Chapter 2
Interactions Between Socioeconomic Status and Components of Variation in Cognitive Ability

Eric Turkheimer and Erin E. Horn

In 2003, our lab published a paper demonstrating that the heritability of intelligence in 7-year-old children from the National Collaborative Perinatal Project was moderated by parental socioeconomic status (SES; Turkheimer et al. 2003). Among children raised in poor homes, identical (MZ) twins were no more correlated than fraternal (DZ) twins, heritability was close to zero, and the family environment accounted for more than half the variance; in children raised in middle-class or better homes, heritability was substantial and the effect of family environment approached zero. This finding was itself a "replication": the effect had been first reported by Sandra Scarr in the 1970s, was met with some methodological resistance at the time (Eaves and Jinks 1972), was placed on the back burner for 20 years, and then decisively replicated by Rowe et al. (1999). We have suggested that the effect be referred to as the "Scarr-Rowe" interaction (Turkheimer et al. 2009). It is not possible to be disinterested when discussing replications of one's own work, but we will do our best to do so in the current chapter. We reviewed the existing evidence in detail as recently as 2009 (Turkheimer et al. 2009), and somewhat more briefly in 2012 (Nisbett et al. 2012). We will do so again in this chapter, with emphasis on the most recent evidence. We will also dig a little deeper into the phenomenon itself.

E. Turkheimer (✉) · E. E. Horn
Department of Psychology, University of Virginia, PO Box 400400,
Charlottesville, VA 22904-4400, USA
e-mail: turkheimer@virginia.edu

E. E. Horn
e-mail: horn@virginia.edu

D. Finkel, C. A. Reynolds (eds.), *Behavior Genetics of Cognition Across the Lifespan*,
Advances in Behavior Genetics 1, DOI 10.1007/978-1-4614-7447-0_2,

2.1 Methodological Considerations

Heritabilities, let alone interactions with heritabilities, are complex quantities. A (broad) heritability is a standardized variance component, the proportion of phenotypic variance accounted for by variation in genotype. In its simplest form, heritability is computed as twice the difference between the intraclass correlations (ICCs) for MZ and DZ twins. ICCs, in turn, are ratios of within-pair and between-pair variances. So heritabilities are computed from zygosity-based differences in ratios of within- and between-pair variances, and interactions with heritabilites are about how differences between ratios vary as a function of linear or nonlinear changes in an exogenous variable.

With that in mind, an increase in heritability as a function of SES could result if MZ twin correlations increase with SES, if DZ correlations decrease, or both. Any such changes in correlations could occur because within-pair variances decrease or between-pair variances increase with SES in MZ pairs, because of the converse in DZ pairs, or because of some combination of the two. In addition, any model of variance changes in biometric components as a function of SES will also imply a model of the total phenotypic variance. Unpacking these effects is probably of greater developmental importance than focusing on the end product of standardized heritability coefficients, which are extremely hard to interpret substantively under the best of circumstances (Turkheimer and Harden, in press).

2.2 National Collaborative Perinatal Project (NCPP)

We will begin by reanalyzing some of the data we reported from the NCPP. Details of the sample can be found in our original report (Turkheimer et al. 2003). There were 114 MZ pairs and 205 DZ pairs, with abbreviated Wechsler Intelligence Scale for Children (WISC) scores obtained at 7 years of age. SES was measured as a weighted composite of parental income, education, and occupational level, and was the same for both members of the pair. We reported the quadratic effects of SES on the unstandardized and standardized variances of components attributable to the additive effect of genotype (A), environmental effects shared among siblings (C), and environmental effects unshared among siblings (E). A model including interactions between SES and each of the three ACE terms fit significantly better than a model with main effects only for Full Scale IQ (FSIQ) and Performance IQ (PIQ) but not for Verbal IQ (VIQ). For both standardized and unstandardized models of FSIQ and PIQ, the A term was near zero for children raised in the poorest homes, while the C term accounted for almost all the variation. In the most affluent homes, the situation was reversed, and the trend lines for the A and C components crossed at a level of SES corresponding to lower-middle-class homes.

