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14 Behavior Genetic Analyses for Cognitive Development in Early Childhood: Comparisons between 42 and 60 Months

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Introduction

Both cognitive functions and physical features change dramatically during early childhood. Intuition suggests that genetic effects are stable and do not change over the course of a life span. Thus, genetic influences on cognitive abilities are presumed to contribute to stability rather than to change in this domain. However, this assumption is absolutely untrue. Indeed, it has been well established that the *heritability* of general and specific cognitive abilities increases from childhood to adolescence (McGue & Bouchard, 1993; Plomin et al., 1997b; Cardon, 1994; Bishop et al., 2003). Although most genetic effects contribute to the continuity of cognitive abilities across developmental stages (Petrill et al., 2004; Rietveld, et al., 2003), new genetic effects have been observed during the transitional period between infancy and early childhood (Fulker et al. 1993).

References to changes in genetic (and environmental) effects signify variations (sources of individual differences) rather than changes in mean values. It is a clear that the mean scores on tests increase as cognitive abilities develop. However, genetic and environmental contributions to individual differences in cognitive abilities or in any phenotype (an operational definition of *heritability*) might not change, or might even decrease.

The process by which the heritability of cognitive functions changes constitutes an interesting and important research question because it directly addresses

Table 1. Numbers of pairs of twins.

	42 months			60 months		
	MZ	DZ	Total	MZ	DZ	Total
Female	27	29	56	17	16	33
Male	30	30	60	12	16	28
Total	57	59	116	29	32	61

Note. MZ: Monozygotic twins. DZ: Dizygotic twins.

the ontogenesis of cognitive development. As demonstrated in the next section, the behavioral genetic analysis of twin data can provide three different types of etiological sources for phenotypic variations: additive genetic, shared environmental, and non-shared environmental.

The current study used a longitudinal dataset on twins reared together to investigate how Japanese children manifested dynamic changes in the etiology of cognitive development from 3.5 to 5 years of age. This article represents a preliminary report on our initial findings because the study is ongoing and data collection will continue.

Method

Participants

The sample consisted of twins living in the Tokyo area. The mean age of participants was 3.54 years (SD = 0.12) at the time of the 42-month assessment and 5.16 years old (SD = 0.10) at the of 60-month assessment. Table 1 shows the numbers of twin pairs; 30 pairs (12 MZ pairs, 18 DZ pairs) participated in both assessments.

Measures

Trained testers conducted the following evaluations on all children in a laboratory setting. Different tests were administered by different testers to each twin in order to avoid tester biases.

Cognitive functioning: Kaufman Assessment Battery for Children (K-ABC)

We conducted the K-ABC following the K-ABC Administration and Scoring Manual (Matsubara et al., 1993). We have reported elsewhere that our data have the same factor structure as that assumed by the K-ABC (i.e., sequential processing and simultaneous processing; see Fujisawa & Ando, 2008 for details). We used standard scores for the sequential scale, simultaneous processing scale and achievement scale.

Analyses

Within-pair correlations and univariate genetic analyses for sequential processing, simultaneous processing, and achievement

We investigated the extent to which genetic and environmental factors account for individual differences in sequential processing, simultaneous processing, and achievement scales. We first examined within-pair correlations for each measure and then conducted separate univariate genetic analyses for each measure.

According to theories of behavioral genetics, individual differences arise from genetic and environmental factors. Environmental factors include shared environmental factors, whereby children growing up in the same family tend be similar, and nonshared environmental factors, whereby each child in the same family has unique experiences that yield differences among children in the same family. Quantitative genetic research assumes that MZ twins are genetically identical and that therefore the correlation between the genetic factors of Twin 1 and Twin 2 is 1.0. In contrast, DZ twins have only half their genes in common, and thus the correlation between the genetic factors of Twin 1 and Twin 2 is 0.5. By definition, assumptions concerning environmental factors are as follows: the correlation between the shared environmental factors associated with Twin 1 and Twin 2 is 1.0 for both MZ and DZ twins growing up in the same family; the correlation between the nonshared environmental factors associated with Twin 1 and those associated with Twin 2 is zero for both MZ and DZ twins because nonshared environmental factors uniquely influence each twin regardless of zygosity.

Based on these assumptions, a higher within-pair correlation for MZ twins than for DZ twins would indicate that genetic factors account more substantially for individual differences on a given measure. Furthermore, the effects of three latent factors (i.e., genetic factors, shared environmental factors, and nonshared environmental factors) can be estimated by quantitative genetic structural equation modeling in which covariance matrices between MZ pairs and DZ pairs are used (for details, see Neale & Cardon, 1992). We examined the extents that the three latent factors affected the individual differences in each measure by using Mx software (Neale, Boker, Xie & Maes, 2002). In addition, we compared the goodness-of-fit indices for the following 4 possible models; ACE model in which the individual difference is accounted by genetic factor, shared environmental factor and nonshared environmental factor. CE model in which the individual difference is accounted by shared environmental factor and nonshared environmental factor. AE model in which the individual difference is accounted by genetic factor and nonshared environmental factor. E model in which the individual difference is accounted only by nonshared environmental factor.

