Original Articles

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Correlation Between the *Bayley Scales of Infant and Toddler Development, Third Edition* and Subsequent Cognitive Function at Age 6 Years in Very-Low-Birthweight Children

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Objectives: The early detection of neurodevelopmental disorders is critical for children born prematurely. Therefore, we examined whether *Bayley Scales of Infant and Toddler Development, Third Edition* (BSID-III) data were correlated with subsequent cognitive function among very-low-birthweight (VLBW) children at 6 years of age.

Methods: We included 30 VLBW children (17 males, 13 females) born at a mean gestational age of 28.5 weeks (mean birth weight, 1,015 g). Developmental status was assessed using the BSID-III at 3 years old and the Kaufman Assessment Battery for Children (K-ABC) at 6 years old. We compared the general cognitive scores and subtest scores of children at these ages.

Results: The BSID-III cognitive, language, and motor composite scores were significantly correlated with the K-ABC mental processing composite score (Spearman's correlation coefficient = 0.68, 0.66, and 0.60, respectively). Multiple regression analysis demonstrated that the language composite score of the BSID-III was most strongly associated with the mental processing composite score of the K-ABC ($\beta = 0.61$, $p = 0.02$).

Conclusions: BSID-III scores at 3 years of age were correlated with general cognitive abilities at 6 years of age. However, our results suggest that the language scales of the BSID-III may better predict later cognitive characteristics in VLBW children. Clinically, children with language impairment should be carefully followed for their cognitive abilities into school age.

Key words: Bayley Scales of Infant Development (BSID-III), development, preterm, subtest, very-low-birthweight (VLBW)

Introduction

Very preterm infants, very-low-birthweight (VLBW) infants, and infants meeting both criteria are at increased risk for developmental difficulties even if they are born without major brain injuries. These difficulties include poorer cognitive ability[1)-7)], poorer executive function (including processing speed and memory function)[1)-6) 8)-10)], and poorer visual perception[1) 6) 10)-12)], as well as increased risks of inattention[1)], hyperactivity[1)], and learning difficulty.[1) 4) 7) 8) 10)] Some of these behavioral and learning difficulties are evident even in VLBW children without intellectual deficits.[13)] Thus, it is important to identify VLBW children at risk for later cognitive and educational difficulties at an early age to allow appropriate interventions to be implemented to improve their overall cognitive and academic potential.

The *Bayley Scales of Infant and Toddler Development* (BSID) has been widely used in recent decades as a guide for the developmental assessment of children, and it can be used to guide supportive intervention. The third edition of the BSID (BSID-III), which was published in 2006, includes five index scores: cognitive, receptive communication,

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expressive communication, fine motor, and gross motor scores. This heavily revised and restructured edition now permits more detailed assessments to identify specific delays for children aged 1–42 months.[14)]

However, only a few studies of the predictive value of the BSID–III have been conducted. A previous study revealed a moderate to large correlation between BSID–III cognitive and language composite scores at 24 months and subsequent general cognitive, verbal, and nonverbal reasoning abilities at 4 years old, as assessed using the *Differential Ability Scale, Second Edition*.[15)] Another study found that the average subscale quotient score of the cognitive, language, and motor scales of the BSID–III examined at a mean age of 32.6 months was valid for predicting moderate and severe delays in the general quotient of the *Griffiths Mental Development Scales* for clinically delayed children at a mean age of 52.4 months.[16)] Conversely, several studies demonstrated that the motor scale of the BSID–III at 2 years of age did not predict motor skills at 4 years of age.[17) 18)] The predictive validity of the BSID–III for long–term overall cognitive ability in preterm children and that of BSID–III subscales for deficits in specific cognitive functions remain unclear.

In the Kaufman Assessment Battery for Children (K–ABC), the mental processing composite is the overall measure of cognitive function, and it is considered equivalent to the intelligence quotient. The mental processing composite consists of two dimensions: the sequential processing and simultaneous processing scales. Based on the cerebral specialization theory, the sequential processing scale measures the ability to process information serially or temporally in a stepwise manner, and it is believed to be associated with the left hemisphere, which specializes in linguistic, serial, and analytical tasks. The simultaneous processing scale measures the ability to solve analogical, spatial, or organizational problems, and it is believed to be associated with the right hemisphere, which is specialized for nonverbal, synthetic, and holistic tasks.[19)] In this study, we examined whether the BSID–III scores of VLBW children at 3 years old are correlated with their cognitive function at 6 years old as measured by the K–ABC and whether the subscale scores of the BSID–III are correlated with specific K–ABC scores. We assumed that the language composite score of the BSID–III would reveal a stronger correlation with the sequential processing scale than with the simultaneous processing scale of the K–ABC.

