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WISC-IV Factor Structures of Japanese Children with Borderline, or Deficient Intellectual Abilities: Testing Measurement Invariance Compared to Simulated Norm

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Abstract

Factor analyses of intelligence tests have been conducted with diverse clinical populations. Factor structures of the Wechsler Intelligence Scale for Children-fourth Edition (WISC-IV) in children with borderline intellectual functioning (BIF) and intellectual disability (ID) were compared to the Japanese norm by using a simulated group. Measurement invariance among simulated, borderline and disability groups was tested by multi-group analyses through structural equation modeling for manual-depended four-factor model. Results indicated that the metric invariance model was supported among the three groups. The correlation coefficients between the four index scores suggested that BIF could be partially explained as resulting from inhibiting and restraining effects among broad abilities when responding to each subtest of intelligence tests. This degrading effect might lower IQ in children having certain clinical problems. On the other hand, ID could be partially understood as a brain impairment consisting of unrelated and isolated activation of broad ability areas. It is concluded that there are differences in factor structures and mechanisms of BIF and ID.

Keywords

Intelligence, WISC-IV, Borderline Intellectual Functioning, Simulation, Measurement Invariance

1. Introduction

Factor analytic studies have examined the structure of psychometric intelligence (Carroll, 1993) and among these, the Wechsler Intelligence Scale for Children

(WISC) has been investigated. As a result by factor analytical evidence the fourth edition of the WISC (WISC-IV) has adopted four index scores and 15 subtests (Wechsler, 2003/2010), instead of discarding the traditional dual intelligence model. There are many reports on the factor structure of the WISC-IV. The manual-depended four-factor model including the Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), and Processing Speed Index (PSI) has been examined and compared with alternative models within various single groups.

1.1. Factor Analytic Studies with Single Group

Regarding educational evaluation, Watkins, Wilson, Kotz, Carbone, and Babula (2006) investigated 432 students referred for special education services and indicated that the manual-depended four-factor model fitted the best. Watkins (2010) examined 355 students referred for psychoeducational assessment and confirmed that the structure of the WISC-IV was best represented by four first-order factors and a second-order general intelligence factor. Similarly, regarding learning problems, Watkins, Canivez, James, T., James, K., and Good (2013) analyzed 794 Irish children with learning difficulties and found that the correlated four-factor model provided the best fit indices. Moreover, Canivez (2014) assessed 345 children with learning difficulties and obtained data showing that a direct hierarchical model provided the best fit, which was also the case with the study by Styck and Watkins (2016) who studied 1537 students diagnosed with specific learning disabilities. Attention deficit hyperactivity disorder (ADHD) has also been investigated. Yang, Cheng, Chang, Liu, Hsu, and Yen (2013) examined 334 Taiwanese children with ADHD and confirmed that the correlated four-factor model of the WISC-IV-Chinese fitted well. Furthermore, Thaler, Barchard, Parke, Jones, Etcoff, and Allen (2015) analyzed 314 children diagnosed with ADHD and indicated that a five-factor model consisting of Gc, Gf, Gv, Gsm, and Gs factors provided a superior fit to the manual-depended four-factor model. However, Styck and Watkins (2017) investigated 233 students diagnosed with ADHD and found that a higher-order four-factor model fitted the data best.

As for hospitalized clinical cases, Bodin, Pardini, Burns, and Stevens (2009) analyzed 344 children that participated in neuropsychological evaluations and showed the best fit indices of the higher-order factor structure of the WISC-IV. Whereas, Devena, Gay, and Watkins (2013) assessed 297 children referred to a children's hospital and obtained a direct hierarchical model including four first-order factors and a general intelligence factor as the best fit. As far as cultural and racial factors are concerned, Nakano and Watkins (2013) investigated 176 Native American children referred for psychoeducational evaluation. They replicated the normative four first-order factor structure and a higher-order general ability factor. On the contrary, Golay, Reverte, Rossier, Favez, and Lecerf (2013) examined 249 French-speaking Swiss children using Bayesian structural equation modeling and found that a direct hierarchical Cattel-Horn-Carrol

(CHC)-based model with five factors plus a general intelligence factor best represented the data. Moreover, Reverte, Golay, Favez, Rossier, and Lecerf (2014) investigated 249 French-speaking Swiss children and obtained a CHC-based model with five factors as the best fit.

