



Genetic and Environmental Sex Differences in Mental Rotation Ability: A Japanese Twin Study

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Sex differences in mental rotation ability have been observed in many countries. A previous study of Finnish participants reported that genetic and environmental influences on mental rotation ability differ between sexes. In this study, we assessed genetic and environmental influences on variance in mental rotation ability in 649 Japanese twins using a mental rotation test. To explain the influence of sex on variance in mental rotation ability, we applied genetic analysis using the sex limitation model. The following two factors explained variance in mental rotation ability: (1) the additive genetic factor, which reflects the accumulated small influence of many genes, and (2) the unique environmental factor, which is a type of environmental factor that differs between co-twins. The shared environmental factor, a type of environmental factor common for co-twins, could not explain the variance in mental rotation ability. Furthermore, the additive genetic factor was the same between sexes (i.e., not qualitative sex differences for the additive genetic factor), indicating that the same genes affect mental rotation ability in both sexes. Despite this observation, the additive genetic influence was greater in males than in females. In contrast, the unique environmental influence was not different between sexes. Considering the current results and those of a previous study, the quantitative sex difference for the additive genetic influences in mental rotation ability may be universal, while the unique environmental differences may depend on the characteristics of specific populations.

■ **Keywords:** mental rotation, variance, sex differences, genetic and environmental factors, twin

Sex differences in spatial ability, especially mental rotation, have been noted. Mean mental rotation scores achieved by males were reported to be higher than those for females (Kimura, 1999). The degree to which sex influences mental rotation scores is mediated by testosterone level (Gouchie & Kimura, 1991; Moffat & Hampson, 1996; Thilers et al., 2006), socioeconomic status (Levine et al., 2005), sex role (Saucier et al., 2002), experience with computer games (Quaiser-Pohl et al., 2006; Terlecki & Newcombe, 2005), and other social factors, such as nationality (Lippa et al., 2010; Silverman et al., 2007).

Recently, sex differences in variations in mental rotation ability have been explained by both genetic and environmental effects (Vuoksima et al., 2010). The results of this study showed that although genetic and environmental factors were the same between sexes, the degree to which these factors influenced mental rotation ability was sex-dependent. These results suggest that the same genes and same environmental situations affect mental rotation ability of males and females to different degrees. However,

the results of Vuoksima et al. (2010) may not be generalizable to other cultural populations. In the study of behavioral genetics, the degree of genetic and environmental effects on a phenotype sometimes changes among groups. The genetic effect of cognitive ability for an Egyptian sample (Abdel-Rahim et al., 1990) was smaller than that for Western samples (Alarcón et al., 1999; Finkel et al., 1995; Johnson et al., 2007; Rijdsdijk et al., 2002) and a Japanese sample (Shikishima et al., 2008).

With regard to mental rotation ability, variances in mental rotation scores have been examined only in Western samples and not in other nationalities, while sex differences in mean mental rotation scores have been

RECEIVED 15 November, 2010; ACCEPTED 14 April, 2011.

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observed in populations of many nationalities, and the degree of sex differences differ among the nationalities (Lippa et al., 2010; Silverman et al., 2007). Moreover, it has been reported that cognitive styles (i.e., the way people think about things), are mediated by cultural differences among different nationalities (Na et al., 2010). There is a possibility that cognitive styles may affect mental rotation scores. Therefore, the degree to which genetic and environmental factors contribute to variations in mental rotation ability may depend on culture. However, to date, genetic and environmental influences on mental rotation ability have been examined only in Western populations.

In the current study, genetic and environmental influences on mental rotation abilities were assessed in Japanese twins. Twins were used because analysis of twin data allows total variance to be decomposed into genetic and environmental variances (Neale & Maes, 2004). In the sex limitation model, which is one type of genetic model using twin data, the influence of quantitative and qualitative sex differences in a phenotype can be examined in terms of genetic and environmental factors (Neale et al., 2006). Quantitative, *scalar*, sex differences resulted from differential genetic and environmental influences of the same genetic and environmental factors. In contrast, qualitative, *non-scalar*, sex differences resulted from different genetic and environmental factors. In this study, quantitative and qualitative sex differences were examined for genetic and environmental effects on mental rotation ability in a Japanese population.

