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Cognitive ability, self-assessed intelligence and personality: Common genetic but independent environmental aetiologies

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ABSTRACT

Self-perceived abilities (SPA), which play an important role in academic achievement, have been recently reported to be fully attributable to genetic and non-shared environmental influences. To replicate and extend this finding, 732 Croatian twins (15–22 years old) were assessed on cognitive ability, self-assessed intelligence (SAI), and Five Factor Model personality traits. In addition to attempting to replicate the finding that SAI is due to genetic and non-shared environmental influences, we used bivariate and multivariate genetic analyses to investigate genetic and environmental influences on the phenotypic association of IQ, SAI, and personality traits. The results replicated the finding that individual differences in SAI can be attributed to genetic and non-shared environmental influences. Bivariate and multivariate genetic analyses showed intelligence, SAI measures, and personality traits are inter-correlated not only at the phenotypic but also at the genotypic level. Multivariate analyses indicate that around 20% of IQ variance could be explained by SAI and personality traits (Neuroticism, Extraversion, Openness). In combination with other recent findings from behavior genetics, this result supports the idea of pleiotropy and generalist genes.

1. Introduction

Even though general intelligence is one of the "most central phenomena in all of behavioral science, with broad explanatory powers" (Jensen, 1998, p. xii), it is widely recognized that factors other than cognitive ability constitute important performance determinants. Most notably, personality traits, typically conceptualized in terms of the Five Factor Model (e.g. Costa & McCrae, 1992) and self-assessed intelligence (SAI) – how intelligent people think they are – are empirically supported as factors that individually add incremental validity to intelligence for the prediction of educational achievements (e.g. Chamorro-Premuzic, Harlaar, Greven, & Plomin, 2010; Spinath, Spinath, Harlaar, & Plomin, 2006). These variables operate, however, not independently and are therefore likely to also have common aetiologies. To understand the causes of inter-relations between intelligence, the Five Factor Model personality traits and SAI, we examine here the genetic and environmental influences that may underlie their phenotypic associations.

1.1. Phenotypic associations

Correlations between IQ test scores and self-estimates of ability typically range between .20 and .50 (e.g. Ackerman & Wolman, 2007; Mabe & West, 1982), which has been used to both confirm and reject the hypothesis that people are able to assess their own intelligence quite accurately. Less disputed is the observation that IQ and self-estimated ability are inter-related predictors of academic performance, each with independent incremental validity (e.g.

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Chamorro-Premuzic & Arteche, 2008; Spinath et al., 2006). Positive effects of self-estimated ability on actual achievement have been consistently reported, even when the psychometric measurement of self-estimates differs across studies. For example, SAI is commonly measured by asking individuals to estimate their IQ on a bell curve of intelligence with a mean of 100 and a standard deviation of 15, whereas self-perceived abilities are often assessed with reference to the school or university curriculum (cf. Spinath et al., 2006). Those differences aside, it has been shown that SAI, academic self-beliefs and related constructs are highly inter-correlated and may be used interchangeably (Peterson & Whiteman, 2007).

In a recent study testing 5957 British school children, self-perceived ability at age 9 was strongly associated with concurrent academic achievement, after controlling for cognitive ability (Chamorro-Premuzic et al., 2010). Moreover, self-perceived ability at age 9 significantly predicted academic achievement and ability perception three years later at age 12, after controlling for academic achievement at age 9 and intelligence at age 9 and 12 (Chamorro-Premuzic et al., 2010). These results have two important implications: (1) self-estimates of ability are stable, trait-like individual difference variables that (2) play a crucial role for academic achievement, and therefore should be further investigated.

Several previous studies have examined SAI and its relationships to the Five Factor Model, reporting mostly positive associations with the personality traits of Extraversion and Openness to Experience, and negative links with Neuroticism and Agreeableness (e.g. Chamorro-Premuzic, Moutafi, & Furnham, 2005; Furnham, Chamorro-Premuzic, & Moutafi, 2005; Furnham, Kidwai, & Thomas, 2001). Observed correlations between Five Factor Model and SAI are typically explained as consequences of the personality trait in question, without reference to actual ability. For example, it has been suggested that neurotics' generally poorer self-concept causes reduced confidence in their aptitude, which is reflected in lower SAI (Chamorro-Premuzic et al., 2005). Based on similar reasoning, extraverts' inherent confidence and assertiveness is thought to lead to higher SAI (Furnham et al., 2005), whereas more agreeable individuals may report lower SAI because of their greater humility and modesty. In contrast, theories explaining positive associations between Openness and SAI typically make reference to actual cognitive ability. Because Openness to Experience is the only Five Factor Model trait that shows stable, albeit moderate, associations with general intelligence (e.g. Ackerman & Heggestad, 1997; Judge, Jackson, Shaw, Scott, & Rich, 2007), its positive relationship with SAI may be due to an accurate reflection of open individuals' greater ability. Overall, the empirical evidence to date has shown that SAI is meaningfully associated with intelligence and personality traits at the phenotypic level; it is, however, unknown if these associations have also common genetic and environmental origins.

1.2. Genetic associations

Intelligence is considered to be one of the most heritable human traits, with studies typically yielding heritability estimates of 25% in young childhood, about 40% in middle childhood, and close to 80% in adulthood. Conversely, shared environmental influences impact IQ in early and middle childhood, but have often been reported to become negligible in later life (Plomin, DeFries, McClearn, & McGuffin, 2001). Two previous studies investigated genetic and environmental influences on self-perceived ability in sub-samples of the Twin's Early Development Study (TEDS). Spinath, Spinath, and Plomin (2008) reported genetic influences of 40% and non-shared environmental effects of 60% accounting for the variance in self-perceived abilities of 4464 children aged 9 years. In line with this, Greven, Harlaar, Kovas, Chamorro-Premuzic, and Plomin (2009) reported a heritability of 51% of self-perceived ability, whereas the common environment accounted for only 2%, in 3785 twin pairs assessed at age 7, 9 and 10 years. These results may seem counterintuitive, because self-estimates of abilities were traditionally thought to be largely shaped by parental beliefs, expectations, and attitudes (e. g. Bandura, 1995; Eccles et al., 1983).

