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Genetic Covariation Among Facets of Openness to Experience and General Cognitive Ability

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Genetic and environmental sources of covariation among cognitive measures of verbal IQ, performance IQ (PIQ), academic achievement, 2-choice reaction time (CRT), inspection time (IT) and the 6 Openness facets of the NEO Personality Inventory-Revised (NEO PI-R) were examined. The number of twin and twin–sibling pairs ranged from 432 (182 MZ, 350 DZ/sibling) to 1023 (273 MZ, 750 DZ/sibling) for cognitive measures, and between 432 (90 MZ, 342 DZ/sibling) — 437 (91 MZ, 346 DZ/sibling) for Openness facets. Structural equation modeling best supported a model with a 3-factor additive genetic structure. A genetic general factor subsumed the 5 cognitive measures and 5 of the 6 Openness facets (Actions did not load significantly). A second additive genetic factor incorporated the 6 Openness facets, and a third additive genetic factor incorporated the 5 cognitive measures. Specific additive and dominance genetic effects were also evident, as were shared common and shared unique environmental influences, and specific unique environmental effects. The Openness facets of Ideas and Values evidenced the strongest phenotypic correlations with cognitive indices, particularly verbal measures. The genetic correlations among Openness facets and cognitive measures ranged from –.06 to .79. Results were interpreted as suggesting that Openness is related to general cognitive ability (*g*) through a genetic mechanism and that *g* engenders a minor but discernable disposition towards Openness for the majority of facets.

There has been growing interest in clarifying the relationship between openness to experience (Openness) and cognitive measures such as IQ and basic mental speed tasks (e.g., Bates & Shieles, 2003; Chamorro-Premuzic et al., 2005; Gignac et al., 2004). Recent evidence has indicated that measured aspects of Openness (facets) may be related to general cognitive ability (*g*; Chamorro-Premuzic, et al., 2005; Gignac, 2005; Gignac et al., 2004), suggesting that shared genetic influences may be implicated. In this article, we examine genetic and environmental structures underpinning relationships among the six facets of the Openness domain of the Revised NEO Personality Inventory (NEO PI-R) and cognitive variables including Verbal IQ (VIQ) and Performance IQ (PIQ), academic achievement (Queensland Core Skills Test [QCST]), and two measures of processing speed, choice reaction time (CRT), and inspection time (IT).

Openness is one of five core domains of personality defined by the NEO PI-R. It is composed of six facets characterized by:

1. appreciation of art, poetry, music, and beauty (Aesthetics)
2. engagement of one's imagination (Fantasy)
3. valuing of emotion, and the experiencing of more intense emotions (Feelings)
4. involvement in varied experiences, and enjoyment of novelty (Actions)
5. pursuit of a manifold array of cultural and intellectual interests (Ideas)
6. questioning of conventional norms and receptivity to unconventional principles (Values; Costa & McCrae, 1992).

In contrast to an abundance of studies of heritability of *g*, which indicate the average heritability is 50% (Plomin, 2003), there are relatively few studies investigating genetic influences on Openness. In studies that have been conducted, heritability estimates of between approximately 40% to 80% have been reported for total Openness (e.g., Bergeman et al., 1993; Borkenau et al., 2001; Jang et al., 1996; Riemann et al., 1997). For the six facets that make up Openness, heritability estimates have fallen between approximately 30% to 60% (Jang et al., 1996, 1998, 2002), although Jang and colleagues (1996) found that environmental influences alone adequately

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accounted for variation in Feelings. For some facets, nonadditive genetic effects in which interacting genes at either the same or different loci produce over/under additive influences have been evidenced (Jang et al., 1996).

Investigation of the genetic architecture of Openness has suggested a two-factor structure (Jang et al., 2002), with general Openness subsuming all six facets, and a second factor subsequently termed Objective Openness (Gignac et al., 2004) incorporating only Actions, Ideas and Values. This factor structure was supported in a phenotypic analysis by Gignac et al. (2004) and by Gignac (2005) in a methodological refinement of the earlier Gignac and colleagues (2004) study.

One explanation for the consistent positive relationship between Openness and IQ is that higher Openness scores reflect greater engagement in activities that increase cultural knowledge resulting in elevated performance on knowledge based indices of intelligence (crystallized abilities) such as Information and Vocabulary (Bates & Rock, 2004). This view derives from findings that Openness consistently correlates about .3 with Verbal IQ (incorporating knowledge items; see Bates & Shieles, 2003), while correlating less consistently with Performance IQ (PIQ; nonverbal, fluid reasoning tasks which are less knowledge dependent). When statistically significant correlations are observed between Openness measures and PIQ they are typically weaker than for VIQ (e.g., Ashton et al., 2000). One limitation of this straightforward interpretation is that knowledge based tests load highly on a *g* factor (Jensen, 1998), indeed typically more strongly than PIQ measures (Gignac, 2006) and hence the relationship between Openness and VIQ incorporates both general and crystallized abilities (Gignac et al., 2004).

Gignac et al. (2004) and Gignac (2005) reported that Objective Openness, but not general Openness, correlated only with *g*, and not with crystallized ability once *g* had been partialled out. Chamorro-Premuzic et al. (2005) reported a significant positive correlation between total Openness and Raven's Progressive Matrices (RPM). They also described significant correlations for three of the Openness facets (Aesthetics, Ideas, and Values) and RPM. These findings are important because RPM is held to be a virtually pure measure of *g* (Jensen, 1998), reflecting domain independent fluid reasoning that is theoretically independent of Openness (Bates & Shieles, 2003). Thus, these findings militate against an explanation that the sole mechanism of the relationship between Openness and IQ is increased declarative knowledge arising from immersion in particular cultural/intellectual pursuits, and suggests that a more fundamental relationship between cognitive abilities and Openness may exist. As such, the relationship with *g* may, at least in part, be genetically mediated.