Materials and Methods

PARTICIPANTS

Twins in late adolescence and early adulthood ($N = 649$), recruited using the Keio Twin Study registry (Shikishima et al., 2006), participated in this study. All participants who reported histories of neurological injury and/or mental disorder were excluded. A standard questionnaire (Ooki & Asaka, 2004) and DNA microsatellite analysis were used to determine zygosity. A total of 160 monozygotic female (MZf), 61 monozygotic male (MZm), 40 dizygotic female (DZf), 26 dizygotic male (DZm), and 32 opposite sex (DZo) twin pairs were included. In addition, three MZf, two MZm, two DZf, and four female DZo single twins participated in the study. However, their co-twins' data were not obtained. Data from single twins were included in calculations of the mean and variance in mental rotation scores but were not included in analyses of covariance between co-twins (Neale & Maes, 2004). The mean ages of twin participants were 21.6 ($SD = 3.8$), 20.5 ($SD = 4.1$), 21.7 ($SD = 3.7$), 21.7 ($SD = 4.5$), and 19.8 ($SD = 3.2$) for MZf, MZm, DZf, DZm, and DZo, respectively. All participants provided informed consent prior to initiation of experimental procedures.

PROCEDURES

We conducted the mental rotation study at Keio University in a room divided into two sections. Co-twins took the mental rotation test in separate sections of the room. We measured each participant's mental rotation performance using a paper-and-pencil test (Vandenberg & Kuse, 1978) consisting of 20 items. Each item had five 3-dimensional figures drawn in two dimensions, including one criterion figure, two correct stimuli that corresponded to the criterion, and two incorrect stimuli. For each item, participants were asked to select the two correct stimuli. Participants were given three minutes to solve the first 10 items and another three minutes for the second 10 items of the mental rotation task. They were asked to complete the tasks as quickly as possible.

DATA ANALYSIS

Mean and Variance of Mental Rotation Scores

Twin participants' performances in the mental rotation test were quantified for each item as the number of selections of both correct stimuli. For analysis of sex differences in the mean and variance of mental rotation scores, structural equation modeling was used because this method permitted description and selection of the best statistical model to explain sex differences among the possible models. In this study, there were four models of the mean and the variance for each sex. In model 1, the mean and variance of mental rotation scores were different between sexes. In model 2, the mean of the mental rotation score was identical between sexes. In model 3, the variance of the mental rotation score was identical between sexes. In model 4, neither the mean nor the variance of mental rotation scores showed sex differences. To evaluate the comparative fit of these four models, we used Akaike's information criterion (AIC), Bayes information criterion (BIC), and $\Delta\chi^2$ values between model 1 and the other models.

Sex Differences in Genetic and Environmental Influences

To estimate the similarity between co-twins in mental rotation scores for each zygosity, we used the double entry method and calculated the Pearson's product-moment correlation coefficient. To investigate genetic and environmental influences on mental rotation ability, we calculated residual mental rotation scores by controlling for statistically significant main effects of age and sex and a significant interaction between age and sex. Residual scores are generally used in genetic modeling (Neale & Maes, 2004). We tested the main effect of age and sex and the interaction effect by using an analysis of covariance (ANCOVA). In the analysis, age was treated as a continuous factor. By contrast, sex was treated as a discrete factor.

