General and supplementary factors of personality in genetic and environmental correlation matrices

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ABSTRACT

Genetic and environmental correlation matrices among 7 personality scales were estimated, using samples of adult and young adult twins from Australia (2081 and 1178 pairs, respectively). A general factor of personality and two supplemental factors were obtained in each. The supplemental factors were tentatively identified as Social conformity and Other-dependence. Factors from the genetic and environmental correlations replicated well across samples, and they were similar in both the genetic and environmental covariation. It was concluded that the structure of personality is inherent in the evolved phenotype, and is not the immediate consequence of either genetic or environmental organizing factors.

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1. Introduction

In an analysis based on the items of two personality questionnaires from a large sample of adult Australian twins, it was concluded that a general factor of personality (GFP) was essentially phenotypic (Loehlin & Martin, 2011). This conclusion was based on the fact that a GFP based solely on nonshared environmental covariation (i.e., derived from the correlations of the differences between members of MZ twin pairs) was almost identical to one derived from correlations reflecting the genes as well as shared and nonshared environments (derived from correlations based on DZ twin individuals).

The present paper asks, first, if this conclusion about a GFP will be supported by a direct analysis of genetic and environmental correlation matrices of personality scales from the Australian data. And, second, if the conclusion will extend to factors supplemental to a GFP.

Note that statements about the genetic or environmental bases of personality structure—for example, the correlations among personality traits—are not the same as statements about the genetic or environmental basis of the location of individuals along the dimensions of such structures. A great deal of evidence has accumulated from twin and adoption studies showing that individual differences on personality traits largely reflect the genes, individual experiences, and errors of measurement, and are only slightly affected by shared family environments, at least after childhood (Johnson, Vernon, & Feiler, 2008). However, there has also been interest in the genetic and environmental basis of personality structure, in the form of multivariate genetic analyses of personality traits. At least three such recent studies have addressed higher-order factors from the Big Five (Jang et al., 2006; McCrae et al., 2008; Riemann & Kandler, 2010). Jang et al. (2006) fit factor models corresponding to Digman's (1997) alpha and beta factors to genetic and environmental correlation matrices. They concluded that the factor structure "was a clear reflection of the organizing effect of multiple genetic influences" (p. 261). However, they obtained very similar factor structures from genetic and nonshared environmental correlation matrices (their Table 2), and it is not entirely clear how the "organizing effect of multiple genetic influences" accounts for the environmental structuring. McCrae et al. (2008) pointed out some of the difficulties of distinguishing substance from artifact in higher-order factors of the Big Five, and concluded that their twin data were consistent with a model in which artifact outweighed substance. Riemann and Kandler (2010), using a multitrait–multimethod approach with some of the same twin data, concluded that a GFP, if it exists at all, makes a very modest addition to models that incorporate a direct negative correlation between Extraversion and Neuroticism.

The present study, using only self-report data, cannot address issues that might be reflected in differences between ratings by self

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and by others. However, it can address differences in the contribution of genetic and environmental covariation to trait correlation, differences that are important if one assumes that substance and artifact may act differently in the two. A multivariate twin study essentially divides the correlations among traits of individuals into components reflecting genetic and environmental causes of their association. If the genetic and environmental contributions to phenotypic correlations are different, this is potentially informative. For example, we might expect that arbitrary stereotypes acquired from the culture would loom larger in the environmental than in the genetic covariation. But what if the genetic and environmental structures turn out to be similar? Our previous study (Loehlin & Martin, 2011) suggested that this might be the case for the GFP, but will this hold for a different method of analysis, and would it be true for supplemental factors as well? It should be recognized that no one kind of study can be entirely conclusive. Cultural views of what-goes-with-what among personality traits may to some extent reflect biologically-based associations among the traits, and human biology may in the short or long term be affected by social environment.

This said, it still seemed worthwhile to investigate the extent to which genes and environments may differ in their contribution to existing personality trait configurations in self-report data: in the present case, the personality configuration under consideration is a GFP and supplementary factors orthogonal to it. The strategy of the investigation was to obtain genetic and environmental correlation matrices among personality scales measured in an adult sample of monozygotic (MZ) and same-sex dizygotic (DZ) twin pairs, and factor analyze these to obtain a GFP and orthogonal supplementary factors. These analyses were carried out with a large sample of adult twins, and replicated in a separate sample of young adult twins.

