology: A cross-sectional analytical study was conducted on 284 high-risk infants attending the NICU follow-up clinic of a tertiary-care hospital. Eighteen clinically relevant maternal, perinatal, and neonatal factors were recorded from medical records. Gross motor development at 12 months was assessed using the ASQ-3 Gross Motor domain. Multivariate linear regression was performed in two steps: an initial model identifying 14 significant variables, followed by a final model yielding 10 independent predictors. The model incorporated the constant and unstandardized coefficients of these predictors to generate a predictive formula for 12-month gross motor scores.
Results: Ten factors significantly predicted 12-month gross motor performance: history of miscarriages, consanguineous marriage, birth asphyxia, meconium aspiration, SGA status, oxygen support days, neonatal seizures, PVL, low Apgar score, and multiple gestation. The final model explained 33.9% of score variance. Model validation against actual ASQ-3 scores demonstrated a sensitivity of 68.80%, specificity of 60.57%, positive predictive value of 52.08%, negative predictive value of 75.71%, and overall accuracy of 63.73%.
Conclusion: The study establishes a clinically applicable predictive model for estimating 12-month gross motor development in high-risk infants. The identified risk factors significantly influence early motor outcomes and highlight the need for targeted physiotherapy, structured follow-up, and parental counselling. Incorporating predictive modelling into routine developmental surveillance may support earlier intervention and improve long-term motor trajectories in vulnerable infant populations.

Keywords: Birth asphyxia, neonatal seizures, meconium aspiration, small-for-gestational-age (SGA), Periventricular leukomalacia (PVL)

Introduction

Gross motor development in the first year of life serves as a key indicator of neurodevelopment and early brain maturation. Motor milestones such as sitting, crawling, standing, and early walking depend on the coordinated development of the motor cortex, cerebellum, and descending motor pathways [1-3]. By 12 months of age, infants are expected to demonstrate postural control and early ambulation, making this a critical time point for detecting developmental delays [4-6]. Deviations from expected milestones may reflect prenatal, perinatal, or neonatal complications affecting neuromotor development [6-9].

High-risk infants—especially those exposed to adverse conditions—show higher rates of delayed gross motor outcomes [10-12]. Several biological and clinical factors significantly influence motor development, including birth asphyxia [13-15], neonatal seizures [16-18], meconium aspiration syndrome [19-21], small-for-gestational-age (SGA) status [22-24], prolonged oxygen support [25], prematurity [6, 8] and multiple gestation [26]. Structural brain injuries such as periventricular leukomalacia (PVL) represent strong predictors of later gross motor disability due to white-matter vulnerability [27-29]. Low Apgar scores also serve as an important neonatal indicator linked to poorer neurodevelopmental outcomes [30-32].

Given the high plasticity of the developing brain, early identification of at-risk infants enables timely physiotherapy interventions that improve long-term developmental outcomes [33-35]. Predictive modelling is increasingly used to quantify the influence of multiple risk factors and estimate future motor trajectories [36-38]. The Ages and Stages Questionnaire (ASQ) is a widely accepted and validated tool across multiple cultures and settings for detecting developmental delays in infants [39-42].

Although many studies have examined risk factors affecting motor development, few have developed a comprehensive predictive model specifically for 12-month gross motor outcomes. This study identifies significant predictors—including history of miscarriage, consanguineous marriage, birth asphyxia, meconium aspiration, SGA, oxygen support days, neonatal seizures, PVL, low Apgar score, and multiple gestation—and uses them to create a regression-based prediction model for estimating 12-month gross motor performance.

Such predictive tools support early diagnosis, improve clinical decision-making, and help ensure timely developmental interventions for high-risk infants.

Objective of the Study
To identify significant prenatal, perinatal, and neonatal risk factors associated with 12-month gross motor development in high-risk infants.

Methodology
Study Design
A quantitative, observational, cross-sectional analytical study was conducted to identify significant predictors of 12-month gross motor development among high-risk infants and to construct a regression-based predictive model.

Study Setting and Participants
The study was conducted in the Neonatal Intensive Care Unit (NICU) and follow-up developmental clinic of a tertiary care hospital. High-risk infants were enrolled and followed until 12 months of corrected age when developmental assessment was performed.