The twin method allowed us to decompose the variance in mental rotation scores into two genetic and two environmental components. One genetic component was

the additive genetic factor (A), reflecting the combined contribution of many genes to the trait. The other genetic component was the non-additive genetic factor (D), representing interactions between different alleles at the same locus or between different genes at different loci. The two environmental components included the shared environmental factor (C), reflecting nongenetic similarities between co-twins, and the unique environmental factor (E), describing nongenetic differences between co-twins. The unique environmental variance included measurement error variance. In our dataset, D and C were not able to be simultaneously treated in the same genetic model (i.e., the ACE model or the ADE model) because only three equations were available from the variance and covariance of monozygotic and dizygotic twins.

We used the sex limitation model (Neale et al., 2006) to investigate the contribution of sex differences to the variance in mental rotation scores. The sex limitation model examines the influence of two types of sex differences (i.e., quantitative and qualitative) on genetic and environmental variance (Figure 1). The model treats quantitative sex differences as sex-dependent path coefficients of paths from the genetic and environmental factors to a phenotype. For example, a difference between a_f and a_m in Figure 1, which represents female and male path coefficients from A to a measured variable (i.e., phenotype), indicates sex differences in the degree of expression of the same additive genetic factor. The model also represents qualitative sex differences in a measured variable by the correlation coefficients of the genetic and shared environmental factors for each DZo pair. In Figure 1, for the DZo pair, r_g (the genetic correlation coefficient) and r_c (the shared environmental correlation coefficient) indicate qualitative sex differences in genetic and shared environmental factors. Values of r_g and r_c below one indicate that the different genetic and/or shared environmental factors affect a measured variable between sexes.

Using the sex limitation model, we conducted genetic analyses in two steps. First, we examined how qualitative sex differences contributed to the variance in mental rotation scores. We calculated AIC and BIC values to evaluate the fit of the ACE, ADE, AE, CE, and E models with or without qualitative genetic and shared environmental sex differences. In this analysis, path coefficients of the paths from genetic and environmental factors to mental rotation

scores were allowed to differ between sexes. Second, using the best fitting model selected in the first analysis, we examined the contributions of quantitative sex differences to the variance in mental rotation scores. We tested the fit of nested models of the best fitting model by constraining each parameter of genetic and environmental factors to be equal between sexes. To compare the fit of these models, we calculated AIC, BIC, and $\Delta\chi^2$ values between the full model and nested models.

Results

For our study sample, we found that the Cronbach's alpha value of mental rotation scores was .83. The mean mental rotation scores were 7.16 ($SD = 3.86$) for females and 10.93 ($SD = 4.64$) for males. The structural equation modeling analysis revealed that model 1 best fit the mean and variance of mental rotation scores (Table 1). Thus, sex differences contributed to the mean and variance of these scores. Correlation coefficients between co-twins of monozygotic twin pairs were larger than those of dizygotic twin pairs (MZf, .44; MZm, .51; DZf, .22; DZm, .20; DZo, .35), which indicates substantial genetic influences on mental rotation scores for both sexes.

We tested the influence of age and sex on mental rotation scores using an ANOVA, which revealed statistically significant main effects of age, $F(1, 646) = 16.62$, $MSE = 16.71$, $p < .001$ and sex, $F(1, 646) = 108.12$, $MSE = 16.71$, $p < .001$, and a significant interaction between age and sex, $F(1, 646) = 3.36$, $MSE = 16.71$, $p < .1$. For the subsequent genetic modeling, we obtained residual mental rotation scores by controlling for the main effects of age and sex and the interaction between age and sex.

As shown by the results of the sex limitation model in Table 2, the AE model, which omitted qualitative sex differences (i.e., the r_g value of 1 in Figure 1), best fit the data. Accordingly, it was revealed that the genetic factor for mental rotation ability did not differ between sexes.