In the same study, Greven et al. (2009) also examined influences on the phenotypic associations of intelligence, self-perceived ability and achievement, and concluded they could be primarily attributed to genetic factors. A common set of genes affected all three constructs, not only when assessed contemporaneously, but also when they were measured at different ages (Greven et al., 2009). Furthermore, genetic factors associated with intelligence accounted for a small proportion (15%) of the genetic variance in self-perceived intelligence but there was little evidence for a similar environmental link. That is, self-perceived ability is on the one hand independent of shared environmental influences, and on the other, shares some of its genetic – but none of its unique environmental – factors with intelligence. Based on these results, we might speculate if self-estimates of ability also share common genetic factors with their phenotypically associated personality traits.

Heritability estimates for personality traits are typically lower than those of intelligence with values ranging from 20 to 50% across samples and ages (Plomin et al., 2001). Probably because of a lack of correlations between IQ and personality at the phenotypic level, only few previous studies have examined the genetic basis of intelligence–personality associations (i.e. Luciano, Wainwright, Wright, & Martin, 2006; Wainwright, Wright, Luciano, Geffen, & Martin, 2008). The results suggested that associations between Conscientiousness and intelligence, which are typically close to zero (e.g. Ackerman & Heggestad, 1997), stemmed primarily from a common genetic factor (Luciano et al., 2006). A subsequent study of the same sample focused on the genetic basis of the intelligence–Openness association. A general genetic factor with substantial loadings from intelligence and two Openness facets supported that their phenotypic association is largely due to genetic factors (Wainwright et al., 2008). To date, no study has examined the genetic and environmental influences on associations between SAI and personality traits.

1.3. This study

In the current study, we aim to (1) replicate previous estimates of heritability for self-perceived ability in a sample slightly more matured than those examined previously (Greven et al., 2009; Spinath et al., 2008). Even though SAI and self-perceived ability are somewhat different constructs, comparisons of current and previous results will give an indication if the genetic contributions to self-assessed ability increase with age akin to the heritability of intelligence and personality. But the specific contribution of this study is that it is the first study to determine genetic and environmental influences on SAI in late adolescence. Subsequently, we will (2) evaluate genetic and environmental influences on the phenotypic associations between intelligence and SAI to confirm previous findings, and on the phenotypic associations between intelligence, SAI and personality traits to extend previous findings. Specifically, we hypothesize in line with Greven et al. (2009) that phenotypic associations between these constructs can be attributed primarily to common genetic effects but that environmental influences are largely independent. We will also address the issue of different SAI measures by examining genetic and environmental influences on the phenotypic associations between intelligence and personality, and two different measures of SAI. We expect for genetic and environmental influences on the phenotypic associations to be commensurable across SAI measures if they actually measure the same latent construct.

2. Method

2.1. Sample

In 2007, twin pairs born between 1985 and 1992 were identified from the Zagreb area register of citizens. From overall 2005 individuals, 732 (36.5%) completed and returned a postal questionnaire. This group included 339 twin pairs with 105 monozygotic (MZ), 120 same sex and 114 different sex dizygotic (DZ) twin pairs. There were 85 male pairs and 140 female pairs in our sample. Their age varied between 15 and 22 years ($M=18.62$, $SD=2.31$). In terms of education our sample was either still in high-school (40%) or finished high-school (55%).

2.2. Measures

2.2.1. Zygosity

Zygosity was determined by a questionnaire constructed for the purpose of this research. Out of eleven items, six evaluated physical similarities (e.g. facial appearance, hair color) and five assessed twin confusion by parents, other family members, teachers, casual friends and strangers. These items have been shown to be valid indicators of zygosity in number of studies (e.g. Buchwald et al., 1999; Gao et al., 2006; Price et al., 2000) with zygosity determination being accurate around 95% (Nichols & Bilbro, 1966; Reed et al., 2005; Segal, 1984; Spitz et al., 1996). Twins' self-reports about their zygosity were coded so that the lower score indicated monozygosity.

2.2.2. Personality

Personality traits were measured with Croatian adaptation of NEO-Five Factor Inventory (Costa & McCrae, 1989, 1992, 2005), a short version of NEO-Personality Inventory (Costa & McCrae, 1989, 1992, 2005). NEO-FFI has 60 items and measures Neuroticism (N), Extraversion (E), Openness (O), Agreeableness (A) and Conscientiousness (C). Cronbach's α coefficients were .81, .72, .57, .66, and .81 for Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness, respectively. These reliabilities are in line with those obtained in previous studies (e.g. Butkovic & Bratko, 2007).

2.2.3. Intelligence

Intelligence was assessed by the Croatian adaptation of a subtest of General Aptitude Test Battery (Tarbuk, 1977), which measures verbal ability. The original test was modified to meet modern Croatian language and shortened to 20 items, of which each presented four words; participants' task was to identify the pair of words which were either synonyms or antonyms. According to the test manual this particular subtest is highly saturated with g factor and will be therefore referred to herein as IQ, also avoiding confusions with self-assessed intelligence.