The above-discussed findings using the single group approach have nearly always replicated the manual-depended four-factor model, irrespective of correlated four-factor model or the four first-order factor solution in the hierarchical model, with the exception of very few studies that have demonstrated a better fit for the CHC-based five-factor model.

1.2. Factor Analytic Studies with Multi Groups

Multi-group analysis has a methodological advantage over the single group approach for rigorously comparing the factor structure of a given group with that of the standardized norm. In recent years, certain studies have used multi-group methodology to examine the factor structure of the WISC-IV. Chen and Zhu (2008) analyzed a nationally representative sample of 2200 children for testing measurement invariance of the WISC-IV factor structure between genders and reported that the partial measurement invariance model was supported for the correlated four-factor model. Chen, Keith, Weiss, Zhu, and Li (2010) tested factorial invariance across countries by using a standardization sample of children in Mainland China, Hong Kong, Macau, and Taiwan. They confirmed that measurement invariance was supported as the second-order hierarchical factor model across all four cultures. Similarly, Chen and Zhu (2012) analyzed a total of 1100 normative and clinical samples of children and demonstrated measurement invariance for the second-order hierarchical model. Also, Weiss, Keith, Zhu, and Chen (2013) analyzed normative and clinical samples to compare higher-order four- and five-factor models and reported that both models were suitable and generally showed full factorial invariance between clinical and nonclinical participants.

Previous studied discussed above have sampled different types of clinically referred children and analyzed the factor structure of their WISC-IV scores. However, there have been only a few studies directly targeting children with low intelligence. It is considered important to examine whether or not a quantitative difference of IQ level can influence their factor structure because differences in the factor structure could possibly explain both a child's performance when addressing intelligence tests as well as the mechanisms of their psychometric intelligence. Findings that promote understanding characteristics of lower IQ children is essential for psychological assessment. The aim of this study was therefore to investigate the factor structure of children having either borderline intellectual functioning (BIF) or intellectual disability (ID) compared to the standardized norm.

2. Methods

2.1. Procedure

The data were collected from child guidance centers on Japanese children 1) that had been administered the Japanese version of WISC-IV (Wechsler, 2003/2010), 2) with an IQ less than 85, and 3) without a diagnosed of a developmental disorder by a child psychiatrist. Child guidance centers in Japan are public agencies designed to search for solutions and solve problems for supporting the sound growth of children who are less than 18 years.

The Japanese version of WISC-IV was standardized in 2010 (Wechsler, 2003/2010) and has a demonstrated reliability of .95 for the full-scale IQ, .86 - .91 for the four index scores, and .74 - .88 for the ten core subtests. These data were collected as a part of routine clinical practice. Informed consent was obtained from parents, caregivers, or the children themselves.

2.2. Participants

Final data of 434 children (155 girls), aged from 5 to 16 years, were obtained. They were children with varied challenges or problems: 1) being abused or maltreated, 2) needing foster care or child welfare institutions, 3) expressing school maladaptation, personality problems, or delinquent behaviors alleged by their parents. They were divided into two groups on the basis of their IQ: Borderline group (n = 314, 70 < IQ < 85), and Disability group (n = 120, IQ < 71). Descriptive statistics on demographic variables and the WISC-IV are shown in **Table 1**.

2.3. Simulation

The Numerical Technologies Random Generator for Excel (NtRand version 3.3; Numerical Technologies, 2016) was used to generate random numbers according to multivariate normal distribution, because standardized normal data were unavailable for this study. The NtRand is a free software and an Excel add-in random generator powered by Mersenne Twister algorithm. There were 1285 simulated cases generated, which is the same numbers as in the Japanese standardization

Table 1. Descriptive statistics in the participated children.

	Borderline Group			Disability Group		
	N	%		*N*	%	
Female	110	35		45	38	
Male	204	65		75	63	
	M	*SD*	95% *CI*	*M*	*SD*	95% *CI*
Age	12.2	2.4	12.5, 11.9	12.2	2.4	12.7, 11.8
FSIQ	78.1	4.1	78.6, 77.7	63.6	5.7	64.6, 62.5
VCI	79.3	8.4	80.2, 78.3	67.9	8.3	69.4, 66.4
PRI	82.6	8.9	83.6, 81.6	69.8	6.4	71.0, 68.7
WMI	82.0	9.9	83.2, 80.9	69.0	8.8	70.6, 67.4
PSI	86.0	9.0	87.0, 85.0	74.5	10.6	76.4, 72.6

Note. FSIQ…Full Scale IQ, VCI…Verbal Comprehension Index, PRI…Perceptual Reasoning Index, WMI…Working Memory Index, PSI…Processing Speed Index.

study (Wechsler, 2003/2010). The simulated group was generated such that there were both ten means of 10.0 on subtest scaled-scores and correlation coefficients between 10 subtests, which replicated the correlation matrix of the Japanese norm.