Academic achievement is a phenotype that shows a consistent positive correlation with IQ (Jensen, 1998). To our knowledge the genetic relationship between Openness facets and academic achievement has not been previously investigated. However, there is evidence that Openness is phenotypically related to academic achievement, with Paunonen and Ashton (2001) reporting that grades in an undergraduate psychology course showed significant correlations with a number of Openness-related scales. The academic achievement measure used here is the QCST that exhibits a strong *g* loading and shows strong phenotypic and genetic correlation with IQ, particularly VIQ (Wainwright et al., 2005).

One way to further investigate the nature of the relationship of Openness with *g* is to incorporate assessment of various processing-speed tasks such as Choice Reaction Time (CRT) and Inspection Time (IT). CRT tasks typically involve the presentation of multiple potential stimuli, for example; two, four or eight lights presented in a structured array, any one of which may illuminate from trial to trial. The respondent must press an appropriate key that corresponds in some way to the particular active stimuli. Thus the task entails making a decision about which key to press and providing an appropriate motor response to that decision.

IT typically requires simple perceptual discrimination. For example, judging which is the longer of two adjacently presented lines. Performance on IT is measured by the minimum presentation time required to reach a predefined level of accuracy. CRT and IT tasks are not cognitively complex and bear little surface relationship with IQ test items. Nevertheless, average correlations derived from meta-analyses of IQ with CRT and IT are −.3 and −.55 respectively (Jensen, 1987; Kranzler & Jensen, 1989) thus supporting theories in which rate of information processing is primary to *g*.

Recently, Bates and Shieles (2003) found Openness to be correlated with crystallized ability but uncorrelated with processing speed (IT), with support for a model in which Openness and *g* independently influence crystallized ability. However, it is important to note this study had a relatively small sample, which was composed solely of University undergraduates, and that crystallized ability was conflated with *g* (Gignac et al., 2004). In the present study, a larger sample is employed with a very broad range of cognitive ability. Additionally, the use of Structural Equation Modeling (SEM) for genetic analyses conforms with Gignac's (2005) recommendation of the use of SEM to most appropriately partition general and crystallized abilities.

Method

Participants

Data were available from 754 families, composed of twins and up to three siblings. The numbers of MZ,

Table 1
Number of Families for MZ, DZ and Sibling Pairings for Openness Facets and Cognitive Measures

		Twin pair	Twin pair + sibling (s)	Single twin + Sibling(s)	Sibling Pair
FA	MZ	64	26	8	12
	DZ	95	49	11	—
AE	MZ	65	26	7	11
	DZ	95	48	11	—
FE	MZ	64	27	7	12
	DZ	95	49	11	—
AC	MZ	64	27	7	12
	DZ	95	49	11	—
ID	MZ	64	27	11	12
	DZ	94	49	7	—
VA	MZ	64	26	8	12
	DZ	92	49	11	—
VIQ	MZ	209	61	—	—
	DZ	296	89	2	4
PIQ	MZ	212	61	—	—
	DZ	297	89	2	4
QCST	MZ	161	21	2	—
	DZ	169	39	10	2
RT	MZ	207	51	—	—
	DZ	265	76	2	3
IT	MZ	195	50	2	—
	DZ	267	74	3	4

Note: In addition to the above, data included between 165–167 unpaired individuals for Openness facets, and between 2–79 unpaired individuals for cognitive data. FA = Fantasy, AE = Aesthetics, FE = Feelings, AC = Actions, ID = Ideas, VA = Values, VIQ = verbal IQ, PIQ = performance IQ, QCST = Queensland Core Skills Test, CRT = mean of log 2-choice reaction time over 96 trials, IT = log inspection time.

DZ/sibling pairings for each variable are shown in Table 1. Potential participants were excluded if there was a history of significant head injury, neurological or psychiatric illness, substance dependence or current use of prescribed medication with central nervous system effects. Written consent was obtained from each participant and their parent/guardian prior to commencement of testing.

Procedure and Materials

Data collection took place as part of an ongoing study of cognition in adolescent twins and their siblings (Wright et al., 2001; Wright & Martin, 2004). At 16 years of age, twins (siblings typically 17 years old) attended the laboratory for testing of IQ, CRT, IT, and a range of other measures not analyzed here (e.g., behavioral and physiological indices of working memory). At this time twins and siblings (or guardians if < 18 years) gave permission for QCST results to be obtained from the Queensland Studies Authority (QSA), formerly the Queensland Board of Senior Secondary School Studies (QBSSSS). Data for QCST results were obtained annually following the administration and scoring of the QCST. The NEO PI-R (Form S) was included in a questionnaire mailed to 1406 participants aged between 17 and 28 years (three twin pairs and two individuals were inadvertently mailed questionnaires when 16 years old). Responses were received from 56% of these participants (mean age = 20.2 (±2) years).

