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Original Article

Analysis of influencing factors for language development delay with comorbid intellectual disability in children and investigation of the effects of early neurobehavioral intervention

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Abstract: Objective: To identify factors associated with comorbid intellectual disability in children aged 2-6 years with language development delay and to evaluate the short-term effects of multidimensional early neurobehavioral intervention. Methods: We retrospectively analyzed 230 children with language development delay treated from March 2021 to April 2024. Based on intelligence testing, 41 had comorbid intellectual disability and 189 did not. Data collected included demographics, birth history, pregnancy complications, family history, feeding mode, hearing status, and parental education. Assessments comprised the Sign-Significant (S-S) language test, Gesell Developmental Scale, Wechsler Preschool and Primary Scale of Intelligence-Fourth Edition (WPPSI-IV), and Vineland Adaptive Behavior Scales (VABS), conducted before and after 3 months of intervention. Results: Lower S-S scores, prematurity, family history of intellectual disability, and high-risk birth were independent predictors, while high-risk pregnancy was not. The S-S score yielded the best discrimination (area under curve 0.796). After intervention, language, cognition, and adaptive behavior improved significantly in both groups (all $P < 0.001$), with effect sizes in the large range. Improvements were consistent across subgroups without significant differences ($P > 0.05$). Conclusion: Multidimensional early neurobehavioral intervention was associated with significant improvements in language, cognition, and adaptive behavior, supporting its potential use for early rehabilitation.

Keywords: Language development delay, intellectual disability, influencing factors, neurobehavioral intervention, Gesell Developmental Scale, pediatric rehabilitation

Introduction

Language development delay in children has become an increasing concern in the field of developmental disorders, with its incidence rising year by year [1]. According to the World Health Organization, approximately 8.4% of children under five years old worldwide experience developmental disorders of varying severity, corresponding to nearly 52.9 million affected children [2]. As one of the most common developmental disorders, language development delay not only impairs communication skills but is often accompanied by deficits in other cognitive domains, particularly intellectual disability [3, 4]. Epidemiological studies suggest that around 9.9% of children present with language development delay [5]. When language delay co-occurs with intellectual disability, the combined impact can markedly compromise language expression and comprehension, further impeding cognitive development, social interaction, and learning, thereby creating significant challenges throughout the child's developmental trajectory [6].

The developing nervous system in children undergoes critical periods characterized by heightened neuroplasticity, providing a strong theoretical basis for early intervention [7]. Evidence indicates that well-designed and timely interventions during these critical windows

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can significantly improve language development and cognitive functioning, reducing the risk of long-term developmental disorders [8]. Therefore, investigating the factors contributing to language development delay with comorbid intellectual disability, and identifying effective early neurobehavioral interventions, holds substantial clinical and practical value.

Research on early neurobehavioral interventions commonly focuses on approaches such as language training, cognitive training, and sensory integration therapy. These methods can partially improve language function and cognitive ability; however, current studies still present notable limitations [9]. In terms of influencing factors, few studies have examined the interplay among multiple determinants, and the underlying mechanisms of comorbidity between language delay and intellectual disability remain poorly understood. Regarding intervention strategies, most studies lack long-term follow-up to confirm the sustainability of treatment effects, and there is limited exploration of individualized approaches tailored to children with diverse needs, making precise intervention difficult.

In light of these challenges, the present study was designed with two major objectives: first, to conduct a comprehensive analysis of the factors associated with language development delay and comorbid intellectual disability in children, thereby providing evidence to support early screening and prevention for timely identification and management; second, to rigorously evaluate the effectiveness of early neurobehavioral interventions in improving language development and cognitive function, with the aim of optimizing intervention protocols to enhance both efficacy and specificity.

Methods

Study population and time frame

This retrospective study included children who visited Norinco General Hospital and Baoji Maternal and Child Health Care Hospital from March 2021 to April 2024. First, all cases related to language development delay were retrieved from the hospital's electronic medical record system (HIS). Within this cohort, those with a concomitant diagnosis of intellectual disability were further identified. Through continuous review over the specified period, a total of 230 cases meeting the study's inclusion criteria were ultimately selected.

Inclusion criteria

(1) Age between 2 and 6 years. (2) Chief complaint or outpatient/inpatient diagnosis of language development delay, meeting diagnostic criteria for language delay: language comprehension or expression markedly below the average level for peers of the same age and cultural background, with exclusion of other causes such as hearing impairment, autism spectrum disorder, or structural anomalies. All pediatric patients underwent a series of examinations, including: otoacoustic emission (OAE) screening, auditory brainstem response (ABR) testing (with a threshold ≤ 30 dB nHL considered normal), and acoustic immittance testing (Type A tympanogram regarded as normal), to rule out middle ear dysfunction or sensorineural hearing impairment. The Autism Behavior Checklist (ABC) (score < 53) and the Childhood Autism Rating Scale (CARS) (score < 30) were used to exclude autism spectrum disorder. Oral examinations, head CT, or MRI were conducted to rule out structural abnormalities in the orofacial region or central nervous system. (3) Availability of intellectual assessment results: diagnosed with intellectual disability (mild, moderate, or severe) according to the "Chinese Classification and Diagnostic Criteria of Mental Disorders, 3rd Edition" (CCMD-3) [10]. Specifically, mild intellectual disability: IQ 55-75; moderate: IQ 40-54; severe: IQ ≤ 39. (4) Complete medical record information.

Ethical approval and informed consent

As this is a retrospective chart review, the Baoji Maternal and Child Health Care Hospital's Ethics Committee approved the study and granted a waiver of signed informed consent, provided that all case data are anonymized. All extracted data were de-identified, with all personally identifiable information (PII) removed from the analytical dataset and replaced with unique study codes.