3. Results & Discussion

3.1. Validity of the Simulation Procedure

Firstly, the validity of the simulation procedure was confirmed. Table 2 shows that 1) means of subtest scores in the simulated group were approximately 10.0 and 2) differences in correlation coefficients between the simulated and the norm were less than |.08| at most. The results, therefore, indicated that the simulated group had a simulated validly similar to the Japanese norm population and could be used as a control group in structural equation modeling analyses using a correlation matrix.

3.2. Correlation Matrix in Borderline and Disability Groups

Secondly, correlation coefficients between the 10 subtests in both borderline and disability groups were calculated (Table 3). Two noticeable differences between Table 2 and Table 3 were the signs and the significance level of coefficients. Among the 45 pairs in the correlation matrix, there were 14 negative correlations, 6 positive correlations, and 25 no correlations in the borderline group; whereas there were 0 negative correlations, 10 positive correlations, and 35 no correlations in the disability group. Therefore, in comparison to the simulated norm, in which all 45 pairs were positively correlated, borderline and disability groups were roughly characterized by negative, or no correlations, respectively.

Table 2. Simulation validity in comparison with the Japanese norm group.

	Bivariate correlation coefficients										Simulated group (N = 1285)				Norm group (N = 1285)	
	1	2	3	4	5	6	7	8	9	10	*M*	*SD*	Skew	Kurtosis	*M*	*SD*
1. BD	–	.34	.33	.22	.23	.32	.30	.42	.22	.30	10.0	3.0	−.24	−.10	10.1	3.0
2. SI	.33	–	.33	.27	.22	.56	.36	.35	.46	.25	10.0	3.1	−.21	−.05	10.0	3.0
3. DS	.26	.32	–	.25	.23	.36	.53	.35	.27	.28	10.1	2.9	−.11	.01	10.1	2.9
4. PC	.21	.26	.21	–	.15	.29	.25	.33	.30	.20	10.1	3.0	−.13	−.07	10.1	3.0
5. CD	.22	.22	.26	.16	–	.19	.20	.21	.20	.56	9.8	3.0	−.20	.04	10.1	3.0
6. VC	.31	.53	.35	.26	.20	–	.40	.36	.58	.23	10.1	3.0	−.13	.05	10.2	2.9
7. LN	.26	.33	.54	.20	.24	.39	–	.36	.31	.27	10.0	3.0	−.09	−.06	10.1	3.1
8. MR	.41	.32	.33	.28	.22	.36	.36	–	.28	.25	10.1	3.0	−.29	.01	10.1	3.0
9. CO	.20	.45	.24	.29	.20	.57	.28	.25	–	.21	10.0	3.0	−.16	.02	10.2	3.0
10. SS	.33	.29	.30	.22	.55	.23	.30	.28	.21	–	10.0	3.0	−.13	−.04	10.2	3.0

Note. The values in the lower triangle are correlation coefficients for Simulated Group, those in the upper triangle are for Norm Group. Multivariate kurtosis in Simulated group = −1.19, *n.s.* BD…Block Design, SI…Similarities, DS…Digit Span, PC…Picture Concepts, CD…Coding, VC…Vocabulary, LN…Letter–Number Sequencing, MR…Matrix Reasoning, CO…Comprehension, SS…Symbol Search.

3.3. Measurement Invariance

Finally, measurement invariance was examined to understand characteristics of abilities in the borderline and disability groups compared to the simulated norm. Multi-group analyses with structural equation modeling were computed to decide the extent to which the measurement invariance model was supported among borderline participants, disability, and simulated groups. The hierarchical or the higher-order model were not analyzed in this study. Instead, the manual-depended model in which the four index scores were correlated with each other was analyzed.

Table 4 showed that results of two and three group comparisons were exceedingly similar. The current study adopted the criterion that the model was approved under the conditions of both comparative fit index (CFI) > .95 and root

Table 3. Correlation matrix and descriptive statistics on subtests.