Multidimensional Aptitude Battery

The MAB (Jackson, 1984) is a multiple-choice test of general intelligence and is well suited for projects using large numbers of participants (Vernon, 2000). The MAB was based on the WAIS-R (Wechsler, 1981) and yields VIQ, PIQ and FSIQ scores. The scales correlate strongly with their WAIS-R counterparts, with Jackson (1984) reporting correlations between the MAB and the WAIS-R of .94 for VIQ, .79 for PIQ and .91 for FSIQ. The scales also have acceptable test–retest reliabilities being equal to or above .95 as reported by Jackson (1984). Similar test–retest reliabilities (VIQ, .89; PIQ, .87; FSIQ, .90) were reported by Luciano (2001) using test–retest data from 50 twin pairs drawn from the same overall sample used here. Three subtests (vocabulary, information, and arithmetic) were used to assess VIQ and two subtests (spatial and object assembly) were used to assess PIQ. Further details regarding these subtests have been provided in previous papers from this laboratory (Luciano et al., 2001b; Wainwright et al., 2004).

Queensland Core Skills Test

The QCST is a test of academic achievement administered to the majority of Year 12 students in Queensland. The test is used to assess individual achievement and as a means of weighting academic performance according to subjects studied and school attended. The test is composed of four papers; the Writing Task (WT), two Multiple-Choice papers (MC 1 and MC 2), and Short Response questions (SR). The maximum score obtainable for the QCST varies slightly in some years due to fluctuations in the number and score value of items in the SR. The test covers a very broad range of scholastically acquired skills such as mathematical problem solving, comprehending, interpreting and explaining passages of prose, interpreting visual stimuli such as cartoons, photographs and flow charts, reading graphs, grasp of scientific methodology, spelling and basic calculations, understanding spatial and mechanical relationships, and producing written prose. While there are some basic skills tested such as spelling, the test primarily aims to assess higher order scholastic achievement such as reasoning, and synthesis and integration of data (Queensland Studies Authority, 2003). Substantial additional detail regarding the QCST is available in other papers produced from this laboratory (Wainwright et al., 2004, 2005) and from the QSA website (2005). While QCST participants are a biased sample of the cohort (academically less able students escape ascertainment by not sitting the QCST), the inclusion of IQ measures acts as a putative screening measure correcting for this bias (see Wainwright et al., 2005).

2-Choice Reaction Time

The CRT task was presented as dripping taps with the participant required to press the appropriate key (keyboard paradigm) to stop a given tap from dripping. CRT was sampled over 96 trials. Trials of less than 150ms or greater than 2000ms were excluded. As there was evidence of a minor speed–accuracy tradeoff, mean CRT was adjusted for proportion of correct responses in the means modeling of the genetic analyses (Luciano et al., 2001b).

Inspection Time

The IT task was presented as a pseudo-computer game with participants selecting the longer of two worms as fishing bait (Luciano et al., 2001a). The lines were 22 mm and 27 mm long and were 9 cm apart, joined by a horizontal bar of 12 mm atop the two stimulus lines. Presentation of the longer line on the left or right was equiprobable. A flash mask composed of two 37 mm lines shaped as lightning bolts was presented immediately after the stimulus for 300 ms to limit iconic processing (Evans & Nettleback, 1993).

Due to an expected wide range of IT, a Parameter Estimation by Sequential Testing (PEST) procedure was used (Findlay, 1978; Pentland, 1980) to allow efficient estimation from short to long IT. The staircase method was employed by which duration of each stimulus presentation (Stimulus Onset Asynchrony [SOA]) was adjusted according to the accuracy/inaccuracy of a participant's previous responses. As the PEST is sensitive to random responses and attentional lapses which introduce biases, IT was estimated by post hoc fitting of a cumulative normal curve (mean = 0) as a function of SOA. The standard deviation (*SD*) of this curve represents the point at which 84% accuracy occurs. Multiplication of the *SD* by the relevant Z score gives the SOA for any desired accuracy threshold (e.g., 1.64 for 95%; Luciano et al., 2001a).

Openness to Experience

Openness to Experience was measured using the NEO PI-R (Costa & McCrae, 1992). Simple composite scores were calculated for each of the six Openness facets of Fantasy, Aesthetics, Feelings, Actions, Ideas and Values. In cases where a single item was missing for a facet score the mean value according to sex was imputed.

Statistical Analysis

Data Screening

The individual observations were analyzed directly using the raw data option in the MX package (Neale, 1997) using maximum likelihood (ML) estimation procedures. All data were screened for normality, univariate and multivariate outliers using a conservative z score of ±3.5. On this basis, the mean value of log transformed CRT trials was taken. IT scores were also given a logarithmic transformation and 10 outlying log transformed IT scores were removed. Multivariate outliers were detected and removed for CRT (six families) and for Values (one family). To permit pooling of QCST data from different years, all QCST scores were standardized using the mean and *SD* of the total QCST population for each year. The mean IQ of NEO PI-R respondents was also compared to the mean IQ of the remainder of the sample to assess whether NEO PI-R respondents represented a biased subsample according to IQ. No substantive difference for Full Scale IQ (FSIQ) was observed between NEO PI-R respondents (m = 112.72) and the remainder of the sample (m = 111.91).

Testing Equality of Means, Variances and Covariances According to Zygosity, Sex and Education

To establish regularity in sampling and measurement the equalities of means and variances according to birth order and zygosity were tested. Equality of means according to sex and duration of education were tested for VIQ, PIQ, CRT and IT, and sex and age for QCST and Openness facets. The effect of session order on CRT and IT was also assessed. Equality of covariances between MZF and MZM and between DZF and DZM were tested to assess differences in the magnitude of genetic effects according to sex for the cognitive variables. Equality of covariance between same sex twin pairs and opposite sex twin pairs was examined to assess whether different genes were being expressed according to sex. Details on the method of assumption testing appear in previous papers published from this laboratory (e.g., Wainwright et al., 2004, 2005).