Exclusion criteria

(1) Known etiologies that clearly affect speech development or cognitive function, such as congenital hearing loss, congenital heart dis-

ease, chromosomal abnormalities, cerebral palsy, etc. All pediatric patients underwent echocardiography to rule out structural heart diseases such as atrial septal defect and ventricular septal defect; peripheral blood karyotyping (with resolution ≥ 400 bands) or chromosomal microarray analysis (CMA) to exclude chromosomal abnormalities including Trisomy 21 and Trisomy 18; and motor function assessment (using the Gross Motor Function Classification System, GMFCS) combined with cranial MRI (to exclude brain injury or maldevelopment) for the exclusion of cerebral palsy. (2) Prior early intervention exceeding 3 months that led to substantial improvement before admission. (3) Coexisting severe psychiatric disorders or autism spectrum disorder that would interfere with assessment of communication. (4) Lack of complete intellectual assessment or language evaluation data in parent report or medical records, making it impossible to confirm a diagnosis of language development delay or intellectual disability. (5) Exclusion criteria: A follow-up period of less than 3 months.

Sample size justification

By reviewing the literature, the incidence of concurrent intellectual disability in children with language development delay is approximately 10% [11], with P = 0.10. Using formula $N = Z^2 \times \frac{P(1-P)}{E^2}$, where Z = 1.96 and the allowable absolute error E = 0.05, the calculation yields N ≈ 139. In this study, a total of 230 children meeting the inclusion criteria were screened during the final review period, which is significantly higher than the minimum sample size requirement, enabling a further improvement in the accuracy of the estimation.

Early neurobehavioral intervention protocol

A multidimensional program was implemented for all participants, comprising the following components. The intervention protocol was standardized and applied to all children. Each child received two 60-minute sessions per week over a 12-week period (totaling 24 sessions). Each session included all seven components of the intervention, with time allocated approximately as follows: oral motor exercises (10 minutes), multi-sensory integration (10 minutes), imitation (10 minutes), expressive communication (10 minutes), emotional regulation (5 minutes), visual symbol recognition (10 minutes), and language-assisted motor activities (5 minutes). All interventions were delivered by licensed speech-language pathologists or occupational therapists with at least two years of pediatric experience. All staff received uniform training on the specific intervention protocol. An intervention log system was established to document the details of each session, including content delivered, child's cooperation, and any unusual observations. Weekly team meetings were held to review the intervention logs and address any implementation issues. (1) Oral sensory-motor stimulation training: Through intraoral massage and perioral muscle stimulation, enhance oral sensory input and motor coordination, thereby promoting the development of muscle functions essential for articulation. (2) Multisensory integration stimulation: Employ multimodal sensory inputs including visual, auditory, olfactory, and tactile stimuli (e.g., educational videos, rubber toys, and scent stimulation) to activate cortical functions, improve perception and attention, and mitigate stress responses to environmental stimuli. (3) Oral and lingual movement imitation training: Under therapist guidance, children perform basic oral motor imitations, such as opening the mouth, protruding the tongue, and licking the lips, to establish oral motor pathways and strengthen foundational movement patterns required for speech production. (4) Active expression induction training: Using brightly colored toys, sound-producing objects, and scented foods, guide children to actively explore and express needs, thereby enhancing language motivation and fostering interest in communication. (5) Emotional regulation and tactile soothing: Through daily full-body tactile massage combined with verbal reassurance, strengthen skin-central nervous system feedback, improve emotional stability, and enhance the child's sense of security and treatment compliance. (6) Image recognition and language repetition training: Utilize cognitive teaching materials containing both images and text for object naming and verbal repetition, reinforcing the association between objects, words, and meanings, and improving both language comprehension and expressive abilities. (7) Fine and gross motor training with language assistance: Conduct motor training activities such as grasping, walking, picking up objects, and stair climbing in conjunction with language instructions, thereby improving motor coordination while simultaneously enhancing language comprehension, execution, and integrated development of speech and movement.

Data extraction and management

Medical records of the 230 included children were downloaded or printed from the HIS system. Data collected encompassed: Basic demographics: sex, age, height, weight. Birth history: prematurity, high-risk birth history. For this study, 'high-risk birth history' was defined as the occurrence of one or more of the following during the perinatal period: birth asphyxia (Apgar score < 7 at 5 minutes), neonatal jaundice requiring phototherapy or exchange transfusion, neonatal hypoxic-ischemic encephalopathy, or neonatal seizures. 'High-risk pregnancy history' was defined as the presence of one or more of the following maternal conditions during pregnancy: gestational hypertension/preeclampsia, gestational diabetes mellitus, placental abnormalities (e.g., placenta previa, placental abruption), or oligohydramnios/polyhydramnios. Preterm birth was defined as a gestational age of less than 37 weeks at delivery. Pregnancy information: high-risk pregnancy history. Family history: family history of language development delay, family history of intellectual disability. Feeding mode, hearing status, residence, and parental education levels. All children underwent standardized scale assessments both before the intervention and 3 months thereafter: S-S Language Development Assessment: A comprehensive evaluation of children's language development level; total scores were recorded and treated as a continuous variable in analysis [12]. The S-S Language Development Assessment: This standardized tool evaluates language comprehension and expression across different developmental stages. It classifies children into specific language phases (e.g., pre-linguistic stage, single-word stage, phrase stage, sentence stage) and provides a quantitative score reflecting their overall language age equivalent. All examiners were trained and certified in the administration of the S-S method. To ensure scoring consistency, regular inter-rater reliability checks were conducted. Based on independent evaluations of 20 randomly selected cases, the intraclass correlation coefficient (ICC) for total S-S scores among our raters was high (ICC = 0.89, 95% CI: 0.86-0.92). Vineland Adaptive Behavior Scales (VABS): Assessment of adaptive behavior in domains such as communication, daily living skills, socialization, and motor skills [13]. Gesell Developmental Scale: Evaluation of developmental quotients in five domains: adaptive behavior, language, fine motor skills, gross motor skills, and social behavior [14]. The Gesell Developmental Schedule: This scale assesses the developmental quotient (DQ) across five domains: adaptive, gross motor, fine motor, language, and personal-social. In our practice, trained assessors regularly calibrated their scoring to ensure consistency. A previous evaluation of inter-rater reliability for Gesell DQ scores within our department showed good agreement across all domains (ICC > 0.85 for all areas). Wechsler Preschool and Primary Scale of Intelligence-Fourth Edition (WPPSI-IV): Measurement of intellectual level to determine presence and severity of intellectual disability [15]. The Wechsler Preschool and Primary Scale of Intelligence-Fourth Edition (WPPSI-IV) was used to assess intellectual ability. It is a standardized instrument designed for children aged 2 years 6 months to 7 years 7 months. Administration and scoring procedures are clearly defined for different age groups within this range, ensuring age-appropriate assessment and accurate IQ scoring for all children in our research cohort.