Included in the questionnaires filled out by both sets of twins were items from personality questionnaires by H. J. Eysenck and C. R. Cloninger: four scales from the former, and three from the latter. The Eysenck and Cloninger scales appear to be partly overlapping and partly distinctive in their coverage of personality (Heath, Cloninger, & Martin, 1994), making them a reasonable choice for extracting a GFP. Their limited number will, however, limit the number of supplementary factors that can be meaningfully defined—as compared, for example, with the 77 scales from 8 personality inventories employed in a previous study (Loehlin, 2012b).

2. Method

2.1. Participants

The participants were twins from two large Australian samples, one a general sample of adults (age range 24–92 years, mean age 42.6) and one of young adults (age range 17–30 years, mean age 23.5). The first was a sample retested by mail in 1988 after an earlier 1980 study; the second consisted of twins who were too young to be tested in 1980 but who responded to questionnaires as adults in 1989. Used in the present study were 2081 same-sex twin pairs from the adult sample, and 1178 from the young adult sample. In the adult sample, 68.3% of the pairs were MZ and 70.3% were female. In the young adult sample, 59.8% were MZ and 64.7% were female. An excess of MZ and female pairs is characteristic of volunteer twin samples (Lykken, Tellegen, & DeRubeis, 1978). The twin pairs were diagnosed as MZ or DZ by questionnaire items concerning physical similarity and confusion by others during childhood.

2.2. Questionnaires

Participants responded by mail to a questionnaire that addressed a variety of topics. It included items from brief versions

of the Eysenck Personality Questionnaire (EPQ; Eysenck, Eysenck, & Barrett, 1985) and Cloninger's Tridimensional Personality Questionnaire (TPQ; Cloninger, Przybeck, & Svrakic, 1991). The EPQ items were scored for four scales: Psychoticism, Extraversion, Neuroticism, and Lie (P, E, N, and L). The TPQ items were scored for three scales: Harm Avoidance, Novelty Seeking, and Reward Dependence (HA, NS, and RD). In the EPQ, the P scale features hostility and social isolation; E, social confidence and participation; N, worries and emotional instability; and L, claims of super-good behavior. L was originally intended to screen out dissimulators, but in the present non-competitive situation can probably be considered as mostly indexing social conformity (Dunlop, Morrison, Koenig, & Silcox, 2012; McCrae & Costa, 1983). In the TPQ, HA reflects caution and fearfulness; NS, a low threshold for boredom and a preference for new experiences; and RD, a sensitivity to rewards, particularly social ones.

2.3. Analyses

In an initial step, genetic (G) and environmental (E) Cholesky models were fit by LISREL in the adult sample to four 14×14 covariance matrices for male and female MZ and DZ twins. Each matrix consisted of the 7 scales for twin 1 followed by the 7 scales for twin 2. The initial covariances were calculated pairwise, and there was slight variation in the Ns due to occasional missing data—the median Ns were used for the model fitting. The Cholesky models were fit under various constraints, such as requiring or not requiring equality of parameters for genes and environment, or males and females. The environmental models included only the unshared environment, in view of the evidence that shared childhood family environments make only a very slight contribution to adult resemblances in personality (cf. Johnson et al., 2008). The fit of models was assessed by chi-square tests and two fit indices, the root mean square error of approximation (RMSEA) and the normed fit index (NFI).

In a second step, the Cholesky matrices were converted to genetic and environmental correlation matrices, according to the method described by Neale and Cardon (1992, pp. 248–253).

In a final step, the various genetic and environmental correlation matrices were factor analyzed by the principal factor method with three iterations to improve the estimate of communalities. In all cases, there were three eigenvalues greater than 1.0. The first factor was taken to represent the GFP, and the second and third factors rotated orthogonally by Varimax, as done in previous studies with this model of a GFP plus supplementary factors (e.g., Loehlin, 2012b, 2013). All analyses were repeated in the young adult sample.