	Bivariate correlation coefficients										Borderline Group (N = 314)			Disability Group (N = 120)		
	1	2	3	4	5	6	7	8	9	10	*M*	*SD*	95%*CI*	*M*	*SD*	95%*CI*
1. BD	–	−.01	.07	.07	.15	−.16	.12	.23*	.07	.24**	7.2	2.3	7.4, 6.9	5.2	1.7	5.5, 4.8
2. SI	−.01	–	−.03	.09	−.12	.36**	−.06	.09	.24**	.09	6.2	2.1	6.5, 6.0	3.8	2.2	4.2, 3.4
3. DS	−.03	−.13*	–	.17	.07	.04	.37**	.11	−.04	−.02	7.4	2.1	7.7, 7.2	5.4	2.1	5.8, 5.1
4. PC	.01	.09	−.14*	–	.22*	.02	.08	.10	.26**	.07	7.9	2.4	8.2, 7.6	5.9	2.4	6.4, 5.5
5. CD	−.14*	−.14*	−.01	−.06	–	−.14	.13	.15	.04	.40**	7.4	2.3	7.7, 7.2	5.8	2.3	6.2, 5.3
6. VC	−.18*	.30**	−.04	−.01	−.06	–	−.01	.11	.41**	−.09	6.5	1.9	6.7, 6.3	4.8	1.7	5.2, 4.5
7. LN	−.08	−.15**	.25**	−.24**	−.06	−.03	–	.20*	.03	.04	6.5	2.2	6.8, 6.3	3.9	1.8	4.2, 3.5
8. MR	.15**	−.03	.05	−.02	−.07	−.08	.06	–	.06	−.04	6.9	2.3	7.2, 6.7	4.3	1.5	4.6, 4.0
9. CO	−.13*	.12*	−.12*	−.04	−.05	.36**	−.12*	−.21**	–	.00	6.9	1.9	7.2, 6.7	5.4	1.6	5.6, 5.1
10. SS	.07	−.22**	−.07	−.10	.20**	−.26**	.02	.05	−.18**	–	7.6	2.1	7.8, 7.4	5.0	2.3	5.4, 4.6

Note. The values in the lower triangle are correlation coefficients for Borderline Group, those in the upper triangle are for Disability Group. *…p < .05, **…p < 0.01. BD…Block Design, SI…Similarities, DS…Digit Span, PC…Picture Concepts, CD…Coding, VC…Vocabulary, LN…Letter–Number Sequencing, MR…Matrix Reasoning, CO…Comprehension, SS…Symbol Search.

Table 4. Comparison of goodness of fit indices with respect to measurement invariance models.

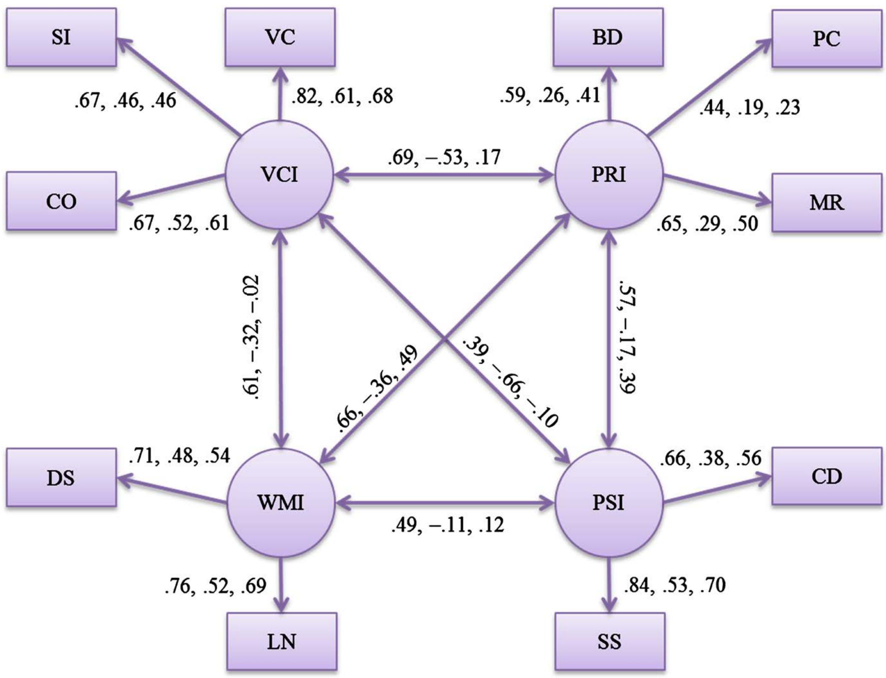
	Two groups										Three groups				
	Simulated/Borderline					Simulated/Disability					Simulated/Borderline/Disability				
	χ^2	*CFI*	*RMSEA*	*AIC*	*BCC*	χ^2	*CFI*	*RMSEA*	*AIC*	*BCC*	χ^2	*CFI*	*RMSEA*	*AIC*	*BCC*
Configural	194.0	.961	.038	338.0	341.4	158.7	.970	.035	302.7	311.2	233.6	.959	.031	449.6	460.7
Metric	196.1	.962	.036	328.1	331.1	165.4	.970	.034	297.4	305.2	242.5	.960	.029	434.5	444.4
Factorial[a)]	563.9	.859	.066	683.9	686.7	259.6	.944	.044	379.6	386.7	665.9	.845	.054	835.9	844.7
Scalar[b)]	1208.2	.676	.098	1320.2	1322.8	656.0	.829	.075	768.0	774.6	1712.2	.556	.089	1866.2	1874.2