Statistical analysis

Statistical analyses were conducted using SPSS version 26.0. The normality of continuous variables was confirmed using the Shapiro-Wilk test, and all were found to be normally distributed. Continuous variables with a normal distribution are presented as mean ± standard deviation (SD); between-group comparisons used independent-samples t-tests. Categorical variables are expressed as counts and percentages; comparisons employed χ^2 tests. Univariate analyses identified clinical variables significantly associated with intellectual disability ($P < 0.05$), which were then entered into a multivariate logistic regression model to determine independent risk factors; results are reported as odds ratios (ORs) with 95% confidence intervals (CIs) and corresponding P values. Collinearity diagnosis was performed for the logistic regression model by calculating the variance inflation factor (VIF) for all included variables. Receiver operating characteristic (ROC) curve analysis assessed the predictive performance

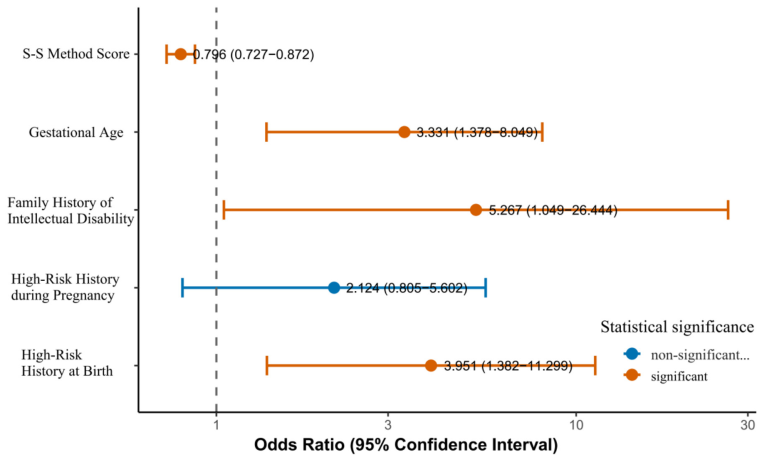

Figure 1. Multivariate logistic regression results for factors independently associated with comorbid intellectual disability in children with language development delay. S-S: Sign-Significant.

of key variables, with area under the curve (AUC) calculated. Subgroup analyses were performed with Bonferroni correction to adjust the *p*-value threshold. P < 0.05 was considered statistically significant.

Results

Comparison of general characteristics between the groups

Among the 230 children assessed for language development delay, 41 (17.8%) were found to have comorbid intellectual disability based on intellectual assessment, and 189 (82.2%) did not. A detailed comparison between the comorbid intellectual disability group and the non-intellectual disability group was described in **Figure 1** and **Table 1**.

Multivariate analysis of factors associated with comorbid intellectual disability

By assigning values to the indicators with significant differences in **Table 2** (assignment table) and performing multivariate logistic regression analysis on S-S method scores, term of pregnancy, family history of intellectual disability, history of high-risk pregnancy, and history of high-risk birth, it was found that S-S method scores, preterm birth, family history of intellectual disability, and history of high-risk birth were independent influencing factors for comorbid intellectual disability. Specifically, lower S-S method scores were strongly associated with an increased risk of concomitant intellectual disability (P = 0.001, OR = 0.796, 95% CI: 0.727-0.872). Preterm birth significantly elevated the risk compared with full-term birth (P = 0.008, OR = 3.331, 95% CI: 1.378-8.049). Similarly, a family history of intellectual disability (P = 0.044, OR = 5.267, 95% CI: 1.049-26.444) and a history of high-risk birth (P = 0.010, OR = 3.951, 95% CI: 1.382-11.299) were both significantly associated with higher comorbidity risk. In contrast, a history of high-risk pregnancy did not retain statistical significance after adjustment (P > 0.05, OR = 3.951, 95% CI: 1.382-11.299).

Collinearity diagnosis indicated no significant multicollinearity among the predictor variables (all VIF < 2.5). See **Table 3**.

Diagnostic value of independent factors

ROC curve analysis was conducted for the four independent influencing factors S-S method scores, term of pregnancy, family history of intellectual disability, and history of high-risk birth to assess their predictive value for comorbid intellectual disability in children with language development delay. The results showed that the AUC for S-S method scores was the largest, demonstrating the strongest discriminative ability. The optimal cut-off value for the S-S score (≤ 49.50) was determined using the Youden's index to maximize sensitivity and specificity. The predictive value of term of pregnancy was moderate, whereas the predictive abilities of family history of intellectual disability and history of high-risk birth were relatively limited. See **Figure 2** and **Table 4**.