To test quantitative sex differences, the AE model with sex-dependent path coefficients was considered as the full model, and sex differences in the path coefficients from the additive genetic factor and the unique environmental factor were tested in the nested models. As indicated in Table 3, the best fitting model was the model with different path coefficients from the additive genetic factor, but

TABLE 1

Fit of Models Comparing Mean and Variance in Mental Rotation Scores

Model	$\Delta\chi^2$	Δdf	p	AIC	BIC
Model 1: $M_{\text{female}} \neq M_{\text{male}}$ $\sigma_{\text{female}} \neq \sigma_{\text{male}}$				2380.30	-253.18
Model 2: $M_{\text{female}} = M_{\text{male}}$ $\sigma_{\text{female}} \neq \sigma_{\text{male}}$	89.86	1	< .001	2468.16	-211.48
Model 3: $M_{\text{female}} \neq M_{\text{male}}$ $\sigma_{\text{female}} = \sigma_{\text{male}}$	10.01	1	< .01	2388.32	-251.41
Model 4: $M_{\text{female}} = M_{\text{male}}$ $\sigma_{\text{female}} = \sigma_{\text{male}}$	118.58	2	< .001	2494.88	-200.36

Note: Bold indicates the best fitting model. M_{female} = female mean, M_{male} = male mean, σ_{female} = female variance, σ_{male} = male variance

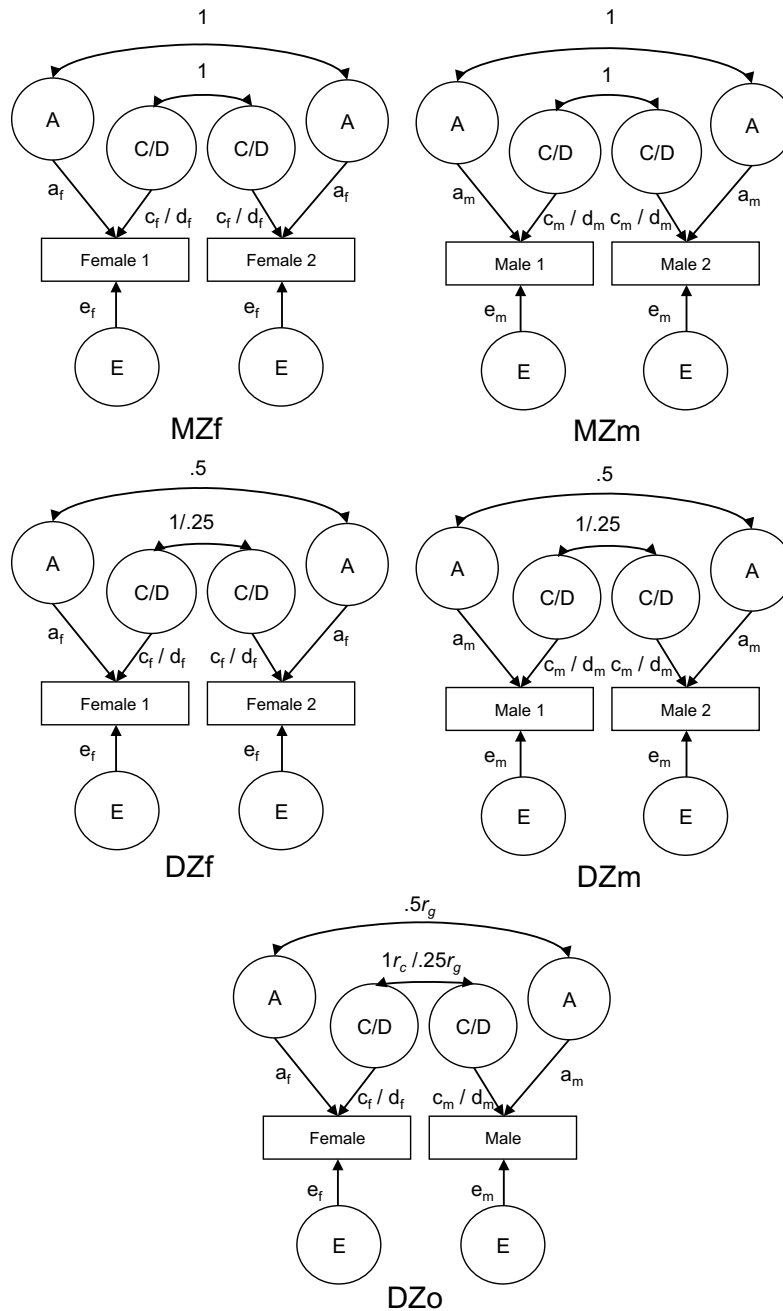


FIGURE 1

Explanation of the sex limitation model.