Methods

1. Participants

The study included 136 VLBW infants who had a birthweight below 1,500 g, who were born at 34 weeks or less of gestation, and who were born and treated in the neonatal intensive care unit of Juntendo University Hospital, Tokyo between April 2007 and March 2010 or Juntendo Shizuoka Hospital, Shizuoka between January 2009 and March 2010. Of the 136 children, 8 died during the perinatal period, 6 were excluded for their inabilities to take the test due to severe developmental delays or behavioral problems, and 92 discontinued outpatient visits before reaching 6 years of age. In total, 30 VLBW children (22%) completed both the BSID–III at 3 years old and the K–ABC at 6 years old. Of these children, all completed the BSID–III cognitive and language assessments, and 25 completed the BSID–III motor assessments, with the remaining 5 unable to complete these assessments because of environmental factors such as a lack of testing time. No child had severe neurosensory impairments (defined as blindness or hearing impairment requiring aids).

Participation in this study was voluntary, and written informed consent was obtained from the participants' caregivers. The study was approved by the Ethics Committee of Juntendo University Hospital (Application Number: 14–121).

2. Data collection

The developmental status of the children was assessed individually by clinical psychologists or pediatricians trained to a uniform standard. In this study, we included the results of the BSID–III cognitive, language, and motor composite scores and subtest scaled scores to assess developmental status at 3 years old. The social–emotional and adaptive behavior scales, which are questionnaires based on the caregiver's report, were excluded, as the Japanese version of the questionnaires has not yet been validated. The BSID–III uses composite scores with a mean of 100 and a standard deviation

(SD) of 15 and scaled scores with a mean of 10 and an SD of 3. Age-standardized scores for each scale were calculated using normative data from the United States according to the participant's chronological age.[14]

The K-ABC Japanese edition[19] was used to assess cognitive function at 6 years old. We included the results of the mental processing composite, sequential processing, and simultaneous processing scales and their subtests which would not be affected by the participants' socio-economic status or their learning environment.[19] The K-ABC uses standard scores with a mean of 100 and an SD of 15.

Maternal and perinatal data were collected retrospectively from the participants' medical records. The maternal data included age at pregnancy, parity, maternal complications during pregnancy (i.e., gestational diabetes and hypertension), prenatal steroid use, and history of multiple births. We ascertained the child's gestational age at birth, birth weight, and Apgar score and determined whether he or she was small for gestational age (SGA; defined as birthweight below the tenth percentile of the general population in Japan). We also recorded the durations of artificial ventilation and hospital stay. Finally, we recorded the presence of common neonatal complications, such as intraventricular hemorrhage, periventricular leukomalacia, respiratory distress syndrome, chronic lung disease (defined as oxygen dependence at a corrected age of 36 weeks), retinopathy of prematurity, sepsis, and necrotizing enterocolitis.

3. Statistical analysis

Spearman's correlation coefficient values (r_s) were used to analyze the correlations between BSID-III and K-ABC scores and between all perinatal factors and developmental assessment scores. To clarify which subscale of the BSID-III was most strongly associated with each K-ABC scale, we conducted multiple regression analysis. The selected independent variables were statistically significant in the univariate analysis among the composite scores and the scaled scores of the BSID-III. All data were analyzed using SPSS software version 22.0 (IBM Corporation). The level of statistical significance was set as $p < 0.05$.

Results

1. Participants' characteristics

The perinatal characteristics of the 30 VLBW children are summarized in Table-1. The mean gestational age at birth was 28.5 ± 2.3 weeks, the mean birthweight was 1,015.1 ± 287.7 g, and 12 children (40%) were diagnosed as SGA. No child had grade 3 or higher intraventricular hemorrhage, but there was one case (3%) of periventricular leukomalacia. Perinatal characteristics (i.e., gestational age at birth, birthweight, and neonatal complications) did not differ according to the completion of the BSID-III motor assessments (data not shown). The BSID-III and K-ABC assessments were performed in children at the mean ages of 36.8 ± 3.1 and 68.8 ± 4.1 months, respectively.

2. Results of the BSID-III at age 3 years

The median (interquartile range) composite BSID-III scores were 100.0 (90.0-100.0), 94.0 (89.5-100.0), and 94.0 (91.0-100.0) for the cognitive, language, and motor subscales of the BSID-III, respectively (Table-2). No child had a cognitive composite score of less than 85 (- 1 SD). Seven children (23%) had language composite scores of less than 85 (- 1 SD), but none had a score of less than 70 (- 2 SD). Regarding the motor scale, 1 child had a composite score of less than 70 (- 2 SD), and 2 children scored between 70 and 84. None of the composite scores was correlated with gestational age, birthweight, or birthweight adjusted for gestational age (data not shown).

The median (interquartile range) receptive communication scaled score was 9.0 (8.0-10.8), and the median expressive communication scaled score was 9.0 (8.0-10.0). The median fine motor scaled score was 10.0 (9.0-12.0), and the median gross motor scaled score was 8.0 (7.0-9.0).