Changes in language ability before and after early neurobehavioral intervention

Early neurobehavioral intervention significantly improved the overall abilities of children with language developmental delay (all P < 0.001). Across all participants, scores on the S-S method assessment scale and the five functional domains of the Gesell Developmental Quotient

Table 1. Baseline characteristics of the study participants

		Intellectual Disability (n = 41)	Non-Intellectual Disability (n = 189)	t/χ^2	P
Gender (%)	Male	25 (60.98)	110 (58.20)	0.107	0.744
	Female	16 (39.02)	79 (41.80)		
Age (years)		4.05±0.95	3.84±1.04	1.189	0.236
Height (cm)		97.44±7.58	99.75±9.54	1.453	0.148
Weight (kg)		16.24±2.88	16.46±2.61	0.480	0.632
S-S Method Score		45.49±4.81	51.07±4.94	6.586	< 0.001
Gestational Age (%)	Preterm birth	15 (36.59)	30 (15.87)	9.184	0.002
	Full-term	26 (63.41)	159 (84.13)		
Feeding Method (%)	Artificial feeding	20 (48.78)	65 (34.39)	2.994	0.084
	Breastfeeding	21 (51.22)	124 (65.61)		
Family History of Language Delay (%)	Yes	8 (19.51)	21 (11.11)	2.158	0.142
	No	33 (80.49)	168 (88.89)		
Family History of Intellectual Disability (%)	Yes	5 (12.20)	4 (2.12)	9.102	0.003
	No	36 (87.80)	185 (97.88)		
Pregnancy High-Risk History (%)	Yes	12 (29.27)	20 (10.58)	9.822	0.002
	No	29 (70.73)	169 (89.42)		
Birth High-Risk History (%)	Yes	10 (24.39)	18 (9.52)	6.964	0.008
	No	31 (75.61)	171 (90.48)		
Father's Education Level (%)	Middle school or below	20 (48.78)	60 (31.75)	4.876	0.087
	High school	15 (36.59)	80 (42.33)		
	College or above	6 (14.63)	49 (25.92)		
Mother's Education Level (%)	Middle school or below	22 (53.66)	70 (37.04)	3.982	0.137
	High school	12 (29.27)	70 (37.04)		
	College or above	7 (17.07)	49 (25.93)		
Hearing Impairment (%)	Yes	8 (19.51)	20 (10.58)	2.513	0.113
	No	33 (80.49)	169 (89.42)		
Residence (%)	Urban	30 (73.17)	130 (68.78)	0.306	0.580
	Rural	11 (26.83)	59 (31.22)		
Severity of Intellectual Disability (%)	Mild	14 (34.15)			
	Moderate	19 (46.34)			
	Severe	8 (19.51)			

S-S: Sign-Significant.

(gross motor, language, adaptive ability, fine motor, and personal-social skills) showed marked and relatively balanced improvements following intervention (all P < 0.001). Moreover, both children with and without comorbid intellectual disability demonstrated significant progress across all indicators (all P < 0.001). See **Figure 3**.

Changes in intellectual level before and after early neurobehavioral intervention

Early neurobehavioral intervention can significantly improve the intellectual level of children with language developmental delay, and the improvement effect is significant in both children with and without comorbid intellectual disability. See **Figure 4**.

Changes in adaptive behavioral ability before and after early neurobehavioral intervention

Early neurobehavioral intervention significantly enhanced the adaptive behavioral abilities of children with language developmental delay (all P < 0.001). Among all participants, scores across the core domains of the Vineland Adaptive Behavior Scales (VABS) including general functioning, communication, social skills, and daily living skills showed notable improve-

Table 2. Coding scheme for logistic regression analysis

Factor	Assignment
S-S Method Score	Continuous variable (raw value)
Gestational Age	Preterm birth = 1, Full-term = 0
Family History of Intellectual Disability	Yes = 1, No = 0
High-Risk History during Pregnancy	Yes = 1, No = 0
High-Risk History at Birth	Yes = 1, No = 0
Comorbid Intellectual Disability	Yes = 1, No = 0

S-S: Sign-Significant.

Table 3. Variance inflation factor (VIF) for included variables

Factor	VIF
S-S Method Score	1.067
Gestational Age	1.008
Family History of Intellectual Disability	1.019
High-Risk History during Pregnancy	1.071
High-Risk History at Birth	1.006

VIF: Variance Inflation Factor, S-S: Sign-Significant.

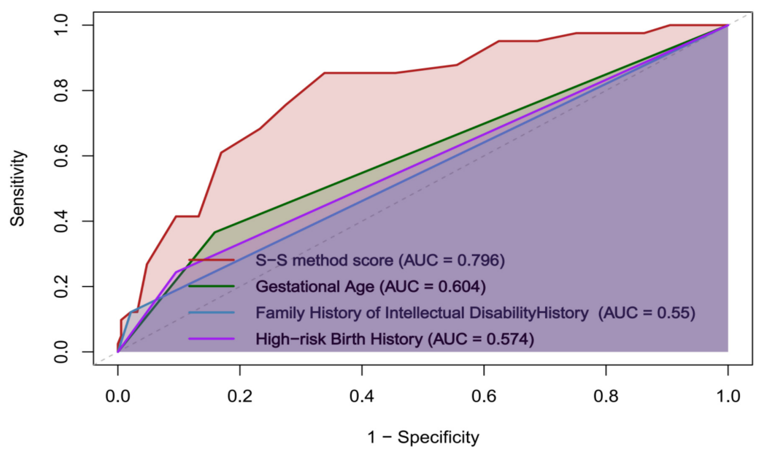

Figure 2. ROC curves for independent factors predicting comorbid intellectual disability in children with language development delay. S-S: Sign-Significant.

ment. Furthermore, both children with comorbid intellectual disability and those without demonstrated significant gains in adaptive behavioral abilities (all P < 0.001). See **Figure 5**.

Improvement of language ability in populations with risk factors through early neurobehavioral intervention

This study compared changes in language ability before and after early neurobehavioral intervention among children with language developmental delay and comorbid intellectual disability, stratified by different risk factors. The results indicated that there were no statistically significant differences in pre- and post-intervention scores, nor in the degree of improvement, between children born preterm versus full-term, or between those with versus without a history of high-risk birth (P > 0.05). However, children with a family history of intellectual disability had significantly lower S-S test scores than those without such a family history before intervention (P < 0.05). Following intervention, no significant differences were observed in S-S test scores between the two groups, and the differences in improvement also did not reach statistical significance (P > 0.05). See **Figure 6** and **Table 5**.