2.2.4. Self-assessed intelligence (SAI)

A normal distribution with a mean of 100 and distribution of six standard deviations (-3 to $+3$) was shown to the participants, together with brief descriptions of the anchor scores (e.g., 55 “mild retardation”, 100 “average”, 145 “gifted”). Participants were asked to provide estimates of their own overall intelligence and ten multiple intelligences taken from Gardner (1999). For each of the ten multiple intelligences (verbal/linguistic, logical–mathematical, musical, body-kinesthetic, spatial, interpersonal, intrapersonal, naturalist, spiritual, existential) a short description was provided. In this study, we use the twins' overall estimate of their own IQ, and the first unrotated component score of their ten multiple intelligences.[1] These will be herein referred to as SAI and factor SAI. We decided to use two measures of SAI (overall SAI and factor SAI) in order to examine whether the type of SAI measure has an effect on heritability of SAI, as well as on genetic and environmental influences on the phenotypic associations of SAI with intelligence and personality. Data about self-assessed intelligence was available for a smaller sample (83 MZ and 173 DZ twin pairs). Therefore all analyses which included SAI were run on this smaller sample.

2.3. Analyses

Prior to genetic model-fitting a series of preliminary analyses was run. MANOVA was used to assess sex and age effects. All measures were residualized for sex and age effects using a regression procedure proposed by McGue and Bouchard (1984). Since both same-sex and opposite-sex DZ twins were included in our sample, we performed preliminary analyses based on sex-limitation models to investigate possible quantitative and qualitative sex differences.

In the behavioral genetics, qualitative sex differences refer to the extent that genes and shared environment overlap between males and females, and quantitative sex differences refer to differing magnitudes of genetic or environmental influences for males and females. These analyses indicated no significant qualitative differences for all

[1] Overall SAI correlated .67 and .68 with the unit-weighted composite score of SAI and first unrotated component of SAI, respectively. Composite and factor SAI correlated .99; therefore, only the results for factor SAI are presented here.

Table 1
Descriptive statistics for IQ, SAI measures and personality traits and intraclass correlations in monozygotic (MZ) and dizygotic (DZ) twins with confidence intervals of 95% in parentheses.

Measures	*N*	M (SD)	MZ	DZ
IQ	668	12.23 (4.19)	.79 (.70–.85)	.61 (.52–.68)
SAI	541	107.03 (11.74)	.57 (.40–.70)	.42 (.29–.54)
Factor SAI	529	0.00 (1.00)	.59 (.42–.71)	.34 (.19–.46)
Neuroticism	658	19.97 (8.59)	.64 (.50–.74)	.22 (.09–.34)
Extraversion	658	30.40 (6.64)	.51 (.35–.64)	.13 (−.01–.25)
Openness	658	23.66 (6.26)	.67 (.55–.76)	.25 (.13–.37)
Agreeableness	658	30.31 (6.13)	.50 (.34–.63)	.26 (.14–.38)
Conscientiousness	658	31.44 (7.44)	.50 (.34–.63)	.29 (.16–.40)

Note. *N* = number of participants, M = arithmetic mean, SD = standard deviation.

measures, while there was a significant quantitative difference in neuroticism. However, since the sample of male twins, especially MZM, was small and same-sex and opposite-sex DZ twins correlations did not differ significantly, we decided to run all analyses on MZ and DZ twins in order to increase statistical power.

The structural equation model fitting program Mx (Neale, Boker, Xie, & Maes, 2003) was used for genetic model-fitting analyses. First univariate analyses were run for each of our variables to estimate the contribution of genetic and environmental factors in explaining individual differences. The goodness-of-fit of each genetic model was measured relative to phenotypic (saturated) model. Therefore, saturated models for each variable were run first and means and variance differences between twin groups were tested using different nested models. Which genetic model to test first was decided based on the pattern of MZ–DZ correlations because this pattern indicates the relative importance of different sources of variance: additive genetic effects (A), non-additive genetic effects (D), shared environmental effects (C) and non-shared environmental effects (E). A series of nested models was run to test if any of the parameters could be dropped from the model without significant worsening of fit. Because our sample size is not large and, as Sullivan and Eaves (2002) state when effects of sampling are large it is more likely than not that applying the principle of parsimony will lead to adoption of the false model, we will report estimates from a full ACE model.

After that a series of bivariate analyses was computed in order to assess if phenotypic relations between our variables are due to overlapping genetic and environmental influences. Finally, multivariate Cholesky decomposition analyses were run predicting IQ with SAI measures and personality traits in order to assess how much of the variance in IQ is explained by SAI and personality and how much is independent of SAI and personality. Also, the order of SAI and personality variables was varied to allow us to assess the extent to which SAI predicts IQ independent of the personality traits. In the first analysis SAI variable was entered followed by personality traits, while in the second analysis personality variables were entered followed by SAI variable.

3. Results

Descriptive statistics for our sample, including means, standard deviations and twin intraclass correlations for MZ and DZ twins were calculated and are presented in Table 1, while correlation matrix showing the relationship between three sets of variables (intelligence, self-assessed intelligence and personality) for MZ and DZ twins separately is shown in Table 2. These correlations show similar pattern for MZ and DZ twins, indicating significant association between IQ, SAI and Openness measures.

Intraclass correlations represent the proportion of total variance due to variance between pairs and are a more appropriate measure of twin pair similarity than Pearson's r. The pattern of MZ–DZ correlations indicates the relative importance of different sources of variance and based on that pattern we decided to fit models in the univariate analyses which included additive genetic (A), shared environmental (C) and non-shared environmental (E) effects. The results of the univariate analyses are presented in Table 3.

As can be seen from Table 3, the best fitting model for SAI measures and personality traits was the one that included additive genetic effects (A) and non-shared environmental

Table 2
Correlation matrix showing the relationship between IQ, SAI measures and personality traits for MZ (above the diagonal) and DZ twins (below the diagonal).