Note. CFI…Comparative Fit Index, RMSEA…Root Mean Square Error of Approximation, AIC…Akaike Information Criterion, BCC…Brown-Cudeck Criterion. a) Factorial model constrained covariance of latent factors between groups in addition to the Metric model. b) Scalar model constrained means of all observational variables in addition to the Factorial model.

mean square error of approximation (RMSEA) < .06 (Hu & Bentler, 1999). The goodness of fit indices of configural and metric invariance models were sufficient, whereas those of the scalar invariance model were not. In addition to the metric invariance model, the factorial invariance model, which constrained correlations between the four index scores to be equal, was also examined. However, it was rejected due to the inadequate goodness of fit indices.

3.4. Factor Structures with Borderline and Disability Groups

Figure 1 shows that correlations between all four abilities influencing the ten subtests are positive in the simulated group, whereas there were three negative correlations and three no correlations in the borderline group and one positive correlation and five no correlations in the disability group. These findings suggest that children with BIF compared to averaged children might have difficulties in coordinating among broad abilities. It is possible that when performing intellectual tasks or intelligence tests, broad abilities of children with an average IQ are integrated, whereas they are mutual inhibited in children with borderline IQ, such that one type of ability becomes activated for problem solving, whereas other types of abilities simultaneously become activated to restrain problem-solving and therefore, the total IQ performance deteriorates. Children with ID might also have difficulties in integrating broad abilities. Also, there might be



The values were in the metric invariance model and were standardized path coefficients of the Simulated, Borderline, and Disability groups, which were from left to right respectively. VCI…Verbal Comprehension Index, PRI…Perceptual Reasoning Index, WMI…Working Memory Index, PSI…Processing Speed Index, BD…Block Design, SI…Similarities, DS…Digit Span, PC…Picture Concepts, CD…Coding, VC…Vocabulary, LN…Letter-Number Sequencing, MR…Matrix Reasoning, CO…Comprehension, SS…Symbol Search

Figure 1. WISC-IV manual-depended model.

small differences between borderline and disability groups, which are related to difficulties in coordination. There were no correlations in the disability group suggesting that the factor structure of children with ID was characterized by unrelated, or isolated performance.

BIF might be partially explained by inhibiting and restraining effects of broad abilities when responding to different subtests of intelligence tests, which might lead to lower IQ scores in children having specific clinical problems, which might cause BIF children to make clinical consultations. On the other hand, ID might be partially understood as a brain impairment causing unrelated and isolated activation of broad ability areas. These findings suggest the possibility of different causal mechanisms in BIF and ID.

4. Conclusion and Limitations

The conclusions of the study are constrained by certain limitations. Regarding the methodology, the present study did not analyze data of actual populations, but instead used a simulation to represent a control group. Although the simulated group had demonstrated statistical validity as a normal population, the generalizability of the present findings is restricted. In the analysis, the current study adopted a manual-depended model in which the four index scores were presumed to be mutually correlated. However, Keith, Fine, Taub, Reynolds, and Kranzler (2006) based on confirmatory factor analysis indicating the superiority of the CHC model to the manual-depended model recommended that testers regroup PRI subtests, and Arithmetic, to reflect better constructs measured by the WISC-IV. It is important to confirm that the findings of this study can be replicated in other models, such as hierarchical, higher-order, and the CHC models. Future research is suggested to clarify these issues.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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