Improvement of intellectual level in populations with risk factors through early neurobehavioral intervention

This study compared changes in intellectual levels before and after early neurobehavioral intervention among children with language developmental delay and comorbid intellectual disability, stratified by different risk factors. The results showed that there were no statistically significant differences in pre- and post-intervention intellectual scores, nor in the degree of improvement, among children born preterm versus full-term, or between those with versus without a history of high-risk birth (P > 0.05). See **Figure 7** and **Table 6**.

Discussion

This retrospective analysis of 230 children aged 2-6 years with language development delay systematically examined independent factors associated with comorbid intellectual disability and evaluated the effects of a multidimensional early neurobehavioral intervention.

Table 4. ROC curve data

	AUC	95% CI	Sensitivity	Specificity	Cut-off
S-S method score	0.796	0.723-0.869	66.14%	85.37%	49.50
Gestational age	0.604	0.502-0.705	84.13%	36.59%	0.50
Family history of intellectual disability	0.550	0.448-0.653	97.88%	12.20%	0.50
High-risk birth history	0.574	0.472-0.677	90.48%	24.39%	0.50

S-S: Sign-Significant.

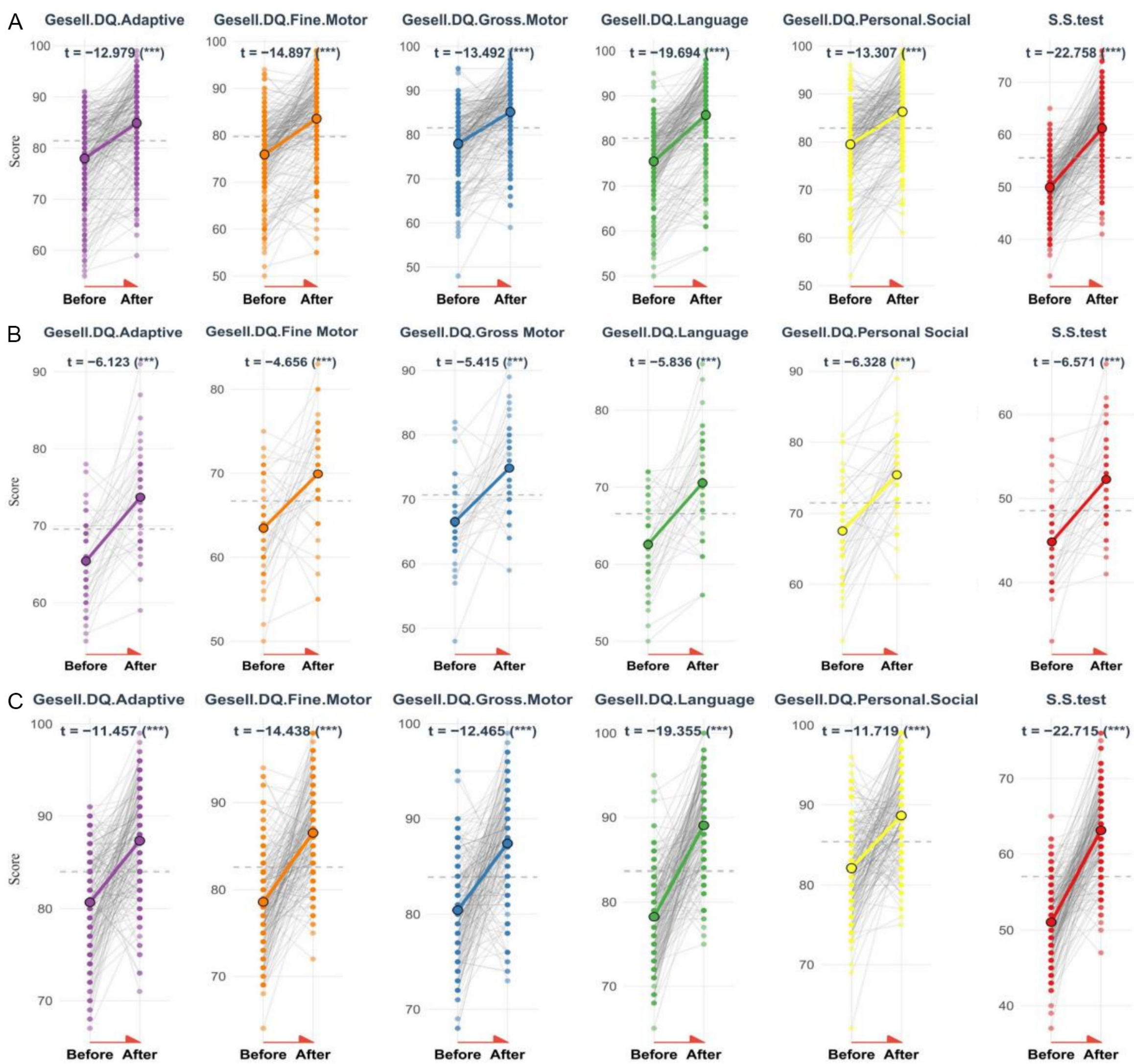

Figure 3. Changes in language ability before and after early neurobehavioral intervention. A. Changes in S-S test, Gesell DQ-Gross Motor, Gesell DQ-Language, Gesell DQ-Adaptive, Gesell DQ-Fine Motor, and Gesell DQ-Personal-Social of children overall before and after intervention. B. Changes in S-S test, Gesell DQ-Gross Motor, Gesell DQ-Language, Gesell DQ-Adaptive, Gesell DQ-Fine Motor, and Gesell DQ-Personal-Social of children with comorbid intellectual disabilities before and after intervention. C. Changes in S-S test, Gesell DQ-Gross Motor, Gesell DQ-Language, Gesell DQ-Adaptive, Gesell DQ-Fine Motor, and Gesell DQ-Personal-Social of children without comorbid intellectual disabilities before and after intervention. S-S: Sign-Significant, DQ: Development Quotient.