	IQ	SAI	Factor SAI	N	E	O	A	C
IQ	x	.30*	.15	−.16	−.12	.28*	.01	−.10
SAI	.34*	x	.63*	−.11	.12	.27*	.04	−.07
Factor SAI	.12	.69*	x	−.14	.08	.28*	.08	.11
N	−.11	−.06	−.09	x	−.34*	−.04	−.25*	−.28*
E	−.19*	−.06	.13	−.33*	x	−.06	−.08	.20*
O	.18*	.18*	.16*	.11	−.13*	x	−.05	.10
A	−.01	−.08	−.04	−.34*	.11	−.21*	x	.22*
C	−.08	.02	.11	−.27*	.24*	−.16*	.25*	x

* $p<0.01$.

Table 3
Univariate model-fitting results for intelligence measures and personality traits: Fit statistics for the saturated, full and best fitting model with parameter estimates.

Measures	Model	−2LL	*df*	$\chi^2(df)$	*p*	A	C	E
IQ	Full saturated	3593.898	658					
	Full ACE (best fitting)	3597.728	664	3.83 (6)	.70	.38 (.20–.57)	.41 (.24–.56)	.21 (.15–.28)
SAI	Full saturated	4104.981	531					
	Full ACE	4113.849	537	8.868 (6)	.18	.57 (.24–.77)	.11 (.00–.35)	.32 (.23–.46)
	Best fitting	4114.612	538	0.763 (1)	.38	.69 (.58–.77)		.31 (.23–.42)
Factor SAI	Full saturated	1426.168	519					
	Full ACE	1439.727	525	13.559 (6)	.04	.66 (.33–.76)	.00 (.00–.25)	.34 (.24–.45)
	Best fitting	1439.727	526	.00 (1)	1.0	.66 (.53–.76)		.34 (.24–.47)
Neuroticism	Full saturated	4564.386	648					
	Full ACE	4575.603	654	11.217 (6)	.08	.60 (.41–.69)	.00 (.00–.13)	.40 (.31–.52)
	Best fitting	4575.603	655	.00 (1)	1.0	.60 (.48–.69)		.40 (.31–.52)
Extraversion	Full saturated	4313.550	648					
	Full ACE	4323.349	654	9.799 (6)	.13	.45 (.24–.57)	.00 (.00–.13)	.55 (.43–.69)
	Best fitting	4323.349	655	.00 (1)	1.0	.45 (.31–.57)		.55 (.43–.69)
Openness	Full saturated	4187.356	648					
	Full ACE	4193.455	654	6.099 (6)	.41	.62 (.39–.71)	.00 (.00–.18)	.38 (.29–.49)
	Best fitting	4281.976	655	.00 (1)	1.0	.62 (.51–.71)		.38 (.29–.49)
Agreeableness	Full saturated	4192.010	648					
	Full ACE	4200.965	654	8.955 (6)	.18	.56 (.27–.67)	.00 (.00–.19)	.44 (.33–.59)
	Best fitting	4200.965	655	.00 (1)	1.0	.56 (.42–.67)		.44 (.33–.58)
Conscientiousness	Full saturated	4445.126	648					
	Full ACE	4451.293	654	6.167 (6)	.40	.46 (.09–.63)	.06 (.00–.32)	.49 (.37–.64)
	Best fitting	4451.463	655	0.169 (1)	.68	.53 (.40–.63)		.47 (.37–.60)

Note. −2LL = minus twice the Log-likelihood of the data, *df* = degrees of freedom, $\chi^2(df)$ = −2LL (and *df*) difference between current and previous model, A = additive genetic variance, C = shared environmental variance, E = non-shared environmental variance, 95% confidence intervals shown in parentheses.

effects (E), while the best fitting model for IQ included also shared environmental effects (C). Due to modest statistical power in the model fitting analysis, heritability estimates from full ACE model will be reported and discussed. Also MZ–DZ correlation pattern indicates lower heritability for SAI measures than model fitting results. This may be due to the fact that there is some C for SAI but we do not have the power to detect it because samples of similar size like ours have more power to detect A than C (Posthuma & Boomsma, 2000) and MZ–DZ ratio of 1:2, like ours, also favors estimating A (Neale, Eaves, & Kendler, 1994). Heritability estimates were .57 and .66 for SAI and factor SAI, and they varied between .45 and .62 for personality traits. Individual differences in IQ were accounted for by genetic (.38) and shared environmental (.41) factors. Two sets of bivariate analyses were run. In the first set relationship between IQ with SAI measures and personality traits was analyzed. Results of those analyses together with phenotypic correlations are presented in Table 4. Based on results of univariate analyses, ACE–AE models were run and genetic and non-shared environmental correlations were calculated.

IQ and SAI had a significant genetic correlation (r_A = .53), and so did IQ and Openness (r_A = .37) and IQ and Extraversion (r_A = −.36), but their environmental influences were independent. Negative genetic correlation with Extraversion indicates that there is a genetic overlap and that genetic influences contributing to lower Extraversion also contribute to higher IQ. Also, genetic correlations for IQ and factor SAI were non-significant, and so were IQ's genetic or environmental correlations with Neuroticism, Agreeableness and Conscientiousness. We calculated bivariate heritabilities, as product of the square root of each univariate heritability and genetic correlation for each trait, to see if the phenotypic correlations could be explained by shared genetic influences between those measures. They indicated that 76% of the correlation between IQ and SAI,

Table 4
Phenotypic correlations of IQ with SAI measures and personality traits and bivariate model-fitting results: Fit statistics and correlation estimates for correlated factors ACE–AE model.