Inclusion Criteria
- Infants classified as high risk due to perinatal or neonatal complications
- Availability of complete maternal, perinatal, and neonatal records
- Infants assessed at 12 months corrected age using the ASQ-3 Gross Motor domain

Exclusion Criteria
- Infants with diagnosed genetic or chromosomal abnormalities
- Major congenital malformations
- Incomplete medical or developmental assessment records

Data Collection
A structured data extraction sheet was used to collect the following categories of variables:

1. Maternal Factors
- History of miscarriage
- Consanguineous marriage

2. Perinatal Factors
- Birth asphyxia
- Meconium aspiration
- Multiple gestation
- Low Apgar score

3. Neonatal Factors
- Small for gestational age (SGA)
- Oxygen support days
- Neonatal seizure
- Periventricular leukomalacia (PVL)

A total of 18 clinically relevant variables were initially recorded based on literature and clinical judgment.

Outcome Measure
The dependent variable was the 12-month Gross Motor Score obtained from the Ages and Stages Questionnaire (ASQ-3).
The ASQ-3 is a validated, parent-completed developmental screening tool widely used in infant development studies.

Step 1: Initial Regression Screening
All 18 independent variables were entered into a multivariate linear regression model.
From this analysis, 14 variables demonstrated statistical significance ($p < 0.05$) and were retained for further regression.

Step 2: Final Regression Model
The 14 significant variables were again analyzed using multivariate linear regression to determine the strongest predictors of 12-month gross motor development. From the initial set of 18 identified factors, a linear regression analysis was conducted, resulting in 14 significant factors. Following this, a regression analysis was carried out again utilizing these 14 significant factors, resulting in 10 significant variables.
Finally, a fit model for 6-month Gross motor was developed using these 10 independent variables.

Table 1: Co-efficient table by linear regression for 12-month Gross motor

Dependent Variable	Independent Variable	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Variance
		B	Std. Error				
12-month Gross Motor	(Constant)	44.542	1.227		36.304	.000	33.9%
	history of miscarriages	-7.543	3.466	-.105	-2.116	.035	
	Consanguineous marriage	-21.784	5.776	-.185	-3.711	.000	
	birth asphyxia	-6.325	2.274	-.146	-2.884	.004	
	meconium aspiration	-9.037	4.192	-.101	-2.070	.039	
	small for gestational age	-9.291	3.816	-.120	-2.458	.015	
	o2support days	-0.426	.095	-.212	-4.316	.000	
	Neonatal seizure	-17.996	2.543	-.348	-6.973	.000	
	PVL	-37.176	14.974	-.121	-2.454	.015	
	Low apgar score	-13.258	5.667	-.120	-2.458	.015	
	Multiple gestation	-6.207	3.171	-.101	-1.945	.053	

From the above table, it is clear that the 10 statistically significant predictors, which formed the basis of the final model:
1. History of miscarriages
2. Consanguineous marriage
3. Birth asphyxia
4. Meconium aspiration
5. Small for gestational age
6. Oxygen support days
7. Neonatal seizure
8. Periventricular leukomalacia (PVL)
9. Low Apgar score
10. Multiple gestation

All predictors with $p < 0.05$ were retained in the model.

These 10 factors had a p-value of less than 0.05 indicative of significant at a 95% confidence interval. One predictive fit model formula is designed from all above 10 factors which is as follow by using constant and β values mentioned in the column of Unstandardized Coefficients of above mentioned 10 significant factors:

12-month Gross Motor Formula
Constant = 44.542
Write 1 for yes answer and write 0 for No answer and number of days according to question Put the value in the formula given below

12-month Gross motor Predicted Infant development score (Ages and Stages questionnaire Score) = 44.542+ [(-7.543) (history of miscarriages)] + [(-21.784) (Consanguineous marriage)] + [(-6.325) (birth asphyxia)] + [(-9.037) (meconium aspiration)] +(-9.291) (small for gestational age) + [(-0.426) (o2support days)] + [(-17.996) Neonatal seizure [(-37.176) (PVL)]+ [(-13.258) (Low apgar score)]+ [(-6.207) (Multiple gestation)]
Re data collection with 284 infants has been collected and data analysis was done

Table 2: Cross-tabulation for Actual Score and Model Score of 12-month Gross Motor Ages and stages Questionnaire by an investigator

		Actual score		Total
		High Risk	No Risk	
Predictive score	High Risk	a=75 True Positive	b=69 False Positive	144
	No Risk	c=34 False Negative	D=106 True Negative	140
Total		109	175	284

1. Sensitivity: 68.80%
Sensitivity = True High Risk/ (True High Risk+ False No Risk) = 75 / (75+34) = 68.80%

2. Specificity: 60.57%
Specificity = True No Risk/ (True No Risk + False High Risk) = 106/ (69+106) = 60.57%

3. Positive Predictive Value: 52.08%
Positive Predictive Value = True High Risk/ (True High Risk+ False High Risk) = 75/ (75+69) = 52.08%