Note: a_f = path coefficient from the additive genetic factor to female score, a_m = path coefficient from the additive genetic factor to male score, c_f = path coefficient from the shared environmental factor to female score, c_m = path coefficient from the shared environmental factor to male score, d_f = path coefficient from the non-additive genetic factor to female score, d_m = path coefficient from the non-additive genetic factor to male score, e_f = path coefficient from the unique environmental factor to female score, e_m = path coefficient from the unique environmental factor to male score. A = the additive genetic factor, C = the shared environmental factor, D = the non-additive genetic factor, E = the unique environmental factor.

an equal path coefficient from the unique environmental factor between sexes. Figure 2 shows a path diagram of the best fitting AE model, including quantitative genetic sex differences only. Non-standardized path coefficients from the additive genetic factor to females' and males' mental rotation scores were 2.34 and 3.53, respectively. These results suggest that sex differences in the additive genetic

variances are responsible for differences in the total variance in mental rotation scores between sexes. In addition, the path coefficients of both sexes from the unique environmental factor to the score were 2.96. All path coefficients in the best fitting model were statistically significant (none of the 95% confidential intervals included zero values).

TABLE 2

Fit of Models Comparing the Inclusion or Exclusion of Qualitative Genetic and Shared Environmental Influences

Model	AIC	BIC
ACE and $r_g < 1$	2309.56	-62.83
ACE and $r_c < 1$	2309.56	-62.83
ACE	2307.56	-65.73
ADE and $r_g < 1$	2309.81	-62.70
ADE	2307.81	-65.60
AE and $r_g < 1$	2305.81	-68.50
AE	2303.81	-71.40
CE and $r_c < 1$	2309.35	-66.73
CE	2307.36	-69.63
E	2354.78	-49.72

Note: Bold indicates the best fitting model. A = the additive genetic factor. C = the shared environmental factor. D = the non-additive genetic factor. E = the unique environmental factor.

Discussion

In this study, we examined the contribution of sex to variances in mental rotation scores by comparing genetic and environmental influences between sexes. We found that the contribution of genetic factors to the variance was smaller for females than for males. For females, the degree of the genetic influence was smaller than the unique environmental influence, while for males, the degree of the genetic influence was larger than the unique environmental influence.

In contrast, sex differences in genetic factors (i.e., qualitative sex differences) were not observed in this study. Previous studies suggest that brain functions and brain structures may underlie sex differences in performance in cognitive ability tests such as a mental rotation task (Butler et al., 2007; Clements-Stephens et al., 2009; Deary et al., 2010). Although the relationships between genes and neural activities are complicated and have yet to be well identified, our results may provide support for the idea that neural activities associated with mental rotation performance in the same cortical regions differ between males and females, but do not support the idea that there are different cortical regions associated with mental rotation ability between sexes.

The results of this study are somewhat consistent with those of Vuoksima et al. (2010). Although the latter study examined a Finnish sample and we examined a Japanese sample, the best-fitting model for both populations was the AE model. Additionally, variance in mental rotation ability was not mediated by sex differences in genetic factors. However, the contribution of genetic factors to the variance was greater for males than for females for both populations. In contrast, the contribution of unique environmental factors to the variance in mental rotation ability was equal between sexes in the Japanese sample of the current study but not in the Finnish sample of the previous study. This discrepancy suggests that the envi-

ronmental contribution to variance in mental rotation ability is sensitive to group differences such as nationality, with regard to sex differences in mental rotation ability. The differential sensitivity of unique environmental effect may explain the effects of nationality on the degree to which sex differences influence mental rotation ability (Lippa et al., 2010; Silverman et al., 2007). To examine the interaction between nationality and sex, focused investigations of unique environmental factors that differ between nationalities are needed.