Multivariate logistic regression revealed that lower S-S method scores, prematurity, a family history of intellectual disability, and a history of high-risk birth were independent risk factors for comorbid intellectual disability in language-delayed children, whereas high-risk pregnancy

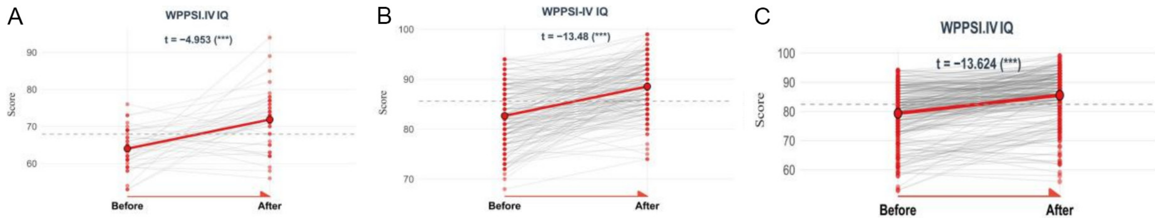

Figure 4. Changes in intellectual level before and after early neurobehavioral intervention. A. Changes in WPPSI-IV IQ of children overall before and after intervention. B. Changes in WPPSI-IV IQ of children with comorbid intellectual disabilities before and after intervention. C. Changes in WPPSI-IV IQ of children without comorbid intellectual disabilities before and after intervention. WPPSI-IV IQ: Wechsler Preschool and Primary Scale of Intelligence - Fourth Edition Intelligence Quotient.

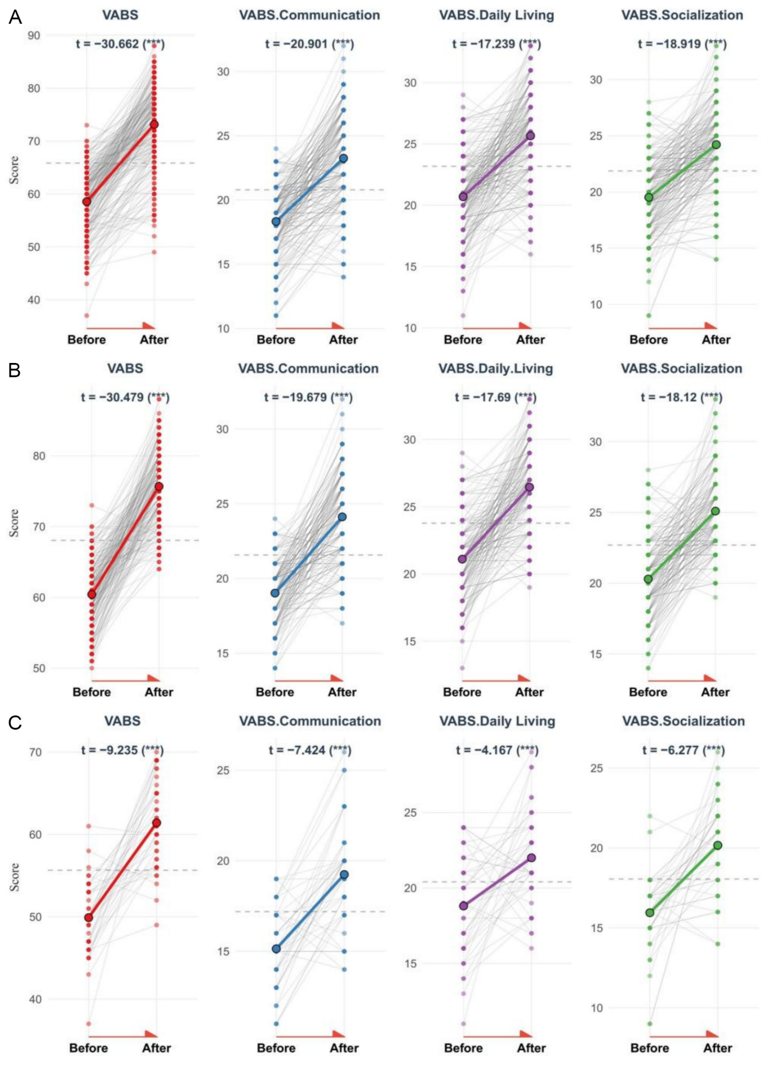

Figure 5. Changes in adaptive behavioral ability before and after early neurobehavioral intervention. A. Changes in total VABS score, VABS-Communication, VABS-Socialization, and VABS-Daily Living of children overall before and after intervention. B. Changes in total VABS score, VABS-Communication, VABS-Socialization, and VABS-Daily Living of children with comorbid intellectual disabilities before and after intervention. C. Changes in total VABS score, VABS-Communication, VABS-Socialization, and VABS-Daily Living of children without comorbid intellectual disabilities before and after intervention. VABS: Vineland Adaptive Behavior Scales.

history did not retain statistical significance after adjustment. The intervention protocol comprising oral sensory-motor stimulation, multisensory integration, oromotor imitation exercises, induced active expression, emotional regulation with tactile soothing, image recognition combined with language repetition, and language-assisted motor training produced significant improvements across all participants (regardless of comorbid intellectual disability) after three months in language ability (S-S scores and Gesell developmental quotients across five domains), cognitive level (WPPSI-IV IQ), and adaptive behavior (VABS core domains). Although baseline differences existed among risk-factor subgroups (preterm vs. full-term birth, high-risk birth vs. non-high-risk birth, family-history high-risk vs. no family history), post-intervention outcomes converged with no significant between-group differences in improvement magnitude, highlighting the clinical value of early screening and intervention in high-risk populations.