IQ with	Phenotypic correlation	Model	−2LL	*df*	Correlation estimates	Bivariate heritability
SAI	.33**	Correlated factors ACE–AE	7668.248	1200	**r_A = .53 (.33 to .79)** r_E = .07 (−.13 to .27)	**.25**
Factor SAI	.13**	Correlated factors ACE–AE	5032.607	1188	r_A = .18 (−.05 to .43) r_E = .05 (−.16 to .25)	.09
Neuroticism	−.13**	Correlated factors ACE–AE	8166.243	1317	r_A = −.18 (−.42 to .02) r_E = −.05 (−.23 to .13)	−.09
Extraversion	−.16**	Correlated factors ACE–AE	7905.368	1317	**r_A = −.36 (−.65 to −.12)** r_E = −.02 (−.20 to .15)	**−.15**
Openness	.21**	Correlated factors ACE–AE	7770.501	1317	**r_A = .37 (.17 to .62)** r_E = .01 (−.17 to .19)	**.18**
Agreeableness	.00	Correlated factors ACE–AE	7796.434	1317	r_A = −.14 (−.38 to .08) r_E = .13 (−.05 to .31)	−.06
Conscientiousness	−.08*	Correlated factors ACE–AE	8045.338	1317	r_A = −.15 (−.39 to .08) r_E = −.04 (−.21 to .13)	−.06

Note. *$p<0.05$; **$p<0.01$, −2LL = minus twice the Log-likelihood of the data, *df* = degrees of freedom, r_A = genetic correlation, r_E = nonshared environmental correlation, 95% confidence intervals shown in parentheses, significant genetic correlations are in bold. All variance estimates from these analyses were within ±.01 of the univariate estimates given in Table 3, except for measured intelligence for which they varied ± .06 of the univariate estimates given in Table 3.

Table 5
Phenotypic correlations of SAI measures with personality traits and bivariate model-fitting results: Fit statistics and correlation estimates for correlated factors AE model.

SAI with	Phenotypic correlation	Model	−2LL	*df*	Correlation estimates	Bivariate heritability
Neuroticism	−.07	Correlated factors AE	8686.970	1191	r_A = −.13 (−.31 to .05) r_E = .00 (−.21 to .21)	−.08
Extraversion	−.01	Correlated factors AE	8436.949	1191	r_A = −.09 (−.30 to .11) r_E = .09 (−.10 to .27)	−.05
Openness	.21**	Correlated factors AE	8291.222	1191	**r_A = .23 (.06 to .41)** r_E = .09 (−.11 to .29)	**.14**
Agreeableness	−.05	Correlated factors AE	8314.232	1191	r_A = −.10 (−.29 to .08) r_E = .04 (−.16 to .23)	−.06
Conscientiousness	.00	Correlated factors AE	8566.059	1191	r_A = .01 (−.18 to .19) r_E = .00 (−.18 to .19)	.01
Factor SAI with	Phenotypic correlation	Model	−2LL	*df*	Correlation estimates	Bivariate heritability
Neuroticism	−.10*	Correlated factors AE	6007.318	1179	**r_A = −.27 (−.45 to −.08)** r_E = .16 (−.06 to .37)	**−.17**
Extraversion	.11*	Correlated factors AE	5754.856	1179	r_A = .13 (−.09 to .33) r_E = .12 (−.07 to .30)	.07
Openness	.19**	Correlated factors AE	5616.553	1179	**r_A = .34 (.16 to .53)** r_E = −.10 (−.30 to .11)	**.22**
Agreeableness	−.01	Correlated factors AE	5,639,606	1179	r_A = −.10 (−.29 to .10) r_E = .09 (−.11 to .29)	−.06
Conscientiousness	.11*	Correlated factors AE	5885.387	1179	r_A = .14 (−.06 to .33) r_E = .07 (−.12 to .25)	.08

Note. *$p<0.05$; **$p<0.01$, −2LL = minus twice the Log-likelihood of the data, *df* = degrees of freedom, r_A = genetic correlation, r_E = nonshared environmental correlation, 95% confidence intervals shown in parentheses, significant genetic and environmental correlations are in bold. All variance estimates from these analyses were within ±.02 of the univariate estimates given in Table 3.

94% of the correlation between IQ and Extraversion, and 86% of the correlation between IQ and Openness are due to shared genetic influences.

In the second set of bivariate analyses relationship between SAI measures and personality traits was analyzed. Results of those analyses together with phenotypic correlations are presented in Table 5. Based on results of univariate analyses, AE models were run and genetic and non-shared environmental correlations were calculated.

Openness had a significant genetic correlation with SAI at .23, and with factor SAI at .34. There was also a significant genetic overlap for Neuroticism and factor SAI at −.27. Again, this negative genetic correlation indicates that genetic influences contributing to lower Neuroticism also contribute to higher SAI. We calculated bivariate heritabilities to see if the phenotypic correlations could be explained by shared genetic or environmental influences between those measures. For factor SAI and Neuroticism and for factor SAI and Openness bivariate heritabilities are higher than phenotypic correlations. This is due to the environmental correlations which are in both cases, although not statistically significant, contributing to phenotypic correlations in the opposite direction from significant genetic correlations. Therefore it seems numerically that genetic influences are explaining more than 100% of their phenotypic correlation. In fact, they indicate that shared genetic influences could explain total phenotypic correlation between Openness and factor SAI and between Neuroticism and factor SAI. Shared genetic influences also explain 67% of the phenotypic correlation between Openness and SAI.

Results of multivariate Cholesky analyses are presented in Tables 6 and 7. We ran models that included either SAI or factor SAI and three personality traits (Neuroticism, Extraversion and Openness) with significant phenotypic correlation with IQ.