3. Results of the K-ABC at age 6 years

The median (interquartile range) mental processing composite score was 96.0 (85.5-99.8), and the median sequential and simultaneous processing scales standard scores were 92.0 (86.5-105.3) and 95.0 (82.0-103.5), respectively (Table-3). Six children (20%) had mental processing composite scores between 70 and 84, and 1 child (3%) had a score of less than 70 (- 2 SD). The 7 children with

Table-1 Participants' characteristics

	Frequency (percentage) N = 30
Gender	
Male	17 (57%)
Female	13 (43%)
Gestational age (week): mean ± SD	28.5 ± 2.3
24-27	13 (43%)
28-33	17 (57%)
Birth weight (g): mean ± SD	1,015 ± 288
ELBW < 1,000 g	14 (47%)
VLBW 1,000-1,499 g	16 (53%)
SGA: birth weight < 10^{th} percentile	12 (40%)
Multiple births	7 (23%)
Apgar score at 5 minutes: mean ± SD	7.9 ± 1.5
≤6	4 (13%)
7-10	26 (87%)
Development-related diagnosis	
Intraventricular hemorrhage, grade 3-4	0 (0%)
Periventricular leukomalacia	1 (3%)
Respiratory distress syndrome	23 (77%)
Chronic lung disease, O_2 at 36 week GA	14 (47%)
Prenatal steroid use	11 (37%)
Surfactant therapy	23 (77%)
Cryotherapy for retinopathy of prematurity	5 (17%)
Sepsis, at age > 72 hours	1 (3%)
Necrotizing enterocolitis	1 (3%)
Days in hospital: mean ± SD	102 ± 68
Days on ventilation: mean ± SD	19 ± 25
Maternal complications during pregnancy	
Hypertension	7 (23%)
Diabetes mellitus	1 (3%)
Maternal age at pregnancy (year): mean ± SD	34.1 ± 5.3
Age at assessment (month): mean ± SD	
BSID-III	36.8 ± 3.1
K-ABC	68.8 ± 4.1

Abbreviations: BSID, Bayley Scales of Infant and Toddler Development; ELBW, extremely low birth weight; GA, gestational age; K-ABC, Kaufman Assessment Battery for Children; SD, standard deviation; SGA, small for gestational age; VLBW, very low birth weight

mental processing composite scores of less than 85 at 6 years old had normal cognitive composite scores at 3 years old. However, 5 of these 7 children had language composite scores of less than 85 at 3 years old. The mental processing composite scores of the remaining 2 children at 6 years old indicated mild delays even though they had cognitive and language composite scores of at least 85 at 3 years old (Table-4).

4. Correlations between BSID-III scores and K-ABC standard scores

There were significant positive correlations between the cognitive composite scores of the BSID-III and the mental processing composite (r_s = 0.68, p = 0.001), sequential processing (r_s = 0.65, p = 0.001), and simultaneous processing scores (r_s = 0.50, p = 0.005) of the K-ABC. There were also significant positive correlations between the language

Table-2 Results of BSID-III

Median scores (interquartile range)			
Cognitive	Composite score		100.0 (90.0-100.0)
Language	Composite score		94.0 (89.5-100.0)
		Receptive communication scaled score	9.0 (8.0-10.8)
		Expressive communication scaled score	9.0 (8.0-10.0)
Motor	Composite score		94.0 (91.0-100.0)
		Fine motor scaled score	10.0 (9.0-12.0)
		Gross motor scaled score	8.0 (7.0-9.0)

Abbreviations: BSID, Bayley Scales of Infant and Toddler Development

Table-3 Results of K-ABC

Median scores (interquartile range)		
Standard scores of cognitive processing subscales	Mental processing composite	96.0 (85.5-99.8)
	Sequential processing scales	92.0 (86.5-105.3)
	Simultaneous processing scales	95.0 (82.0-103.5)

Abbreviations: K-ABC, Kaufman Assessment Battery for Children

Table-4 Number of participants per score range of BSID-III and K-ABC

			K-ABC Mental processing composite		
			≧85	70-84	≦69
BSID-III	Cognitive composite score	≧85	23	6	1
		70-84	0	0	0
		≦69	0	0	0
	Language composite score	≧85	21	2	0
		70-84	2	4	1
		≦69	0	0	0
	Motor composite score	≧85	18	3	1
		70-84	1	1	0
		≦69	1	0	0

Abbreviations: BSID, Bayley Scales of Infant and Toddler Development; K-ABC, Kaufman Assessment Battery for Children