The finding that lower S-S method scores are significantly associated with an increased risk of comorbid intellectual disability suggests that

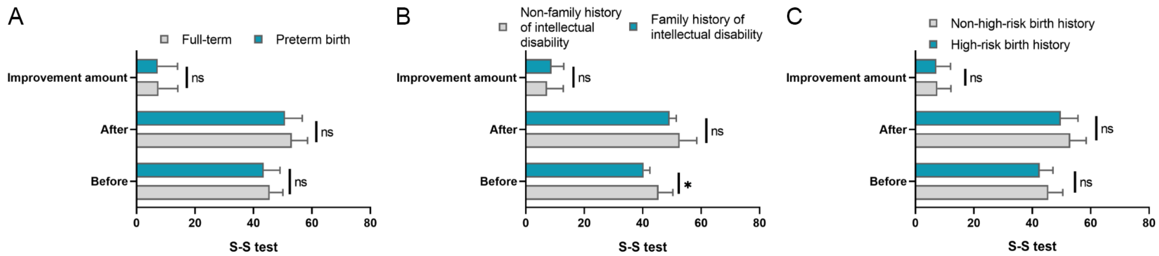

Figure 6. Improvement of language ability in risk factor populations by early neurobehavioral intervention. A. Changes in S-S test and improvement differences before and after intervention in children with preterm birth and vaginal delivery. B. Changes in S-S test and improvement differences before and after intervention in children with and without family history of intellectual disability. C. Changes in S-S test and improvement differences before and after intervention in children with and without history of high-risk birth. S-S: Sign-Significant.

pronounced delays in foundational language skills often coexist with broader neurodevelopmental anomalies [16]. Prior studies indicate that atypical myelination asymmetries in regions such as the left caudate nucleus and prefrontal cortex, as well as asymmetries in pathways like the right extreme capsule, can influence language acquisition [17]. Additionally, disruptions in cognitive network function frequently co-occur with language development disorders, and children with severe language delays who do not receive timely intervention during critical developmental windows may experience further deficits in subsequent cognitive development [18]. Low language scores identified by parents or clinical assessment tools can therefore serve as early warning signals for potential intellectual disability, underscoring the need for comprehensive evaluation and prompt intervention in children with markedly low S-S scores [19].

Prematurity also emerged as a significant factor associated with comorbid intellectual disability, consistent with extensive literature on neurodevelopmental risks in preterm infants. Preterm birth can result in immature brain development and heightened susceptibility to perinatal complications, inflammatory responses, and environmental stressors, increasing the likelihood of white matter injury and abnormal neural circuit connectivity, which may manifest as language and cognitive deficits [20]. Longitudinal studies and meta-analyses corroborate that preterm children often exhibit moderate to severe cognitive and language impairments during childhood [21, 22]. These findings underscore the necessity of rigorous neurodevelopmental monitoring and early intervention strategies for preterm infants, leveraging windows of neuroplasticity to reduce the risk of later intellectual disability.

A family history of intellectual disability independently predicted comorbid intellectual disability in this cohort, suggesting that genetic susceptibility or shared familial environmental factors may adversely affect neurodevelopment. Previous research has similarly documented strong associations between familial intellectual disability and children's verbal IQ [23]. In our study, children with such a family history had lower baseline language scores; however, after early intervention, their language levels caught up to those without family history, indicating that timely multidimensional intervention can yield substantial improvements even in the presence of genetic or familial environmental risks. These findings highlight the importance of early screening, individualized intervention, and family-centered guidance to optimize developmental outcomes for high-risk children.

Birth high-risk history was likewise associated with elevated risk of comorbid intellectual disability, emphasizing the critical role of perinatal management and early monitoring. Perinatal factors such as hypoxic-ischemic injury and infection or inflammation can exert lasting detrimental effects on neurodevelopment, with clear evidence linking these factors to later cognitive, language, and behavioral disorders [24, 25]. Our real-world retrospective data confirm the predictive value of high-risk birth history for intellectual impairment in language-delayed children, suggesting that clinical practice should strengthen neurodevelopmental assessment, follow-up management for high-

Table 5. Cohen's d improvement in S-S scores in each subgroup

Group	Subgroup	Before intervention	After intervention	Improvement amount	P (Before intervention)	P (After intervention)	P (Improvement amount)	Cohen's d (95% CI) for improvement amount
Gestational Age	Premature birth (n = 15)	43.53±5.54	50.80±5.87	7.27±6.77	0.203	0.207	0.901	-0.040 (-0.674-0.594)
	Full-term birth (n = 26)	45.58±4.48	53.12±5.41	7.54±6.57				
Family history of intellectual disability	Yes (n = 36)	45.44±4.91	52.69±5.83	7.25±5.56	0.030	0.197	0.554	-0.243 (-1.443-0.957)
	No (n = 5)	40.40±2.07	49.20±2.28	8.80±4.21				
Birth High-Risk History	Yes (n = 10)	42.60±4.50	49.80±5.87	7.52±4.63	0.100	0.112	0.854	0.063 (-0.568-0.694)
	No (n = 31)	45.55±4.91	53.06±5.40	7.20±4.80				

S-S: Sign-Significant.

Table 6. WPPSI-IV IQ improvement in each subgroup Cohen's d

Group	Subgroup	Before intervention	After intervention	Improvement amount	P (Before intervention)	P (After intervention)	P (Improvement amount)	Cohen's d (95% CI) for improvement amount
Gestational Age	Premature birth (n = 15)	63.13±4.76	71.33±5.79	8.20±6.64	0.433	0.757	0.782	0.088 (-0.546-0.722)
	Full-term birth (n = 26)	64.50±5.62	72.15±9.14	7.65±5.76				
Family history of intellectual disability	Yes (n = 36)	64.53±5.05	72.28±7.87	7.25±5.56	0.087	0.369	0.628	-0.211 (-1.411-0.989)
	No (n = 5)	60.20±6.14	68.80±9.28	8.60±7.54				
Birth High-Risk History	Yes (n = 10)	62.80±4.39	70.00±6.60	7.20±5.69	0.416	0.407	0.709	-0.141 (-0.722-0.490)
	No (n = 31)	64.39±5.57	72.45±8.42	8.06±6.46				

WPPSI-IV IQ: Wechsler Preschool and Primary Scale of Intelligence - Fourth Edition Intelligence Quotient.