First we ran two models with SAI, one when SAI was entered followed by personality traits, and second when personality variables were entered followed by SAI, which both showed that majority of IQ variance (78%) is independent of SAI and personality. This suggests that around 20% of IQ variance could be explained by SAI and personality traits. SAI contributed 12% when included first in the model, but only 6% when it was entered after personality traits. This indicates that SAI predicts only 6% of the IQ variance independent of personality traits. Subsequently we ran two models with factor SAI, one when factor SAI was entered followed by personality traits, and second when personality variables were entered followed by factor SAI, which again showed that majority of IQ variance (84%) is independent of factor SAI and personality. Regardless of the order of factor SAI and personality traits in this analysis, factor SAI explained less than 1% of the IQ variance.

4. Discussion

The aims of this study were twofold: on the one hand, heritability estimates, which were established in previous research for self-perceived ability, were replicated for self-assessed intelligence (SAI) in a sample of Croatian twins in late adolescence. On the other, this study also extended previous findings by: (1) exploring genetic and environmental influences on the phenotypic associations between intelligence, SAI and personality traits, as well as (2) examining the effect of different SAI measures on these associations.

Table 6
Test statistics for Cholesky decomposition models.

	Model	−2LL	*df*	$\chi^2(df)$	*p*
1	Cholesky ACE SAI, N, E, O, IQ	20587.040	3133		
1a	Drop C N, E, O	20595.035	3145	7.995 (12)	.79
1b	Drop C SAI	20596.540	3147	1.505 (2)	.47
2	Cholesky ACE factor SAI, N, E, O, IQ	17935.226	3121		
2a	Drop C N, E, O	17940.634	3133	5.408 (12)	.94
2b	Drop C factor SAI	17941.661	3135	1.027 (2)	.60

Note. −2LL = minus twice the Log-likelihood of the data, *df* = degrees of freedom, $\chi^2(df)$ = −2LL (and *df*) difference between current and previous model.

Table 7
Standardized path estimates from best fitting Cholesky models.

Additive genetic factor											
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
SAI	.83					Factor SAI	.81				
N	−.10	.76				N	−.21	.75			
E	−.05	−.24	.63			E	.10	−.23	.63		
O	.18	.13	−.03	.75		O	.26	.17	−.06	.71	
IQ	.34	−.07	−.24	.17	.51	IQ	.09	−.09	−.29	.22	.54
N	.77					N	.78				
E	−.23	.63				E	−.24	.63			
O	.10	−.06	.77			O	.10	−.05	.77		
SAI	−.11	−.11	.20	.79		Factor SAI	−.22	.04	.30	.72	
IQ	−.12	−.28	.23	.25	.51	IQ	−.11	−.29	.23	−.01	.54
Common environment factor											
	C1	C2	C3	C4	C5		C1	C2	C3	C4	C5
SAI	.00					Factor SAI	.00				
N	.00	.00				N	.00	.00			
E	.00	.00	.00			E	.00	.00	.00		
O	.00	.00	.00	.00		O	.00	.00	.00	.00	
IQ	.00	.00	.00	.00	.57	IQ	.00	.00	.00	.00	.59
N	.00					N	.00				
E	.00	.00				E	.00	.00			
O	.00	.00	.00			O	.00	.00	.00		
SAI	.00	.00	.00	.00		Factor SAI	.00	.00	.00	.00	
IQ	.00	.00	.00	.00	.57	IQ	.00	.00	.00	.00	.59
Unique environment factor											
	E1	E2	E3	E4	E5		E1	E2	E3	E4	E5
SAI	.56					Factor SAI	.58				
N	−.02	.64				N	.10	.62			
E	.07	−.26	.69			E	.09	−.27	.68		
O	.07	−.02	−.09	.62		O	−.06	.00	−.08	.62	
IQ	.04	−.02	−.03	.00	.45	IQ	.04	−.04	−.03	.01	.45
N	.64					N	.63				
E	−.26	.69				E	−.25	.69			
O	−.02	−.08	.62			O	−.01	−.09	.62		
SAI	−.02	.05	.07	.56		Factor SAI	.09	.11	−.04	.56	
IQ	−.02	−.03	.01	.04	.45	IQ	−.03	−.02	.00	.05	.45

4.1. Heritability of SAI

In line with Greven et al.'s (2009) and Spinath et al.'s (2008) results, genetic and non-shared environmental factors best explained individual differences in SAI and factor SAI. As Greven et al. (2009) pointed out, this finding challenges the traditionally accepted notion that SAI was largely shaped by parental expectations and beliefs (e.g. Bandura, 1995; Eccles et al., 1983). That said, SAI was not exclusively explained by genetic variance but non-shared environmental factors, such as unique learning experiences, impacted on SAI. However, in our study heritability estimates from multivariate models, as well as MZ–DZ correlation pattern, suggest that there might be some shared environmental influences for SAI measures, but there is not enough statistical power to detect it.

In the current study, heritability estimates of SAI were slightly higher than those previously reported by Greven et al. (2009) and Spinath et al. (2008), who found that genetic factors accounted for 40% and 50% in young children from TEDS. This discrepancy in heritability estimates may be due to psychometric differences in employed self-assessed intelligence measure (here) or other test instruments of self-perceived ability (e.g. Spinath et al., 2006).

However, it is also possible that the observed divergence is a consequence of age differences between samples. It is well established that the amount of variance in a given phenotype that is accounted for by genetic factors typically increases with age, while environmental influences tend to decrease (Plomin et al., 2001). Participants in the current sample were on average 18 years old, which is about twice as old as the children in the TEDS studies. Therefore, it could be that heritability of SAI also increases with age like heritability of other trait dimensions of individual differences.

This study also estimated heritabilities for the Five Factor Model personality traits, all of which showed no meaningful shared environmental effects, and were heritable at about 50% on average, which is typical finding for heritability of personality. For IQ, significant contributions were found for genetic (38%), shared environmental (41%) and unique environmental (21%) factors. Having in mind the age of our sample, the limited sample size and used measure of IQ, this finding is in line with the literature showing the importance of shared environmental influences in earlier developmental periods.