The shared environmental factor, which makes co-twins alike irrespective of genetic relatedness, did not significantly contribute to the variance in mental rotation ability for either sex. In addition, no quantitative sex differences in the unique environmental influence on mental rotation ability were observed in this study. In contrast to the current and Finnish (Vuoksima et al., 2010) results yielded from genetic analysis, several studies have reported that family and social factors affect the impact of sex on mental rotation ability (Levine et al., 2005; Lippa et al., 2010; Silverman et al., 2007). The divergent results may indicate a gene-environment correlation (Rutter, 2006): the genetic contribution to mental rotation ability may be mediated by family and social factors. For example, an environment associated with mental rotation ability may be selected by other behaviors affected by genes. Thus, the genes may influence mental rotation ability via their environment.

In this study, we clearly showed that the degree of the genetic influence in mental rotation ability differs between sexes. In contrast, qualitative sex differences in genetic factors were not detected. This might be because of a statistical flaw caused by the relatively small sample size of DZ twin participants. Nonetheless, at least our data clearly indicate quantitative sex differences because of the ample sample size of MZ and DZ twin participants.

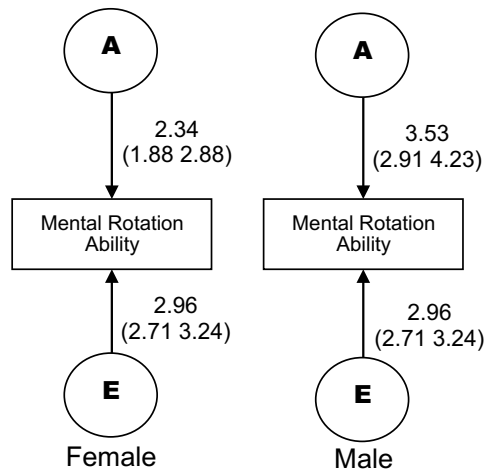
In conclusion, this study provides the first evidence of quantitative sex differences in genetic, but not environmental, influences on mental rotation ability, and does so by using a Japanese sample. Future investigations of the

TABLE 3

Fit of AE Models Comparing the Inclusion or Exclusion of Quantitative Genetic and Environmental Influences

AE model	$\Delta\chi^2$	Δdf	p	AIC	BIC
$a_f \neq a_m, e_f \neq e_m$				2303.81	-71.40
$a_f = a_m, e_f \neq e_m$	4.85	1	.03	2306.66	-71.88
$a_f \neq a_m, e_f = e_m$	0.75	1	.39	2302.56	-73.93
$a_f = a_m, e_f = e_m$	11.79	2	< .01	2311.60	-71.31

Note: Bold indicates the best fitting model. a_f = path coefficient from the additive genetic factor to female score, a_m = path coefficient from the additive genetic factor to male score, e_f = path coefficient from the unique environmental factor to female score, e_m = path coefficient from the unique environmental factor to male score.

**FIGURE 2**

Path diagram of the best-fit model.

Note: Left and right figures in parenthesis represent the lower and upper limit of 95% confidence intervals around the path coefficient, respectively. A = the additive genetic factor. E = the unique environmental factor.

influence of a gene–environment correlation on variances in mental rotation ability should be considered.

Acknowledgments

This study was supported in part by Grant-in-Aid for Scientific Research (B) (16330133) by the Japanese Ministry of Education, Culture, Sports, Science and Technology. We are grateful to the twins who participated in the present study. Additionally, we thank Dr. Shinji Yamagata for his useful comments and Mr. Hiroshi Maruyama for his help in conducting the test.

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