Multivariate Modeling

Dominance and common environment effects are negatively conflated and may not be simultaneously modeled for a given variable (Neale & Cardon, 1992). Inspection of MZ and DZ correlations indicated that dominance effects outweighed common environmental effects for the Openness facets of Fantasy, Feelings, Actions, and Ideas and thus dominance effects were modeled in these instances with common environment modeled for Aesthetics and Values. Common environmental effects were evident for VIQ, QCST and CRT, while there was an indication of slight dominance effects for PIQ and IT. However, dominance influences have not typically been evidenced for these measures (e.g., Luciano et al., 2004) and weak sibling correlations derived from somewhat small samples were implicated in the relatively low reported DZ correlations, particularly for IT. As such, common environment was modeled for all cognitive variables.

A Cholesky decomposition (ACDE, with separate Cholesky decompositions stipulated for C and D) was used as a base against which competing models were initially assessed (e.g., Rietveld et al., 2000). Three principal models were tested against the Cholesky decomposition. For additive genetic effects Model 1 stipulated a genetic general factor (incorporating all Openness facets and cognitive measures) as well as two genetic group factors, the first incorporating the six Openness facets, and the second incorporating the five cognitive measures. Specific additive genetic effects were also modeled for each variable. Consistent with previous research, for the cognitive measures a single common environment factor was stipulated, with a separate shared common environment factor applied to Aesthetics and Values. Two dominance genetic factors were stipulated, the first for Fantasy and Feelings being nonobjective Openness facets, and the second for Actions and Ideas being objective Openness facets. Unique environmental effects were stipulated as a Cholesky decomposition.

Model 2 was of the same form as Model 1 except that the genetic general factor was replaced by a genetic factor in which the six Openness facets and the two primarily verbal measures (VIQ and QCST) were incorporated. Model 3 was also of the same form as Model 1 except that the genetic general factor was replaced by a genetic factor that incorporated only the three objective Openness facets and the five cognitive measures. Thus the primary model comparisons were among an additive general genetic factor influencing general Openness and *g*, an additive genetic factor influencing general Openness and verbal cognitive measures, and an additive genetic factor influencing objective Openness and *g*.

Results

Assumption Testing

Females obtained significantly higher scores for Fantasy ($p < .05$), Aesthetics, Feelings, Actions, and Values (all $p < .001$). Males obtained significantly higher scores for VIQ and PIQ and showed shorter IT (all $p < .001$). There was no significant effect for sex on any other variables. Older age was associated with higher scores on Feelings, Ideas and Values (all $p < .05$). Months of education had a significant effect on VIQ and PIQ (all $p < .001$) with longer duration of education associated with higher VIQ and PIQ. Session order had a significant effect on CRT such that slower mean CRT was observed in session two compared to session one ($p < .001$). Significant differences in means were observed between twins and siblings for Fantasy, Aesthetics and QCST, with siblings obtaining higher mean Fantasy scores, Aesthetics scores (all $p < .05$) and QCST scores ($p < .005$). Based on the results of assumption testing, regression effects for sex (Fantasy, Aesthetics, Feelings, Actions, Values, VIQ, PIQ and IT), age (Feelings, Ideas and Values), duration of education (VIQ and PIQ), session order (CRT), and twin/sibling status (Fantasy, Aesthetics and QCST) were incorporated into the means modeling in subsequent analyses.

For Openness facets there was a significant difference in covariation between MZM and MZF for Ideas ($p < .001$) only. However, no significant difference was observed between DZM and DZF for this variable. This and the very small sample of MZM suggested that the disparity between MZM and MZF was a sampling anomaly. Differences in covariation between same-sex and opposite-sex DZ pairs were observed for Fantasy, sesthetics, and sctions (all $p < .05$). However, given the multiple covariance assumptions assessed (five covariance assumptions per variable) these differences were not significant. Additionally, the limited number of MZM for Openness facets would have provided inadequate power for sex specific effects. For cognitive variables there were no significant differences in covariation between MZM and MZF nor between DZM and DZF, nor between same-sex and opposite-sex DZ pairs. Thus sex limitation for differences in magnitudes of genetic effects or effects according to different genes were not incorporated. Unequal variances were found between males and females for both CRT and IT (all $p < .01$), with males exhibiting greater variance on both measures. Consequently scalar sex limitation by which the standardized variance components (e.g., heritability estimate) for males and females are constrained to be equal despite unequal variances (Neale & Cardon, 1992) was applied to both CRT and IT. Modeling of scalar sex limitation using twin and sibling data was achieved according to the parameterisation described by Medland (2004).

Phenotypic Analyses

Means (*SD*) and MZ and DZ correlations are shown in Table 2. Phenotypic correlations are shown in Table 3. Correlations among Openness facets ranged from .17 between Fantasy and Values to .47 between Aesthetics and Ideas. Correlations among the nonob-

Table 2

Means (*SD*) for Females and Males, and MZ and DZ/Sibling Correlations for Openness Facets and Cognitive Measures (Numbers of Pairings for Correlations are Shown in Parentheses)