One additional check was made on the models to be fit, concerning whether models featuring non-additive rather than additive genetic variance might be superior. A model allowing G and E to be unequal, but the same across subgroups, was refit using a .25 genetic correlation for DZs (i.e., assuming complete genetic dominance) as well as a .00 genetic correlation (as might be approached by epistasis involving multiple genes). Neither produced a decrease in χ^2—in fact, both yielded a slight increase—so models assuming additive genetic variance (genetic r_{DZ} of .5) were used throughout.

3. Results and discussion

3.1. Model fits

The fits of various Cholesky models to the initial covariance matrices are summarized in Table 1.

In Rows 1 and 4 of the table is a maximally economical model, in which the genetic and unshared environmental parameters are constrained to be equal, and the same across subgroups. This model yielded χ^2s of 1065.1 and 741.0 in the two samples, for 392 degrees of freedom. Both χ^2s are highly statistically significant ($p \ll .001$), although the models fit reasonably well by RMSEA, for which values less than .08 are considered to represent acceptable fits, and the NFIs of .89 and .87 are not far short of a conventional criterion of .90.

The subsequent rows represent successive relaxations of constraints. In Rows 2 and 5 the G and E parameters are allowed to differ, although still required to be constant across the sex and zygosity groups. In Rows 3 and 6, the G and E parameters are allowed to differ by sex. Statistically, one can reject the Row 1 and 4 models, which equate parameters for both G and E and males and females. In the adult sample, one can also reject the Row 2 model, that relaxes the equality constraints for G and E but retains them for sex. In the young adult sample, a model with equal parameters for the sexes is not rejected ($p = .501$). Models that allow inequality of parameters both for G and E and for males and females are acceptable in both samples. The chi-square difference tests on the righthand side of the table indicate that both relaxations significantly improved the fit of the models. However, all the models after Rows 1 and 4 have RMSEAs well under .05, considered conventionally to represent an excellent fit, with NFIs in the neighborhood of .95; and even the fully equated Row 1 and 4 models do not fit badly in descriptive terms. In short, with these large twin samples one may conclude that the G and E and male and female parameters do differ, but this does not mean that the differences are dramatic ones: models constrained to equality in these respects still fit the data reasonably well.

The genetic and environmental correlation matrices for the two samples (sexes combined) are presented in Appendix Table A1.

3.2. GFPs

The GFPs for the two samples are given in Table 2, in the form of loadings of the seven Eysenck and Cloninger scales on the first principal factor from the G and E correlation matrices with sexes combined (corresponding to Rows 2 and 5 in Table 1). The first two columns give the G loadings on the GFP, and the third and fourth columns the E loadings. For comparison, the corresponding loadings from a phenotypic analysis are shown in the rightmost columns of the table.

Looking across Table 2, it appears that for the most part the loadings are similar: large positive loadings for Extraversion and large negative ones for Harm Avoidance; substantial positive loadings for Novelty Seeking, especially in the G covariation, and negative loadings for Neuroticism, perhaps a little higher in the E covariation. Reward Dependence and Psychoticism both show positive loadings, smaller in E. Finally, there are low loadings for Lie, negative in the G covariation. The differences on Novelty Seeking and Lie, in particular, suggest a more general adventurousness in the genetic GFP, compared to the simple social confidence of the environmental version. In the rightmost columns, the phenotypic GFPs agree well across samples, and are similar to those based on the G and E covariation, often lying between them.

3.3. Supplemental factors

Does similarity also hold for factors beyond the GFP? The next two tables provide corresponding loadings for two supplemental

Table 1
Fit of gene-environment models to covariances in two Australian twin samples.

Equated	χ^2	df	p	RMSEA	NFI	dχ^2	ddf	p
Adult sample								
1. G = E, m = f	1065.1	392	≪.001	.058	.89	–	–	
2. G ≠ E, m = f	485.0	364	<.001	.027	.95	580.1	28	≪.001
3 G ≠ E, m ≠ f	341.2	308	.094	.014	.96	143.8	56	≪.001
Young adult sample								
4. G = E; m = f	741.0	392	≪.001	.056	.87	–	–	
5. G ≠ E; m = f	363.2	364	.501	.007	.94	377.8	28	≪.001
6. G ≠ E; m ≠ f	277.8	308	.891	.000	.95	85.4	56	.007

Note: G = genetic, E = unshared environment; m = males, f = females; RMSEA = root mean square error of approximation, NFI = normed fit index; d = difference (from preceding row);
≪ = much less than.
*N*s: Adult sample 2081 pairs; young adult sample 1178 pairs.