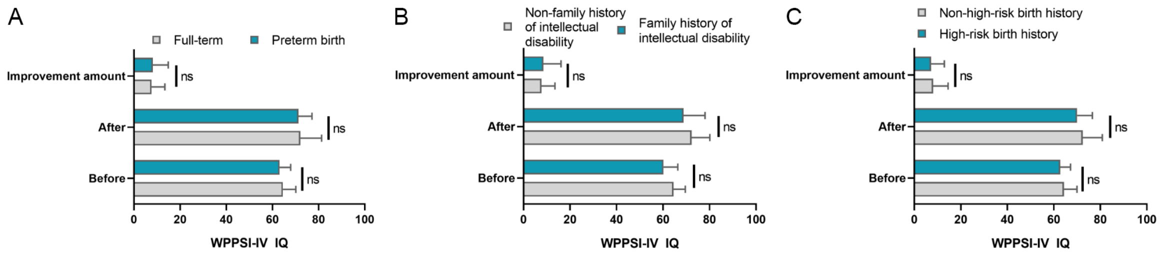

Figure 7. Improvement of intellectual level in risk factor populations by early neurobehavioral intervention. A. Changes in WPPSI-IV IQ and improvement differences before and after intervention in children with preterm birth and vaginal delivery. B. Changes in WPPSI-IV IQ and improvement differences before and after intervention in children with and without family history of intellectual disability. C. Changes in WPPSI-IV IQ and improvement differences before and after intervention in children with and without history of high-risk birth. WPPSI-IV IQ: Wechsler Preschool and Primary Scale of Intelligence - Fourth Edition Intelligence Quotient.

risk neonates, and early initiation of intervention when language delays are detected.

Although high-risk pregnancy history showed an association with comorbid intellectual disability in univariate analysis, it did not reach significance in multivariate regression. This may relate to heterogeneity of pregnancy risk factors in the sample, variability in record completeness, or collinearity with prematurity and birth high-risk factors. The literature remains inconclusive regarding independent effects of high-risk pregnancy on later neurodevelopmental outcomes [26, 27]. Future research should aim to more precisely categorize types of pregnancy-related risks and verify their independent effects on language and cognitive outcomes through larger or multicenter cohort studies, in order to refine early screening indicators. It would also be valuable to further investigate the specific mechanisms by which different types of high-risk pregnancy influence language development.

The multidimensional early neurobehavioral intervention implemented in this study produced significant improvements across all children with language developmental delay, consistent with multisensory integration theories and the principles of neuroplasticity windows. Specifically, approaches such as oral sensory-motor stimulation, multisensory integration, oromotor imitation, induced active expression, emotional regulation with tactile soothing, and language-assisted fine and gross motor training likely facilitate neural circuit reorganization and synaptic plasticity through multimodal sensory input and motor practice, thereby enhancing the efficiency of language-related neural networks and improving cognitive function.

Systematic reviews have demonstrated that early intervention can enhance both expressive and receptive language abilities in children with language delay; however, studies investigating comprehensive multidimensional interventions across different risk backgrounds and in children with comorbid intellectual disability remain relatively limited. Our findings indicate that, regardless of baseline language or cognitive levels, children can achieve substantial behavioral improvements through scientifically structured and continuous interventions. Furthermore, post-intervention outcomes converged across risk-factor subgroups, suggesting that these interventions exert broadly promotive effects. These methods are therefore suitable for wide clinical application and may be extended to structured home-based programs.

Similar studies have reported that individualized early interventions in neurodevelopmental disorders significantly enhance cognitive and language functions, with positive downstream effects on later learning and social abilities [28]. Our study further suggests that children from various risk backgrounds including preterm birth, high-risk birth, and family history of intellectual disability respond similarly to structured interventions, implying that programs grounded in core neuroplasticity principles can be effective across diverse risk profiles. Nevertheless, limitations in sample size and follow-up duration may have constrained the detection of potential subgroup differences; future research with larger cohorts and extended follow-up periods is warranted to explore differential responses more comprehensively.

Several limitations warrant attention. The retrospective design precludes full control of confounding variables and the absence of a control (non-intervention) group means that observed improvements may partly reflect natural developmental trajectories. First, the retrospective design and the absence of a non-intervention control group mean that the observed improvements may partly reflect natural developmental trajectories, a critical confounder in young children. Although the magnitude and consistency of improvements across all functional domains within a short 3-month period particularly among older children and those with more severe delays whose natural progress tends to be slower suggest a substantial contribution of the intervention beyond expected developmental gains, we cannot rule out the effect of maturation. Therefore, the results regarding the intervention's effectiveness should be interpreted with caution. Future randomized controlled trials are necessary to confirm the efficacy of this multidimensional intervention protocol. Using a single-center data limits generalizability. Furthermore, neuroimaging techniques were not employed to directly verify mechanisms of brain network remodeling. As this study was designed to evaluate the effects of a comprehensive intervention, the independent contribution of each component was not analyzed separately. Future research could employ a stratified intervention design to further explore the individual effects of specific measures and provide a basis for optimizing individualized intervention protocols. Furthermore, since the current study only assessed short-term outcomes over a 3-month period, long-term follow-up data are lacking. Thus, the sustainability and long-term efficacy of the intervention warrant further investigation.

In summary, comorbid intellectual disability in children with language development delay is jointly influenced by S-S scores, prematurity, family history, and birth high-risk history, with S-S score showing particularly strong predictive value. Early neurobehavioral intervention can comprehensively improve language, cognitive, and behavioral functions in these children.

Disclosure of conflict of interest

None.

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