	Mean (*SD*)		MZ	DZ/siblings
	Female	Male		
FA	19.93 (4.81)	19.21 (4.56)	.48 (90)	.13 (345)
AE	19.21 (5.30)	16.27 (5.33)	.32 (91)	.28 (344)
FE	21.70 (3.98)	19.17 (4.03)	.43 (91)	.16 (346)
AC	16.69 (3.44)	15.22 (3.54)	.45 (91)	.16 (346)
ID	19.36 (5.18)	19.49 (5.67)	.43 (91)	.10 (345)
VA	21.58 (3.37)	20.32 (3.79)	.58 (90)	.31 (342)
VIQ	109.19 (10.85)	111.42 (11.93)	.80 (270)	.48 (749)
PIQ	110.12 (16.54)	114.78 (15.72)	.72 (273)	.33 (750)
QCST	0.18 (0.99)	0.21 (1.02)	.86 (182)	.43 (350)
CRT	2.46 (0.04)	2.46 (0.05)	.61 (258)	.36 (652)
IT	1.92 (0.20)	1.88 (0.23)	.36 (245)	.11 (644)

Note: DZ/sibling correlations incorporates pairings between DZ twins, DZ twins and their siblings, siblings of DZ twins, and between MZ twins and their siblings, and siblings of MZ twins. FA = Fantasy, AE = Aesthetics, FE = Feelings, AC = Actions, ID = Ideas, VA = Values, VIQ = Verbal IQ, PIQ = Performance IQ, QCST = Queensland Core Skills Test, CRT = mean of Log 2-Choice Reaction Time over 96 trials, IT = Log Inspection Time.

Table 3

Phenotypic Correlations (ML) among the Openness Facets and Cognitive Measures

Measures	FA	AE	FE	AC	ID	VA	VIQ	PIQ	QCST	CRT
AE	0.42									
	(777)									
FE	0.40	0.45								
	(777)	(777)								
AC	0.22	0.27	0.19							
	(777)	(777)	(778)							
ID	0.26	0.47	0.38	0.26						
	(777)	(777)	(777)	(777)						
VA	0.17	0.25	0.22	0.20	0.28					
	(772)	(772)	(772)	(772)	(772)					
VIQ	0.11	0.16	0.20	0.00	0.40	0.26				
	(556)	(556)	(556)	(556)	(556)	(552)				
PIQ	0.07	0.10	0.13	0.00	0.28	0.17	0.51			
	(555)	(555)	(555)	(555)	(555)	(551)	(1502)			
QCST	0.12	0.18	0.24	0.07	0.42	0.32	0.82	0.56		
	(418)	(419)	(419)	(419)	(418)	(416)	(946)	(950)		
CRT	0.03	–0.10	–0.07	–0.01	–0.23	–0.09	–0.27	–0.23	–0.30	
	(555)	(555)	(555)	(555)	(555)	(551)	(1354)	(1358)	(951)	
IT	–0.04	–0.05	–0.07	0.00	–0.12	–0.09	–0.26	–0.33	–0.30	0.19
	(527)	(527)	(527)	(527)	(527)	(523)	(1391)	(1394)	(912)	(1274)

Note: Numbers of individuals are shown in parentheses.

In addition to the above, data included between 165–167 unpaired individuals for Openness facets, and between 2–79 unpaired individuals for cognitive data. FA = Fantasy, AE = Aesthetics, FE = Feelings, AC = Actions, ID = Ideas, VA = Values, VIQ = verbal IQ, PIQ = Performance IQ, QCST = Queensland Core Skills Test, CRT = CRT = mean of log 2-choice reaction time over 96 trials, IT = inspection time.

jective Openness facets, ranging from .40 to .45, were stronger than correlations among the objective Openness facets which ranged from .20 to .28. For Openness facets overall, Ideas and Values evidenced the strongest correlations with cognitive measures. Correlations tended to be stronger between Openness facets and verbal cognitive measures, with VIQ and QCST accounting for 16% and 18% of variation in Ideas respectively. While VIQ and QCST accounted for 7% and 10% of variation in Values. Ideas also evidenced the strongest Openness facet correlation with PIQ (8% of variation), and with the mental speed measures, explaining 5% and 1% of the variation in CRT and IT respectively. However, in general phenotypic correlations between Openness facets and mental speed measures were extremely weak with Openness facets typically accounting for less than 0.5% variation in CRT and IT.

Genetic Analyses and Model Fitting

Table 4 shows the various models that were fit to the data. A Cholesky decomposition was stipulated as a base against which competing models were compared. Model 1, which incorporated a general additive genetic factor, in conjunction with an additive genetic Openness factor, and an additive genetic factor incorporating the five cognitive measures alone, showed a satisfactory fit compared to the Cholesky decomposition. Both Model 2, in which the genetic general genetic factor from Model 1 was replaced by a genetic factor in which the six Openness facets and the two primarily verbal measures (VIQ and QCST) were incorporated, and Model 3, in which the genetic factor from Model 1 was replaced by a genetic factor which incorporated only the three objective Openness facets and the five cognitive measures, evidenced a statistically significant loss of fit in comparison with Model 1. Nonsignificant parameters were pruned from Model 1 resulting in the final model. Figure 1 shows path diagram with parameter estimates for genetic and environmental influences for this model.