Table-5 Correlation between BSID-III and K-ABC standard scores

Spearman's correlation coefficient: r_s			K-ABC		
			Mental processing composite	Sequential processing scales	Simultaneous processing scales
BSID-III	Cognitive composite score		0.68**	0.65**	0.50**
	Language composite score		0.66**	0.40*	0.64**
		Receptive communication scaled score	0.62**	0.29	0.67**
		Expressive communication scaled score	0.57**	0.48**	0.47**
	Motor composite score		0.60**	0.28	0.59**
		Fine motor scaled score	0.55**	0.44*	0.41*
		Gross motor scaled score	0.38	0.03	0.49*

**: $p<0.01$
*: $p<0.05$
Abbreviations: BSID, Bayley Scales of Infant and Toddler Development; K-ABC, Kaufman Assessment Battery for Children

Table-6 Multiple regression analyses of K-ABC standard scores

		K-ABC								
		Mental processing composite			Sequential processing scales			Simultaneous processing scales		
		B	SE B	β	B	SE B	β	B	SE B	β
BSID-III	Cognitive composite score	-0.05	0.26	-0.04	0.12	0.29	0.09	-0.07	0.28	-0.05
	Language composite score	0.83	0.31	0.61*	0.64	0.30	0.45*	0.60	0.33	0.42
	Motor composite score	0.19	0.28	0.14	-	-	-	0.53	0.30	0.37
R^2			0.46			0.25			0.46	

*: $p<0.05$

Abbreviations: BSID, Bayley Scales of Infant and Toddler Development; K-ABC, Kaufman Assessment Battery for Children

composite scores of the BSID-III and the mental processing composite ($r_s=0.66$, $p=0.001$), sequential processing ($r_s=0.40$, $p=0.027$), and simultaneous processing scores ($r_s=0.64$, $p=0.001$) of the K-ABC. The correlations between the motor composite scores of the BSID-III and mental processing composite ($r_s=0.60$, $p=0.001$) and simultaneous processing standard scores ($r_s=0.68$, $p=0.001$) of the K-ABC were significant (Table-5).

Multiple regression analysis illustrated that the language composite score of the BSID-III was a significant predictor of the mental processing composite score of the K-ABC (standardized partial regression coefficient: $\beta=0.61$, $p=0.02$). The analysis also illustrated that the language composite score of the BSID-III was a significant predictor of the sequential processing score of the K-ABC ($\beta=0.45$, $p=0.04$). Meanwhile, in multiple regression analysis of the simultaneous processing score of the K-ABC using the cognitive, language, and motor composite scores of the BSID-III, none of the scores was significantly predictive (Table-6).

Discussion

This study illustrated that cognitive, language, and motor development, as assessed using the BSID-III at 3 years of age, was correlated moderately with general cognitive ability measured using the mental processing composite of the K-ABC at 6 years old in our small group of VLBW children. The cognitive and language composite scores of the BSID-III correlated positively with both the sequential and the simultaneous processing scores of the K-ABC. However, multiple regression analysis revealed that the language composite score of the BSID-III was significantly associated with the mental processing composite of the K-ABC.

Our finding is consistent with that of a previous study revealing a moderate to large correlation between BSID-III scores and subsequent general cognitive abilities at 4 years old.[15] Our results extend this research by demonstrating that developmental status as assessed using the BSID-III is associated with cognitive function in school-age children. Meanwhile, our findings that some children had K-ABC mental processing composite scores of less than 85 at 6 years old despite having normal BSID-III cognitive composite scores at 3 years old led us to speculate that the BSID-III cognitive composite score may underestimate cognitive deficits in some cases and including the results of language composite scores of the BSID-III may increase the predictive validity.

The results of multiple regression analysis support the cerebral specialization theory[19], as the language composite score was most strongly associated with the sequential processing scales of the K-ABC. Furthermore, language impairment at 3 years old may be a risk factor for later cognitive impairment, particularly regarding sequential processing. In clinical practice, VLBW children with language impairment at 3 years old should be carefully followed for their cognitive abilities into school age.

Furthermore, the expressive communication subscale, rather than the receptive communication subscale, of the BSID-III may predict the sequential processing scales score of the K-ABC. Further research is needed to confirm the relationship between the subscale scores of the BSID-III and specific K-ABC subtest scores.

The limitations of this study were the small number of participants and the lack of a term control group. Future research should examine the

relationship between BSID-III scores and preschool cognitive function in a larger sample of children who have been categorized by BSID-III score. The use of English-based testing tools in our study may have partially influenced the results. Using a control group consisting of term children whose native language is Japanese may enable us to better elucidate the developmental characteristics of VLBW children.

Conclusions

The cognitive and language development of VLBW children, as assessed using the BSID-III at 3 years old, appears to be related to their general cognitive function at 6 years old. Our results suggest that using both cognitive and language score scales of the BSID-III may better predict later cognitive characteristics in VLBW children.

Conflict of interest

There were no conflicts of interest.

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