Table 2
Genetic and environmental general factors of personality in two Australian twin samples.

Scale	Genes		Unshared environment		Phenotype	
	Adult	YAdult	Adult	YAdult	Adult	YAdult
Eysenck						
Psychoticism	.31	.24	.17	.30	.28	.31
Extraversion	.80	.84	.67	.66	.72	.71
Neuroticism	−.46	−.42	−.54	−.59	−.53	−.55
Lie	−.18	−.31	.04	.07	−.11	−.10
Cloninger						
Harm Avoidance	−.87	−.82	−.79	−.82	−.84	−.84
Novelty Seeking	.68	.71	.31	.33	.50	.47
Reward Dependence	.38	.41	.27	.17	.24	.16

Note: Loadings on first principal factor from genetic, environmental, and phenotypic correlation matrices. YAdult = young adult sample.

Table 3
Factor loadings of first supplemental factor in two Australian twin samples: Social conformity (reversed)?

Scale	Genes		Unshared environment		Phenotype	
	Adult	YAdult	Adult	YAdult	Adult	YAdult
Eysenck						
Psychoticism	.26	.37	.09	.30	.23	.28
Extraversion	.06	.05	.28	.12	.14	.12
Neuroticism	.68	.68	.40	.33	.49	.46
Lie	−.53	−.46	−.30	−.46	−.44	−.48
Cloninger						
Harm Avoidance	.44	.47	.21	.11	.30	.26
Novelty Seeking	.60	.57	.43	.46	.55	.55
Reward Dependence	.13	−.02	.21	−.02	.10	.01

Note: YAdult = young adult sample.

Table 4
Factor loadings of second supplemental factor in two Australian twin samples: Other-dependence?

Scale	Genes		Unshared environment		Phenotype	
	Adult	YAdult	Adult	YAdult	Adult	YAdult
Eysenck						
Psychoticism	−.51	−.64	−.41	−.30	−.43	−.50
Extraversion	.31	.23	.12	.31	.32	.34
Neuroticism	.29	.16	.10	.27	.25	.18
Lie	.13	.17	.15	.04	.13	.17
Cloninger						
Harm Avoidance	.14	.10	.04	.04	.12	.04
Novelty Seeking	−.07	−.20	−.17	.02	−.00	−.08
Reward Dependence	.64	.74	.41	.42	.58	.64

Note: YAdult = young adult sample.

Table 5
Genetic and environmental general factors of personality for males and females in two Australian twin samples.

Scale	Genes				Unshared environment			
	Adult		Young adult		Adult		Young adult	
	M	F	M	F	M	F	M	F
Eysenck								
Psychoticism	.40	.28	.08	.34	.13	.19	.28	.32
Extraversion	.78	.81	.89	.80	.63	.69	.58	.70
Neuroticism	−.45	−.45	−.50	−.38	−.60	−.51	−.57	−.60
Lie	−.23	−.18	−.20	−.39	.08	.02	.06	.08
Cloninger								
Harm Avoidance	−.89	−.86	−.84	−.80	−.77	−.79	−.79	−.83
Novelty Seeking	.68	.69	.67	.72	.39	.28	.23	.38
Reward Dependence	.33	.40	.54	.33	.30	.26	.17	.17

Note: Loadings on first principal factor from genetic and environmental correlation matrices. M = males, F = females.

factors extracted from the genetic and environmental correlation matrices, along with those from the phenotypic covariation.

Table 3 suggests that the first supplemental factor may represent a conformity factor (reversed), if the Lie scale is taken to represent conformity to social rules. Loading opposite to it are two forms of departure from normative social behavior—Novelty Seeking and Neuroticism.

The second supplemental factor, shown in Table 4, is again fairly consistent across the various analyses. It might be interpreted as Other-dependence, with a strong emphasis on Reward Dependence, and a rejection of the alienation and hostility of Psychoticism. Alternatively, it might be considered to represent interpersonal warmth. This would be consistent with the Psychoticism and Reward Dependence loadings, and scales for Social close-ness and Warmth were loaded on a similar factor in another data set (Loehlin, 2012b).