The strongest loadings on the general genetic factor were for QCST (.80) and VIQ (.69). The strongest loadings on the general genetic factor for Openness facets were for Ideas (.51) and Values (.38). For the genetic Openness factor stronger loadings were generally evident for the non-objective Openness facets (Aesthetics, .50; Feelings, .45). The strongest loading for the factor incorporating the five cognitive measures only, was for IT (–.53). The shared dominance factor for Actions and Ideas accounted for 6% and 10% of their variances respectively. Specific genetic influences were not relevant to variation in Aesthetics and Ideas. However, specific genetic influences accounted for between 12% (Feelings) and 40%

Table 4

Competing Models for Factor Structure of Genetic, Common Environment, and Unique Environment Influences

Model	–2LL	*df*	Versus	Δ–2LL	Δ–*df*	*p* value
1 Cholesky Decomposition (ACDE)	70162.19	11195				
2. Three factor additive genetic model. Factor 1 influences the six Openness facets and the five cognitive measures	70219.68	11255	1	57.49	60	.57
3. Model 2 reduced	**70244.64**	**11298**	**2**	**24.96**	**43**	**.99**
4. Three factor additive genetic model. Factor 1 influences the six Openness facets and the verbal cognitive measures	70246.73	11258	2	27.05	3	< .001
5. Three factor additive genetic model. Factor 1 influences the three objective Openness facets and the five cognitive measures	70242.20	11258	2	22.52	3	< .001

Note: Model 1 incorporates an additive general genetic factor influencing general Openness and *g*. Model 2 incorporates an additive genetic factor influencing general Openness and verbal cognitive measures. Model 3 incorporates an additive genetic factor influencing objective Openness and *g*. A *p* value of < .05 indicates a significant loss of fit.

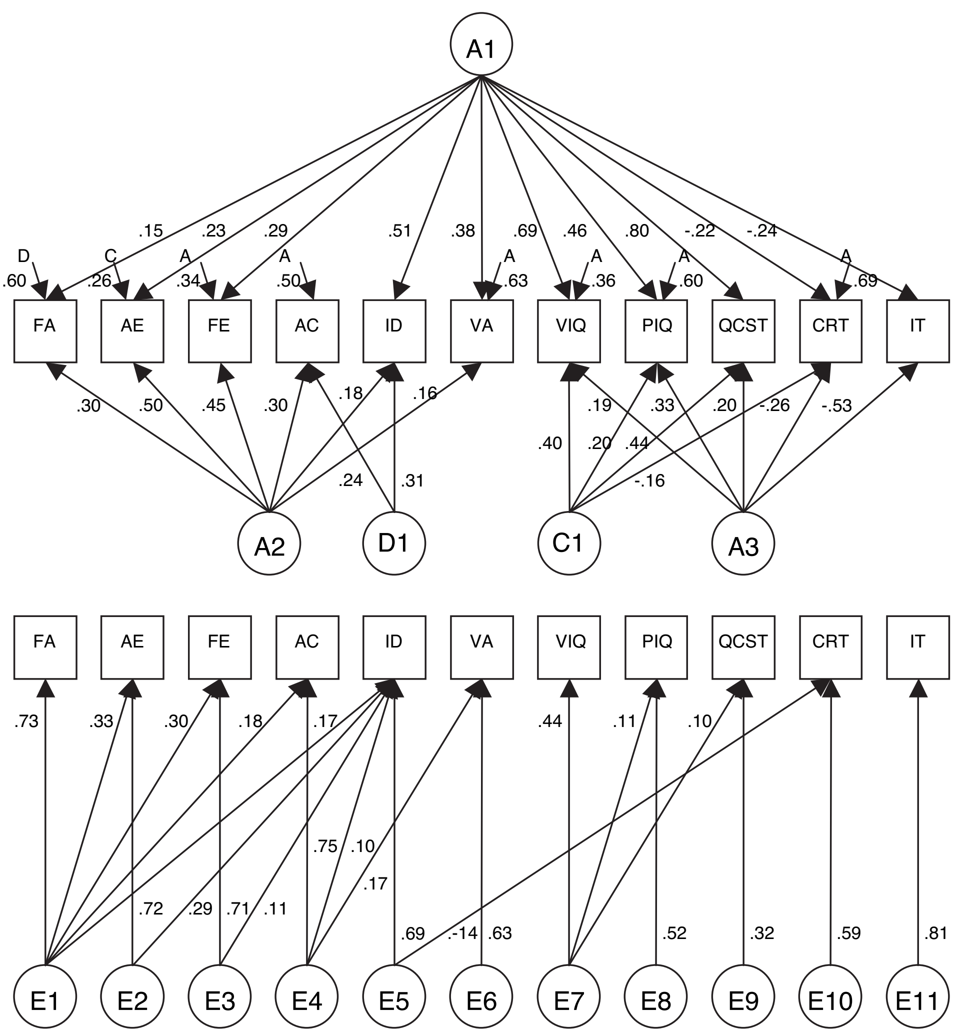

Figure 1

The upper path diagram shows genetic and common environmental influences.

Note: A1 represents an additive general genetic factor, A2 represents and additive genetic openness factor, and A3 represents an additive cognitive factor. D1 represents a shared dominance genetic factor, and C1 represents a shared common environment factor. Specific influences labeled A (additive genetic), D (dominance genetic) and C (common environment) are shown as arrows. The lower path diagram shows unique environmental influences. For clarity, for the unique environmental effects, only paths of value greater than 0.1 are shown. FA = Fantasy, AE = Aesthetics, FE = Feelings, AC = Actions, ID = Ideas, VA = Values, VIQ = Verbal IQ, PIQ = Performance IQ, QCST = Queensland Core Skills Test, CRT = CRT = mean of Log 2-Choice Reaction Time over 96 trials, IT = Inspection Time.