We will use a slightly different, and less parameterized, model here. For Twin i in Pair j and Zygosity Group k, an IQ score y_{ijk} can be represented as a pair mean b_{0jk}, plus within-pair variance around the pair mean σ_k^2:

$$y_{ijk} = b_{0jk} + \sigma_k^2$$

The pair intercepts b_{0jk} can then be modeled as a population mean β_0 and between-pair variance τ_k^2, the variance of the pair means around the population mean. A classical twin model involves reparameterizing the within- and between-pair variances in MZ and DZ twins as the familiar ACE components: additive genetic (A), shared (C), and nonshared environmental (E) effects. In the MZ twins, the within-pair variance is equal to

$$\sigma_{MZ}^2 = E$$

and the between-pair variance is equal to

$$\tau_{MZ}^2 = A + C$$

In the DZ pairs, the within-pair variance equals

$$\sigma_{DZ}^2 = \frac{1}{2}A + E$$

And the between-pair variance equals

$$\tau_{DZ}^2 = \frac{1}{2}A + C$$

With the additional constraint that the total phenotypic variances are equal in the MZ and DZ pairs, these equations can be solved for the ACE variances. Expressing the ACE variances as proportions of their sum gives the familiar standardized ACE coefficients.

A biometric interaction model entails expressing the within- and between-pair variances, or the standardized or unstandardized ACE variances derived from them, as some function of a moderator variable, in this case, SES. We prefer an exponential function rather than a quadratic one as a model of the variances. Exponential models share with quadratic models the desirable property of being positive, but have the additional advantage of being monotonic uniformly increasing or decreasing with respect to the moderator. Quadratic models of variances are by definition parabolic with respect to the moderator, and once again, biometric interaction

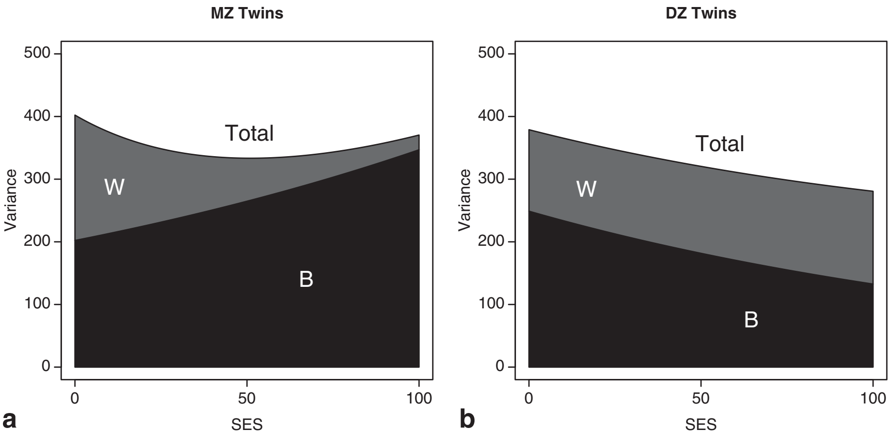

Fig. 2.1 Unstandardized between-(*B*), within-(*W*), and total variance in IQ for **a** identical (*MZ*) and **b** fraternal (*DZ*) twin pairs in the National Collaborative Perinatal Project (NCPP). *SES* socioeconomic status

models are difficult enough to explain without having to account for why a biometric variance first increases, and then decreases, as a function of SES.

In its least parameterized form, the model results in eight parameters, describing an intercept and log-linear effect of SES on the between- and within-pair variances in MZ and DZ twin pairs. The intercept tests for the magnitude of the between- and within-pair variances at SES = 0; the log-linear slopes test the interactions between the variances and familial SES. We fit the model in Mplus 6.12 (Muthén and Muthén 2011), using full-information maximum likelihood estimation. As was the case in the original report, the individual interaction terms did not reach statistical significance, but the omnibus test of a model with all four interactions fit significantly better than a main-effects model ($p = .033$).

Since all the results we will report in this paper have been reported before, and because our main goal is comparative description of results across studies, we will focus on graphical presentation. The results for the between and within variances are illustrated in Fig. 2.1a and b. In this figure, which we will use extensively, the between and within or ACE variances are plotted as an exponential function of SES and stacked on top of each other, so the model for the total variance is evident as well as the model for the individual components. In this instance, we can see that the largest effects are for the MZ pairs, for whom differences within pairs decrease as a function of SES, while differences between pairs increase. To a lesser extent, the converse is true for the DZ pairs.