3.4. Sex differences

What of differences between the sexes? In Table 5, GFP loadings from genetic and environmental correlation matrices are shown separately for males and females. Although there are a few sex differences, for example in the loading of Psychoticism on the genetic GFP in the young adult sample, for the most part the genetic and environmental loadings are similar for both sexes in both the adult and young adult samples.

The same is true for the supplemental factors, although there is more inconsistency evident here. Some of this may be due to

Table 6
Loadings for 1st supplemental factor (Social conformity reversed?) for males and females.

Scale	Genes				Unshared environment			
	Adult		Young adult		Adult		Young adult	
	M	F	M	F	M	F	M	F
Eysenck								
Psychoticism	.33	.20	.00	.32	.14	.06	−.18	.17
Extraversion	.03	.07	.21	.00	.28	.27	.36	.21
Neuroticism	.71	.68	.64	.71	.40	.39	.43	.40
Lie	−.48	−.55	−.25	−.46	−.38	−.26	−.10	−.39
Cloninger								
Harm Avoidance	.44	.45	.46	.52	.21	.21	−.01	.15
Novelty Seeking	.59	.61	.38	.53	.50	.40	.09	.47
Reward Dependence	.14	.16	.38	.03	.13	.26	.43	.06

Note: M = males, F = females.

Table 7
Loadings for 2nd supplemental factor (Other-dependence?) for males and females.

Scale	Genes				Unshared environment			
	Adult		Young adult		Adult		Young adult	
	M	F	M	F	M	F	M	F
Eysenck								
Psychoticism	−.58	−.48	−.77	−.65	−.34	−.45	−.43	−.36
Extraversion	.33	.30	.04	.28	.20	.10	.00	.24
Neuroticism	.26	.30	−.20	.12	.17	.06	−.20	.12
Lie	.30	.08	.37	.16	.06	.19	.54	.11
Cloninger								
Harm Avoidance	.04	.16	−.05	.02	.03	.02	−.07	.03
Novelty Seeking	−.09	−.07	−.61	−.16	−.17	−.17	−.43	−.09
Reward Dependence	.76	.58	.68	.71	.35	.42	.09	.42

Note: M = males, F = females.

chance differences in rotation in the smaller samples, especially the males, but presumably not all of it—because, at least in the adult sample, dependable sex differences of some sort presumably exist in the correlations themselves (*cf.* Table 1).

Table 6 shows the loadings on the first supplemental factor by sex. The loadings for adults—where, based on the statistical tests, sex differences might be expected—are in fact fairly consistent across the sexes. In the (smaller) young adult sample, where equality could not be rejected, they appear somewhat less so: note the differences, for example in the loadings on Psychoticism, Extraversion, and Reward Dependence on the genetic side, and Novelty Seeking and Reward Dependence for the unshared environment.

Table 7 shows the corresponding loadings for the second supplemental factor. For both sexes, Reward Dependence and (negative) Psychoticism are more strongly related to this factor in the genetic than in the environmental covariation. For young adult males, Novelty Seeking is much more negatively related to Other-dependence, in both the genetic and environmental covariation, than it is in the other three groups. Also, Social conformity (Lie) tends to be more strongly related to the Other-dependence factor in males than in females, except in the case of unshared environment for the adults.

However, as mentioned, it is possible that some of the above-mentioned differences may simply reflect differences in factor alignment during rotation, especially in the (smallest) young male sample, and they had perhaps best be regarded as hypotheses meriting further investigation.

4. General discussion

For the most part, the analyses in this paper support previous phenotypic analyses with these and other data sets as to the nature of the GFP (Loehlin, 2012a, 2012b, 2013). Perhaps the most notable difference between the G and E versions of the GFP found here were the more general adventurousness reflected in the former. The results of the present paper do qualify the conclusions previously drawn from an item-level analysis of these data using a different approach (Loehlin & Martin, 2011). Although the GFPs from G and E correlation were still found to be generally similar, suggesting the primary organization of personality is at the level of the phenotype, some minor differences between the G and E GFPs were detectable in the present analyses.