Table 5

Heritabilities (diagonal), Genetic Correlations (italics below diagonal) and Proportions of Covariation Accounted for by Genetic Factors Among the OpennessFacets and Cognitive Measures (above diagonal)

Measures	FA	AE	FE	AC	ID	VA	VIQ	PIQ	QCST	CRT	IT
FA	**.47**	.43	.45	.40	.51	.61	1.00	1.00	1.00	1.00	1.00
AE	*.48*	**.31**	.65	.56	.44	.67	1.00	1.00	1.00	.48	1.00
FE	*.41*	*.83*	**.40**	.69	.60	.85	1.00	1.00	1.00	.92	1.00
AC	*.20*	*.43*	*.33*	**.40**	.50	.24	.00	.00	.00	.00	.00
ID	*.31*	*.60*	*.58*	*.33*	**.39**	.80	.87	.83	.98	.49	1.00
VA	*.21*	*.41*	*.39*	*.10*	*.48*	**.56**	1.00	1.00	.95	.94	1.00
VIQ	*.19*	*.36*	*.40*	*.00*	*.70*	*.44*	**.64**	.75	.72	.73	1.00
PIQ	*.13*	*.23*	*.26*	*.00*	*.45*	*.28*	*.57*	**.68**	.77	.82	.87
QCST	*.22*	*.40*	*.45*	*.00*	*.79*	*.49*	*.89*	*.64*	**.68**	.76	.98
CRT	*–.06*	*–.12*	*–.13*	*.00*	*–.23*	*–.14*	*–.32*	*–.29*	*–.35*	**.60**	1.00
IT	*–.09*	*–.17*	*–.19*	*.00*	*–.33*	*–.21*	*–.56*	*–.59*	*–.61*	*.42*	**.34**

Note: FA = Fantasy, AE = Aesthetics, FE = Feelings, AC = Actions, ID = Ideas, VA = Values, VIQ = verbal IQ, PIQ = performance IQ, QCST = Queensland Core Skills Test, CRT = CRT = mean of log 2-choice reaction time over 96 trials, IT = inspection time.

(Values) of variation in the remaining Openness facets. For Openness facets, only for Aesthetics was there an effect of common environment, accounting for 7% of the variation. A shared common environment factor was pertinent to variation in four of the five cognitive measures (not IT) accounting for between 4% (CRT) and 19% (QCST) of their variation. Unique environmental effects were substantial for each of the Openness facets, and were also particularly strong for CRT and IT explaining 35% and 66% of their variances respectively.

Genetic correlations among Openness facets and cognitive measures ranged from .00 (Actions shared no genetic relationship with any cognitive variables) to .79 between Ideas and the QCST. Overall, Ideas evidenced the strongest genetic correlations with cognitive measures. The weakest genetic correlations among Openness facets and cognitive measures were with the mental speed measures ranging from .00 (Actions) to –.33 (between Ideas and IT). Heritabilities, genetic correlations and proportions of covariance accounted for by genetic factors are shown in Table 5.

Discussion

For the additive genetic structure three shared factors in addition to specific influences satisfactorily fit the data. The first factor was interpreted as genetic *g* (Plomin, 2003) due to its incorporation of the five cognitive measures in conjunction with the Openness facets of Fantasy, Aesthetics, Feelings, Ideas, and Values. The second shared factor was a general Openness factor that has been previously reported (Gignac, 2005; Gignac et al., 2004; Jang et al., 2002). The third shared additive genetic factor incorporated all the cognitive measures, with the strongest loading on IT. This factor may reflect aspects of *g* unrelated to Openness, or possibly attentional processes (Luciano et al., 2004), or a mental speed component due to the cognitive tests being timed. Overall, the genetic factor structure of the model suggests an independent set of genes which influences *g* and the majority of Openness facets, a second independent set of genes influencing Openness facets only, and a further independent set of genes influencing cognition independent of Openness.

Importantly, this genetic factor structure was better supported than a competing model in which Openness facets shared genetic variance with verbal measures alone. Likewise, it also provided a better fit than a model in which only objective Openness facets shared genetic variance with the five cognitive measures. Thus the findings are in line with previous reports indicating a relationship between Openness facets and *g* (e.g., Chamorro-Premuzic et al., 2005; Gignac, 2005; Gignac et al., 2004; Holland et al., 1995), and inconsistent with reports of Openness being only related to crystallized intelligence (Ashton et al., 2000; Bates & Shieles, 2003).

Gignac et al. (2004) and Gignac (2005) reported a relationship between objective Openness (Ideas, Actions, Values) and *g*, but found no relationship with general Openness. In contrast, we find a genetic relationship with *g* for two objective Openness facets (Ideas and Values) as well as the three nonobjective facets (Fantasy, Aesthetics and Feelings). However, it is notable that the strongest facet loadings on the genetic *g* factor were for objective Openness facets of Ideas and Values which also evidenced the strongest phenotypic correlations with cognitive measures. Our results are reasonably consistent with phenotypic findings by Chamorro-Premuzic et al. (2005) in which Aesthetics, Ideas and Values correlated significantly with RPM. The absence of a relationship between *g* and Actions in our and the Chamorro-Premuzic et al. (2005) study is interesting. It may be that Actions reflects a greater behavioral adventurousness, reflective of a broader sensation seeking, while Ideas and Values capture an inclination toward cognitive enterprize and intellectual independence. Also interesting is that Aesthetics is related, albeit weakly to *g* in both studies. One possibility is that there is a slight effect whereby deeper appreciation of artistic works facilitated by higher levels of *g* engenders greater aesthetic interests.