Results

Descriptive statistics

The descriptive statistics for the raw scores on each measure are presented in Table 2 and 3. None of the measures produced significant sex differences. Scores on sequential and simultaneous processing did not differ significantly according to zygosity, but achievement scores tended to be higher among DZ than among MZ twins.

Concurrent and longitudinal correlations among measures

Concurrent and longitudinal correlations among measures are presented in Table 4. All concurrent correlations among measures were significant both at 42 and 60 months. Sequential processing and achievement scores at 42 months were significantly correlated with the same measures at 60 months. However, the longitudinal correlation of simultaneous processing scores was not significant. The only longitudinal correlations among different measures to reach statistical significance were those between the achievement scores at 42 months and the sequential scores at 60 months.

Within-pair correlations and univariate genetic analyses

Within-pair correlations are shown in Figure 1. All within-pair correlations were significant, with the exception of the within-pair correlations of the sequential processing scores of DZ twins at 42 months. The within-pair correlations of MZ twins were higher than were those of DZ twins with respect to sequential processing scores at 42 months and simultaneous processing scores at 60 months, whereas other within pair-correlations did not differ significantly with respect to zygosity. These results suggest that genetic factors significantly affected individual differences in sequential processing at 42 months and simultaneous processing at 60 months, whereas environmental rather than genetic factors affected individual differences on other measures.

Table 2. Means of measures (standard deviations are in parenthesis) by sex.

Measures	Male	Female	
Sequential processing			
42 months	18.78 (5.38)	19.08 (5.31)	t=-.38, df=182, *ns*.
60 months	33.48 (7.28)	33.48 (6.77)	t=.00, df=122, *ns*.
Simultaneous processing			
42 months	29.60 (8.23)	30.72 (7.50)	t=-1.07, df=224, *ns*.
60 months	42.39 (8.53)	42.88 (6.26)	t=-.37, df=121, *ns*.
Achievement			
42 months	285.76 (47.34)	291.33 (35.81)	t=-.97, df=210, *ns*.
60 months	310.86 (40.93)	314.17 (31.26)	t=-.51, df=121, *ns*.

Table 3. Means of measures (standard deviations are in parenthesis) by zygosity.

Measures	MZ	DZ	
Sequential processing			
42 months	19.04 (5.16)	18.79 (5.53)	t=.32, df=180, *ns*.
60 months	33.67 (7.27)	33.47 (7.27)	t=.16, df=120, *ns*.
Simultaneous processing			
42 months	29.18 (8.10)	31.07 (7.66)	t=-1.79, df=222, $p < .1$.
60 months	41.60 (8.09)	43.73 (6.82)	t=-1.59, df=119, *ns*.
Achievement			
42 months	281.67 (35.11)	295.38 (46.96)	t=-2.39, df=208, $p < .05$.
60 months	307.21 (35.99)	318.89 (35.13)	t=-1.81, df=119, $p < .1$.

Table 4. Concurrent and longitudinal correlations among measures.

	SEQ 42	SIML 42	ACHV 42	SEQ 60	SIML 60
SIML 42	.35**	—			
ACHV 42	.46**	.49**	—		
SEQ 60	.33*	-.07	.46**	—	
SIML 60	-.05	.01	.19	.37**	—
ACHV 60	.26^{+}	.08	.77**	.52**	.44**

Note. SEQ: sequential processing, SIML: simultaneous processing, ACHV: achievement. 42: 42 months, 60: 60 months. **: $p < .01$, *: $p < .05$, $^{+}$: $p < .1$.

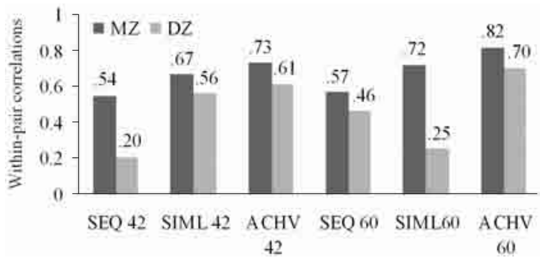

Figure 1. Within-pair correlations of sequential processing, simultaneous processing and achievement scores.

Note. Correlation coefficients were shown above bars. SEQ: sequential processing, SIML: simultaneous processing, ACHV: achievement. 42: 42 months, 60: 60 months.

The results of within-pair correlations were consistent with those of the univariate behavior genetic analyses (see Table 5–7). The AE model achieved the best fit; this model explains individual differences in terms of genetic and nonshared environmental factors and accounted for differences in sequential processing at 42 months and in simultaneous processing at 60 months. The CE model, which explains individual differences in terms of shared and nonshared environmental factors, demonstrated the best fit for the other measures. The ACE model, which explains individual differences in terms of genetic, shared, and nonshared environmental factors represented the best for the achievement scores at 42 months.