4.2. Genetic associations

Intelligence, SAI measures and personality traits were found to be inter-correlated at the phenotypic level and bivariate and multivariate analyses were used to explore aethiology of these phenotypic relations. Both bivariate and multivariate analyses show that there are shared genetic influences between IQ, SAI measures and some personality traits.

Bivariate results indicate that phenotypic associations between IQ and SAI (r = .33), IQ and Extraversion (r = −.16), and IQ and Openness (r = .21) were to 76%, 94% and 86% accounted for by their common genetic influences. The common genetic variance of SAI and Openness accounted for 67% of their phenotypic correlation (r = .21), while the common genetic variance of factor SAI and Openness accounted for 100% of their phenotypic correlation (r = .19). The same was found for phenotypic association between factor SAI and Neuroticism (r = −.10), which was 100% accounted for by common genetic influences. However, this finding that genetic influences contributing to lower Neuroticism also contribute to higher self-assessed intelligence was limited to one measure of self-assessed intelligence, factor SAI. Therefore, replication is necessary before weight is given to this finding. None of the observed phenotypic associations was found to be due to common non-shared environmental factors. For Agreeableness and Conscientiousness, no overlap of genetic or environmental factors with intelligence or SAI was observed, but there were some phenotypic associations.

Personality traits which showed phenotypic and genetic association in bivariate analyses with IQ and SAI measures were included in multivariate analyses. Results from multivariate analysis show that around 80% of IQ variance is independent of SAI measures and personality traits of Neuroticism, Extraversion and Openness. The rest of the IQ variance is due to genetic overlap with SAI measures and those personality traits. The largest amount of IQ variance is explained by personality traits, while SAI explained more than factor SAI.

Overall, the current study suggested that phenotypic associations between intelligence, SAI measures and personality traits are rooted in a common genetic origin. In other words, what makes these constructs related seems to be their common genetic background, while unique experiences affect each of these constructs independently. In combination with other recent findings from behavior genetics, this result supports the idea of pleiotropy (i.e. a set of genes affects several traits rather than only one) and generalist genes (Kovas & Plomin, 2006). We would therefore expect that genes (i.e. DNA polymorphisms) that are associated with SAI will also be linked to intelligence and some personality traits.

4.3. Limitations and conclusion

Our study is based on a sample relatively small compared to previous studies (e.g. Greven et al., 2009; Spinath et al., 2006). This has an implication on accuracy of heritability estimates reported here which have large confidence intervals. Thus, future studies are needed to replicate the current findings in larger samples of twins. However, heritability estimates of personality and intelligence are in line with previous studies and these similarities make sampling errors an unlikely explanation for the current results. Also, this study benefits from the employments of standardized, well-validated psychometric instruments for intelligence, SAI and the Five Factor Model personality.

This study confirmed that SAI was largely affected by genetic and non-shared environmental influences. Phenotypic associations between cognitive ability, SAI and personality traits, like Openness, Extraversion and Neuroticism, were largely accounted for by common genetic factors, while non-shared environmental effects were independent across constructs. Intelligence and personality have traditionally been perceived as independent entities, while SAI and related constructs may be referred to as difficult-to-classify hybrids. However, the current results make an alternative perspective also plausible, whereby personality, intelligence, and self-perceptions share one common genetic origin and hence, each might be a form of expression of Jensen's g-nexus.

References

Ackerman, P. L., & Heggestad, E. D. (1997). Intelligence, personality, and interests: Evidence for overlapping traits. *Psychological Bulletin*, *121*, 219–245.

Ackerman, P. L., & Wolman, S. D. (2007). Determinants and validity of self-estimates of abilities and self-concept measures. *Journal of Experimental Psychology. Applied*, *13*, 57–78.

Bandura, A. (1995). Comments on the crusade against the causal efficacy of human thought. *Journal of Behavior Therapy and Experimental Psychiatry*, *26*, 179–190.

Buchwald, D., Herrell, R., Ashton, S., Belcourt, M., Schmaling, K., & Goldberg, J. (1999). The Chronic Fatigue Twin Registry: Method of construction, composition, and zygosity assignment. *Twin Research*, *2*, 203–211.

Butkovic, A., & Bratko, D. (2007). Family study of manipulation tactics. *Personality and Individual Differences*, *43*, 791–801.

Chamorro-Premuzic, T., & Arteche, A. (2008). Intellectual competence and academic performance: Preliminary validation of a model. *Intelligence*, *36*, 564–573.

Chamorro-Premuzic, T., Harlaar, N., Greven, C. U., & Plomin, R. (2010). More than just IQ: A longitudinal examination of self-perceived abilities as predictors of academic performance in a large sample of UK twins. *Intelligence*, *38*, 385–392.

Chamorro-Premuzic, T., Moutafi, J., & Furnham, A. (2005). The relationship between personality traits, subjectively-assessed and fluid intelligence. *Personality and Individual Differences*, *38*, 1517–1528.

Costa, P. T., Jr., & McCrae, R. R. (1989). *The NEO-PI/NEO-FFI manual supplement.* Odessa, FL: Psychological Assessment Resources.

Costa, P. T., Jr., & McCrae, R. R. (1992). *Revised NEO Personality Inventory (NEO-PI-R) and NEO Five-Factor Inventory (NEO-FFI) professional manual.* Odessa, FL: Psychological Assessment Resources, Inc.

Costa, P. T., Jr., & McCrae, R. R. (2005). *Priručnik za Revidirani NEO inventar ličnosti (NEO PI-R) i NEO petofaktorski inventar (NEO-FFI) (Manual for NEO-PI-R and NEO-FFI).* Jastrebarsko: Naklada Slap.