It is noteworthy that there is a general trend for Openness facets to correlate most strongly with the verbal measures, less strongly with PIQ and least strongly with the mental speed measures. This suggests that relationships between Openness facets and cognitive measures diminish as the cognitive measures become more 'biological'. However, it should be noted that relatively modest variation in both CRT (12%) and IT (34%) was due to general influences arising from the first and third additive genetic factors, with specific genetic effects (CRT) and unique environmental influences (CRT, IT) contributing substantially to their variance. The finding of a limited effect of genetic *g* on mental speed measures is not unusual having been previously reported from this laboratory and others (Luciano et al., 2004; Rijsdijk et al., 1998). Ideas clearly showed the strongest relationships with the two mental speed measures accounting for approximately 5% of the variance in the CRT and 1% of the variance in IT. This is not surprising as Ideas is the most obviously cognitively oriented facet in the Openness domain.

The precise mechanism of the joint effect of genetic *g* on cognitive indices and Openness measures is not immediately transparent from the present study. One possibility is known as mosaic pleiotropy in which *g* and aspects of Openness are both directly influenced by a particular set of genes. An alternative explanation is known as relational pleiotropy in which the genes impact directly on one variable which in turn influences the other variable (Allison et al., 1998). For instance, a set of genes influences *g* and higher *g* results in tendencies to engage in independent thought, and seek varied intellectual stimulation which is manifested in higher Openness facet scores. In contrast, the mechanism could run in the opposite direction such that the set of genes directly influences Openness, and then Openness influences *g*.

This latter possibility is of course essentially an environmental explanation for the relationship between Openness measures and *g* in which personality traits direct behaviors which increase measured IQ. However, because the genetic correlations between Openness facets and IQ measures is via a general genetic factor (rather than with crystallized measures alone) such an account is less tenable because *g* is theoretically uninfluenced by personality variables (Bates & Shieles, 2003; Jensen, 1998). It is suggested that the most reasonable explanation is that inherent in higher levels of *g* is a minor albeit demonstrable tendency towards Openness. This is consistent with the assertion of Gow et al. (2005) that 'the associations between personality and intelligence may occur early in development' (p. 760). It is possible that a more stringent examination of the competing hypotheses could be achieved in the future by using genetically informative data to compare models which specify different causal directions. However, we note that the absence of environmental correlation between Openness facets and IQ measures indicates limited potential for a good fitting causal direction model. Such analysis also requires a number of important conditions to be met including variables having markedly different modes of inheritance, there being sufficient sample size to distinguish between competing models, and the availability of test-retest data (Duffy & Martin, 1994; Heath et al., 1993).

Phenotypic and genetic relationships among Openness facets and VIQ and QCST were strikingly similar. The finding that Openness facets are related to academic achievement is consistent with the previous report from Paunonen and Ashton (2001). However, it should be noted that the QCST is strongly phenotypically correlated with VIQ and shares nearly all its genetic variance with VIQ (Wainwright et al., 2004) and such concordance is not surprising. Furthermore, the delineation of standardized measures of academic achievement and IQ tests remains contentious (Wainwright et al., 2004).

Genetic correlations among Openness facets and cognitive measures tended to be modest, reflecting the effects of specific genetic influences on both the majority of the Openness facets and cognitive measures. However, it is clear that there is a substantial genetic overlap between Ideas and cognitive measures, particularly verbal indices. The proportions of phenotypic correlations between Openness facets and cognitive measures accounted for by genetic influences typically ranged from moderate to strong, reflecting the absence of correlation engendered by common environment influences, and weak contributions to these correlations by shared unique environmental influences. Interestingly, correlations among the Openness facets themselves showed a much stronger contribution from shared unique environmental influences. Thus, idiosyncratic experiences appear to engender greater coherence among Openness facets, while having limited joint effects on Openness and cognition. While one possibility is correlated test error it is also conceivable that particular environmental influences, such as peer group experiences could narrow or broaden an array of behaviors. For instance, exposure to peers interested in visual arts, theatre, etc., (Aesthetics) may engender increased focus on the emotional response of the individual (Feelings), and an expanded tendency toward introspection (Fantasy).

Heritabilities for the six Openness facets ranged from .31 to .56, which is consistent with estimates derived from previous research (Jang et al., 1996, 1998, 2002). Also in keeping with previous research on Openness and a number of other personality variables, dominance effects outweighed common environmental influences for a number of facets (Jang et al., 1996; Luciano et al., 2006). Where common environmental influences were suggested in preference to dominance effects for Aesthetics and Values the influences were weak and for Values were able to be dropped from the model, and it has been generally observed that common environmental influences are not pertinent to variation in Openness facets (Borkenau et al., 2001; Jang et al., 2002). The largest component of variance was due to unique environmental influences. This contrasts with the somewhat limited influence of unique environmental effects on the IQ and QCST measures. However, substantial proportions of the unique environmental effects on the Openness facets are likely to have arisen from test error, and it is established that in general, NEO PI-R measures have lower test–retest reliabilities than IQ assessments (Caruso, 2000).

In summary, five Openness facets were influenced by a general genetic factor with pervasive influence on crystallized and fluid cognitive measures, reflecting genetic *g*. While the additive genetic loadings on the non-objective Openness facets of Fantasy, Aesthetics and Feelings were significant it was evident that genetic *g* was more pertinent to variation in the Objective Openness facets of Ideas and Values. Stronger phenotypic correlations with verbal rather than performance or mental speed measures were also evidenced. Common environmental effects were generally not necessary to explain variation in Openness facets, while unique environmental effects on Openness facets were substantial, in part reflecting test unreliability. Phenotypic correlation among Openness facets was partly influenced by shared unique environmental effects possibly representing correlated test error or multiplicitous effects on different facets of Openness arising from idiosyncratic experiences. Overall, the results were interpreted as being inconsistent with the notion that the sole mechanism of the relationship between Openness and IQ is increased verbal knowledge arising from behaviors directed by personality traits.

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