The models with the best fit for each measure underscored the contrasts between the data obtained at 42 months and those obtained at 60 months. Despite the longitudinal phenotypic correlations (see Table 4), the genetic factors affected individual differences in sequential processing and achievement at 42 months but not at 60 months. On the other hand, the genetic factors did not affect individual differences in simultaneous processing at 42 months but did at 60 months. However, these contrasts should be interpreted with caution because the sample size at 60 months was relatively small for behavioral genetic analyses.

Discussion

This study showed that genetic and environmental factors contribute to changes from 42 to 60 months of age. The effects of genetic factors decreased (or disappeared) and that of shared environmental factors emerged (or increased) with respect to sequential processing and achievement. On the other hand, the genetic impact on simultaneous processing increased. These heterogeneous results may be

Table 5. Results of univariate genetic analyses and model selections: Sequential processing

42 months	ACE	**AE**	CE	E
A	0.54 (0.00, 0.71)	0.54 (0.29, 0.71)	—	—
C	0 (0.00, 0.46)	—	0.39 (0.18, 0.56)	—
E	0.47 (0.29, 0.71)	0.47 (0.29, 0.71)	0.61 (0.44, 0.82)	1 (1, 1)
χ^2	8.29	8.29	11.60	23.86
df	3	4	4	5
p	0.04	0.08	0.02	0.00
AIC	2.29	0.29	3.60	13.86
RMSEA	0.22	0.17	0.22	0.30
60 months	ACE	AE	**CE**	E
A	0.12 (0.00, 0.73)	0.65 (0.44, 0.79)	—	—
C	0.51 (0.00, 0.73)	—	0.59 (0.40, 0.74)	—
E	0.38 (0.22, 0.59)	0.35 (0.21, 0.56)	0.41 (0.26, 0.60)	1 (1, 1)
χ^2	0.65	3.53	0.81	
df	3	4	4	
p	0.89	0.47	0.94	
AIC	-5.35	-4.47	-7.19	
RMSEA	0.00	0.06	0.00	

Note: Best fit models were indicated by bold letters. A: variance estimates of genetic factor. C: variance estimates of shared environmental factor. E: variance estimates of nonshared environmental factor. 95% confidential intervals were shown in parentheses.

attributable to the limited size of the sample. Many facets of cognitive abilities tend to be interrelated and associated with overlapping genetic factors (Kovas & Plomin, 2006). Furthermore, data from both assessments were available for relatively few pairs (MZ: 12 pairs, DZ: 18 pairs). Our forthcoming challenges will include simultaneous/multivariate and longitudinal analyses.

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Table 6. Results of univariate genetic analyses and model selections: Simultaneous processing

42 months	ACE	AE	**CE**	E
A	0.12 (0.00,0.56)	0.68 (0.54, 0.78)	—	—
C	0.53 (0.12, 0.72)	—	0.62 (0.49, 0.73)	—
E	0.35 (0.23, 0.50)	0.32 (0.22, 0.46)	0.38 (0.27, 0.51)	1 (1, 1)
χ^2	5.50	11.50	5.87	58.34
df	3	4	4	5
p	0.14	0.02	0.21	0.00
AIC	-0.50	3.50	-2.13	48.34
RMSEA	0.11	0.15	0.07	0.45
60 months	ACE	**AE**	CE	E
A	0.63 (0.00, 0.81)	0.67 (0.46, 0.81)	—	—
C	0.05 (0.00, 0.61)	—	0.55 (0.34, 0.70)	—
E	0.33 (0.19, 0.55)	0.33 (0.19, 0.54)	0.45 (0.30, 0.66)	1 (1, 1)
χ^2	2.96	2.97	6.34	27.11
df	3	4	4	5
p	0.40	0.56	0.18	0.00
AIC	-3.05	-5.03	-1.66	17.11
RMSEA	0.05	0.00	0.14	0.35

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Table 7. Results of univariate genetic analyses and model selections: Achievement

42 months	**ACE**	AE	CE	E
A	0.51 (0.19, 0.85)	0.81 (0.72, 0.88)	—	—
C	0.30 (0.00, 0.57)	—	0.65 (0.53, 0.75)	—
E	0.19 (0.12, 0.31)	0.19 (0.12, 0.28)	0.35 (0.25, 0.47)	1 (1, 1)
χ^2	14.03	16.77	23.24	82.03
df	3	4	4	5
p	0.00	0.00	0.00	0.00
AIC	8.03	8.77	15.24	72.03
RMSEA	0.26	0.24	0.30	0.54
60 months	ACE	AE	**CE**	E
A	0.20 (0.00, 0.64)	0.82 (0.69, 0.89)	—	—
C	0.62 (0.18, 0.84)	—	0.76 (0.63, 0.85)	—
E	0.19 (0.11, 0.34)	0.18 (0.11, 0.31)	0.24 (0.15, 0.37)	1 (1, 1)
χ^2	0.31	6.69	1.59	52.05
df	3	4	4	5
p	0.96	0.15	0.81	0.00
AIC	-5.69	-1.31	-6.41	42.05
RMSEA	0.00	0.13	0.00	0.57

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