4. Negative Predictive Value: 75.71%
Negative Predictive Value = True No risk/ (True No Risk + False No Risk) = 106 / (34+106) =75.71%

5. Overall accuracy = 63.73%
Overall accuracy = (True High Risk+ True No Risk) / (True High Risk+ False High Risk+ True No Risk+ False No Risk) = (75+ 106) / (75+69+34+106) = 181/ 284 = 63.73%

Discussion

The present study developed a predictive model for estimating 12-month gross motor development based on a range of prenatal, perinatal, and neonatal factors. The findings indicate that infants exposed to these early biological risks show significantly reduced gross motor scores at 12 months, supporting previous evidence that neurodevelopment is highly sensitive to early-life complications [43].

Among all predictors, neonatal seizures and periventricular leukomalacia (PVL) demonstrated the strongest negative influence on motor outcomes. Neonatal seizures serve as early markers of acute neurological dysfunction and are strongly associated with long-term impairments in muscle tone, postural control, and motor coordination due to disruption of immature neuronal circuits [44, 45]. PVL, a major white-matter injury, affects descending motor pathways and is one of the leading causes of delayed motor milestone acquisition and motor disability [46-48].

Birth asphyxia also significantly predicted lower gross motor outcomes. Hypoxic-ischemic injury compromises basal ganglia and cortical motor areas essential for early motor development [49, 50]. Consistent with this, infants presenting with low Apgar scores showed reduced motor performance, reflecting the association between early physiological instability and later neurodevelopmental delay [51, 52].

Infants affected by meconium aspiration syndrome (MAS) also demonstrated delayed gross motor scores. MAS often results in hypoxemia, pulmonary inflammation, and prolonged hospitalization, which impede early neural and motor maturation [53, 54]. Similarly, infants who were small for gestational age (SGA) showed poorer motor outcomes, consistent with studies reporting that intrauterine growth restriction affects brain maturation, white matter development, and neuromotor integration [55-57].

Prolonged oxygen support days also significantly predicted poor motor outcomes. Longer respiratory support often reflects underlying pulmonary or systemic illness severity, both of which have detrimental effects on overall early neurodevelopment and motor control [58, 59].

Maternal factors also played an important role. A history of miscarriages may indicate underlying maternal genetic, endocrine, or immunological issues that affect fetal neurological development [60, 61]. Furthermore, consanguineous marriage was found to negatively affect 12-month gross motor performance, consistent with evidence linking consanguinity to autosomal recessive disorders, congenital anomalies, and developmental disabilities [62, 63].

Lastly, multiple gestation significantly contributed to lower motor performance. Twin or higher-order pregnancies carry increased risks of prematurity, low birth weight, and perinatal complications, all of which predispose infants to neurological vulnerability and motor delay [64, 65].

Overall, the present study highlights the multifactorial determinants of early gross motor development. Using predictive models to identify high-risk infants allows clinicians to initiate physiotherapy, neurodevelopmental stimulation, and parent-focused interventions earlier, ultimately improving motor outcomes and reducing long-term disability [66, 67].

Conclusion

The present study successfully identified ten significant prenatal, perinatal, and neonatal predictors of 12-month gross motor development in high-risk infants. Variables such as neonatal seizures, periventricular leukomalacia, meconium aspiration, birth asphyxia, prolonged oxygen support, consanguineous marriage, small for gestational age,

history of miscarriages, low Apgar score, and multiple gestation were found to have a significant negative impact on gross motor outcomes.

Using these factors, a linear regression–based predictive model was developed, offering an objective method to estimate the 12-month Gross Motor ASQ score. This model provides a clinically valuable tool for early identification of infants at risk of motor delay, enabling timely physiotherapy referral, targeted neurodevelopmental interventions, and enhanced parental counselling.

Overall, the study highlights the importance of early risk factor recognition and demonstrates that predictive modelling can play a crucial role in guiding early developmental surveillance. Implementing such models in clinical settings may improve long-term motor outcomes and reduce the burden of developmental disabilities in vulnerable infant populations

Limitation and future scope

The study has certain limitations, including its single-centre design, retrospective data dependence, lack of environmental or socio-developmental factors, and limited neuroimaging information, with predictions restricted only to 12-month gross motor outcomes. Despite these limitations, the model provides valuable clinical utility by enabling early identification of high-risk infants, supporting timely physiotherapy referral, guiding NICU discharge planning, and improving developmental surveillance. Future research should validate the model in larger multi-centre cohorts, incorporate environmental and parental variables, expand predictions to other developmental domains, integrate the model into digital tools, and conduct long-term follow-up to strengthen predictive reliability.

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