The supplemental factors have been less consistent across various data sets (Loehlin, 2013). A conscientiousness or conformity factor has usually been found, and the first supplemental factor in this analysis could be interpreted as one. Other factors have varied more widely across studies, but an other-dependence or similar factor has sometimes been present.

We should emphasize that because of the limited number of scales used in this study, and the fact that a fair amount of study-to-study variation has previously been reported, these two may properly be regarded as supplemental factors, but should not be considered "the" supplemental factors. Our impression is that supplemental factors are more sensitive to the particular measures used in a given study than is the GFP. Nevertheless, the two found here were reasonably robust across sex and adult age differ-

Table A1
Genetic and environmental correlations among 7 personality scales in two Australian twin samples.

Scale	P	E	N	L	HA	NS	RD
Adult sample							
Psychoticism	1.00	.13	−.06	−.22	−.26	.41	−.22
Extraversion	.10	1.00	−.21	−.09	−.63	.58	.51
Neuroticism	−.09	−.22	1.00	−.19	.76	.06	.12
Lie	−.06	−.03	−.12	1.00	−.06	−.51	−.07
Harm Avoidance	−.12	−.49	.54	−.09	1.00	−.33	−.20
Novelty Seeking	.18	.31	−.02	−.16	−.16	1.00	.31
Reward Dependence	−.13	.31	−.03	.03	−.14	.12	1.00
Young adult sample							
Psychoticism	1.00	.10	.13	−.31	−.14	.50	−.41
Extraversion	.14	1.00	−.27	−.21	−.65	.59	.53
Neuroticism	−.18	−.25	1.00	−.07	.70	.06	−.03
Lie	−.11	−.01	−.21	1.00	−.01	−.59	.00
Harm Avoidance	.21	−.49	.47	−.13	1.00	−.34	−.30
Novelty Seeking	.27	.28	−.05	−.18	−.08	1.00	.12
Reward Dependence	−.08	.25	−.01	.07	−.14	.08	1.00

Note: Genetic correlations above diagonal in each table, and unshared environment correlations below. Sexes combined.

ences, and one of them (social conformity) has shown up in data from studies using a variety of ratings and questionnaires.

One might ask why there should be supplemental factors at all? If the GFP measures social efficacy, one possibility is that supplemental factors reflect different ways of achieving it. Social conformity is one way, but its opposite, originality (combined with high intelligence, perhaps) provides another. Likewise, a person may depend a great deal on others or be largely independent, and still be socially (and reproductively) efficacious. The presence of a variety of social roles and social niches permits the viability of a variety of personalities (*cf.* Penke, Denissen, & Miller, 2007).

If it is true that personality structuring occurs primarily at the level of the phenotype, what does that imply? Consistent structuring across self-ratings and others' ratings—not assessed in this study, but found for the GFP elsewhere (Loehlin, 2012a; Loehlin & Horn, 2012)—could result from raters' implicit theories of personality, whether rating themselves or others (McCrae, Jang, Livesley, Riemann, & Angleitner, 2001). But why should genetic and environmental contributions to this implicit theory be similar? One possibility is that implicit theories are (fairly) veridical. In this view, the phenotypic personality represents the outcome of a long history of biological evolution in social and cultural contexts, and implicit theories of personality are (to a considerable degree) shaped by behavioral reality. Not wholly so, presumably—and discrepancies, such as the greater role of Novelty Seeking in the genetic GFP, provoke speculation. (Did novelty seeking, in conjunction with other social leadership traits, lead to successful migrations in human prehistory? Do current cultural environments downplay it? And what is the basis of the novelty-seeking? Is it negative—low threshold for boredom? Is it positive—flexibility? curiosity motivation?) The present analyses suggest that large genetically informative samples receiving a wide variety of personality measures will be helpful in future studies, particularly if the investigation is extended to traits supplemental to a GFP.

Studies in the domain of personality have one great advantage in this regard: it is not essential that the investigator assemble huge samples of exotic groups such as twins reared apart or members of adoptive families. Given the extensive data showing that shared family environment has little lasting impact on personality traits, effective genetic analyses can be done using ordinary siblings, parents and offspring, or other relatives.

Acknowledgements

Appendix A

See Appendix Table A1.

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