The ratio of between-pair variance to total phenotypic variance defines an ICC that can also vary as a function of SES. Figure 2.2 shows the result. As would be expected on the basis of the between and within variances, the ICC increases dramatically for the MZ pairs and decreases somewhat less dramatically for the DZ pairs. Finally, the ICCs can be combined with some identifying assumptions (equal

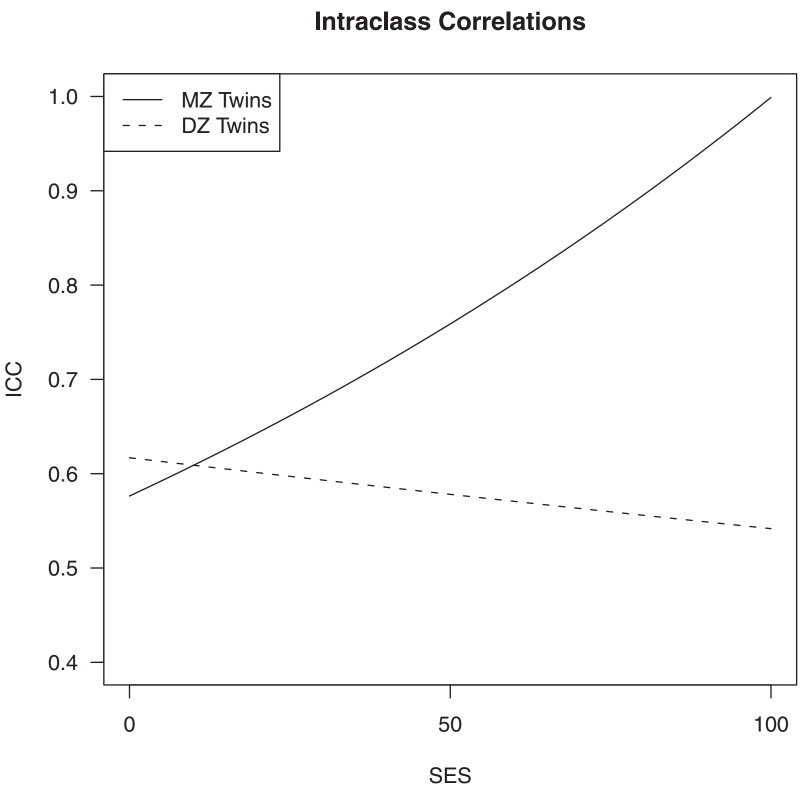

Fig. 2.2 Intraclass correlations (*ICCs*) of IQ for identical (*MZ*) and fraternal (*DZ*) twin pairs in the National Collaborative Perinatal Project (NCPP). *SES* socioeconomic status

phenotypic variance in MZ and DZ pairs, equal environmental similarity in MZ and DZ pairs, twice as much genetic similarity in MZ pairs) to parameterize the model in terms of either unstandardized or standardized variances attributed to additive genetic (A), familial environmental (C), and unique environmental (E) variances. As illustrated in Fig. 2.3a and b, these results are similar to those we originally reported. Since the total phenotypic variance has been set equal in the MZ and DZ pairs in the unstandardized ACE model illustrated in Fig. 2.3a, this is a good place to observe that the model of the total variance decreases slightly as a function of increasing SES.

We conclude that as familial SES increases, MZ twins tend to become more similar to each other, against a background of increases in the magnitude of differences between pairs. Differences within DZ pairs do not change substantially as a function of SES, whereas the magnitude of differences between pairs decreases. These between- and within-pair relations with SES can also be expressed as an increase in A variance with increasing SES, a corresponding decrease in C and E variance, or both. As will be the case in many of the studies we will review here, this

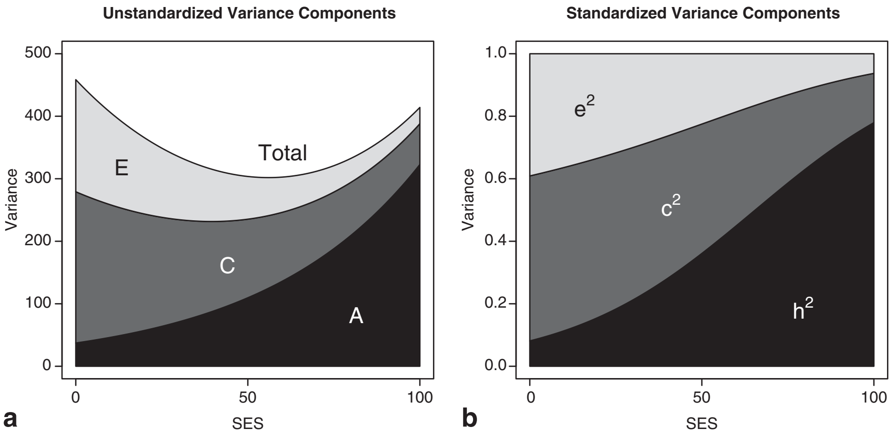

Fig. 2.3 **a** Unstandardized and **b** standardized additive genetic (*A*; h^2), shared environmental (*C*; c^2), and nonshared environmental (*E*; e^2) sources of variance in IQ in the National Collaborative Perinatal Project (NCPP). *SES* socioeconomic status

study lacks the statistical power to discriminate between changes in genetic effects as a function of SES in one direction and changes in environmental effects in the other. The effects are highly correlated, because ultimately the A, C, and E variances must sum to the total phenotypic variance.