Eccles, J. S., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., & Midgley, C. (1983). Expectancies, values, and academic behaviours. In J. T. Spence (Ed.), *Achievement and achievement motivation* (pp. 75–146). San Francisco: W.H Freeman.

Furnham, A., Chamorro-Premuzic, T., & Moutafi, J. (2005). Personality and intelligence: Gender, the Big Five, self-estimated and psychometric intelligence. *International Journal of Selection and Assessment*, *13*, 11–24.

Furnham, A., Kidwai, A., & Thomas, C. (2001). Personality, psychometric intelligence and self-estimated intelligence. *Journal of Social Behaviour and Personality*, *16*, 97–114.

Gao, W., Li, L., Cao, W., Zhan, S., Lv, J., Qin, Y., Pang, Z., Wang, S., Chen, W., Chen, R., & Hu, Y. (2006). Determination of zygosity by questionnaire and physical features comparison in Chinese adult twins. *Twin Research and Human Genetics*, *9*, 266–271.

Gardner, H. (1999). *Intelligence reframed.* New York: Basic Books.

Greven, C. U., Harlaar, N., Kovas, Y., Chamorro-Premuzic, T., & Plomin, R. (2009). More than just IQ. School achievement is predicted by self-perceived abilities — But for genetic rather than environmental reasons. *Psychological Science*, *20*, 753–762.

Jensen, A. R. (1998). *The g factor: The science of mental ability*. Westport, CT: Praeger Publishers.

Judge, T., Jackson, C., Shaw, J., Scott, B., & Rich, B. (2007). Self-efficacy and work-related performance: The integral role of individual differences. *Journal of Applied Psychology*, *92*, 107–127.

Kovas, Y., & Plomin, R. (2006). Generalist genes: Implications for the cognitive sciences. *Trends in Cognitive Science*, *10*, 198–203.

Luciano, M., Wainwright, M. A., Wright, M. J., & Martin, N. G. (2006). The heritability of conscientiousness facets and their relationship to IQ and academic achievement. *Personality and Individual Differences*, *40*, 1189–1199.
Mabe, P. A., & West, S. (1982). Validity of self-evaluation of ability: A review and meta-analysis. *Journal of Applied Psychology*, *69*, 280–296.
McGue, M., & Bouchard, T. J. (1984). Adjustment of twin data for the effects of age and sex. *Behavior Genetics*, *14*, 325–343.
Neale, M. C., Boker, S. M., Xie, G., & Maes, H. H. M. (2003). *Mx: Statistical Modelling. VCU Box 900126, Richmond, VA 23298* (6th Edition): Department of Psychiatry.
Neale, M. C., Eaves, L. J., & Kendler, K. S. (1994). The power of the classical twin study to resolve variation in threshold traits. *Behavior Genetics*, *24*, 239–258.
Nichols, R. C., & Bilbro, W. C. (1966). The diagnosis of twin zygosity. *Acta Genetica*, *16*, 265–275.
Peterson, E. R., & Whiteman, M. C. (2007). "I think I can, I think I can…": The interrelationships among self-assessed intelligence, self-concept, self-efficacy and the personality trait intellect in university students in Scotland and New Zealand. *Personality and Individual Differences*, *43*, 959–968.
Plomin, R., DeFries, J. C., McClearn, G. E., & McGuffin, P. (2001). *Behavioral genetics* (4th Edition). New York: Worth Publishers.
Posthuma, D., & Boomsma, D. I. (2000). A note on the statistical power in extended twin designs. *Behavior Genetics*, *30*, 147–158.
Price, T. S., Freeman, B., Craig, I., Petrill, S. A., Ebersole, L., & Plomin, P. (2000). Infant zygosity can be assigned by parental report questionnaire data. *Twin Research*, *3*, 129–133.
Reed, T., Plassman, B. L., Tanner, C. M., Dick, D. M., Rinehart, S. A., & Nichols, W. C. (2005). Verification of self-report of zygosity determined via DNA testing in a subset of the NAS-NRC Twin Registry 40 years later. *Twin Research and Human Genetics*, *8*, 362–367.
Segal, N. M. (1984). Zygosity testing: Laboratory and the test investigator's judgment. *Acta Geneticae Medicae et Gemellologiae*, *33*, 515–521.
Spinath, B., Spinath, F. M., Harlaar, N., & Plomin, R. (2006). Predicting school achievement from general cognitive ability, self-perceived ability, and intrinsic value. *Intelligence*, *34*, 363–374.
Spinath, F. M., Spinath, B., & Plomin, R. (2008). The nature and nurture of intelligence and motivation in the origins of sex differences in elementary school achievement. *European Journal of Personality*, *22*, 211–299.
Spitz, E., Moutier, R., Reed, T., Busnel, M. C., Marchaland, C., Roubertoux, P. L., & Carlier, M. (1996). Comparative diagnoses of twin zygosity by SSLP variant analysis, questionnaire, and dermatoglyphic analysis. *Behavior Genetics*, *26*, 55–63.
Sullivan, P. F., & Eaves, L. J. (2002). Evaluation of analyses of univariate discrete twin data. *Behavior Genetics*, *32*, 221–227.
Tarbuk, D. (1977). *Test 4/MFBT - Rjecnik (Vocabulary). Prirucnik za psihologijsko ispitivanje s pomoću baterije MFBT: forma P-1 (Manual). Zagreb.*
Wainwright, M. A., Wright, M. J., Luciano, M., Geffen, G. M., & Martin, N. G. (2008). Genetic covariation among facets of openness to experience and general cognitive ability. *Twin Research and Human Genetics*, *11*, 275–286.