Throughout this review, we will emphasize that the most basic biometric description of the interaction between genes and SES involves changes in MZ and DZ twin similarities and differences as a function of SES. Parameterizing these differences in terms of ACE parameters, although useful in many circumstances, involves making identifying assumptions that are sometimes viewed as controversial (Charney 2012), and introduces a level of abstraction about "genes" and "environment" that comes in between the observed data (involving changes in the between- and within-pair variances in MZ and DZ twins) and their interpretation. Standardizing the analysis to produce heritability coefficients introduces yet another layer of complexity to a phenomenon that is already difficult to understand.

Most of the studies we will review will not provide enough information to permit reinterpretation in terms of variation within and between pairs or unstandardized variance components. We will, nevertheless, focus our review on the following characteristics of study results, wherever possible:

1. Does phenotypic variance increase or decrease as a function of SES?
2. Do between- and within-twin pair variances increase or decrease as a function of SES?
3. Do MZ and DZ correlations increase or decrease as a function of SES?
4. Do standardized and unstandardized ACE components increase or decrease as a function of SES?

2.3 Early Studies

The original Scarr (Scarr-Salapatek 1971) study analyzed 635 Black and 357 White twin pairs from the Philadelphia school system who had been administered aptitude and achievement tests between the 2nd and 12th grades. Zygosity was unknown, so DZ twin correlations were estimated from the correlations in the opposite sex pairs, and MZ correlations were estimated from the difference between the same and opposite sex pairs. Tables 6 and 7 in Scarr-Salapatek (1971) report estimated ICCs for verbal and nonverbal aptitude scores broken down by race, SES, and estimated zygosity. In all four comparisons (Verbal and Nonverbal in Blacks and Whites), estimated MZ correlations were substantially lower in the lower SES group relative to the higher SES group (mean difference in correlation = .225), whereas in the DZ twins there was no difference in correlation between the high and low SES groups (mean difference in correlation = − .011). Scarr-Salapatek also reported the variances of Verbal, Nonverbal, and Total Scores for Low, Medium, and High SES Blacks and Whites. Across six (two races by three tests) comparisons, variances were higher in all six high SES groups compared to the low SES groups (mean difference = 13 %). Although Scarr-Salapatek also reported mean squares between and within twin pairs, due to the uncertainty about zygosity the data are presented in a way that does not allow computation of between- and within-pair or ACE variances for MZ and DZ twins. However, such computations are possible for Fischbein (1980), a description of which follows.

Fischbein (1980) analyzed a sample of 94 MZ and 229 DZ Swedish pairs who were administered a verbal and inductive reasoning test at age 12. Similar to Scarr-Salapatek (1971), MZ twin correlations increased as a function of increasing SES (Verbal Test r = .661, .678, and .755 for low, middle, and high SES groups, respectively; Inductive Test r = .439, .615, and .697). DZ twin correlations either decreased or were unchanged as a function of increasing SES (Verbal Test r = .519, .436, and .374; Inductive Test r = .332, .318, and .216). Fischbein (1980) reported what he called "variances" between and within pairs, although they are actually not variances but mean squares, of the kind that were commonly reported when variance components were computed using classical repeated measures analysis of variance rather than the random effects models that are more prevalent today (Shrout and Fleiss 1979). It is possible to compute the between- and within-pair variances from the mean squares Fischbein (1980) reported, and from those one can compute the ACE variances. These variances are reported in Table 2.1.The largest effects are on the between-pair variances, which decrease as a function of SES in the MZ twins and increase in the DZ twins. The pattern for the within-pair variances is less systematic, but the ACE variances follow a clear pattern: A variances increase sharply with increasing SES, while both C and E variances decrease.

van den Oord and Rowe (1998) analyzed data from 3,266 sibling, half-sibling, and cousin pairs drawn from the National Longitudinal Survey of Youth (NLSY). Children were administered the Mathematics, Reading Recognition, and Reading Comprehension tests at an average age of 9.5 years. Extensive data were available on their rearing environments. The data were analyzed using multilevel models;

Table 2.1 Between, within, and ACE variances derived from mean squares reported by Fischbein (1980)

Variance components	Low SES	Mid SES	High SES
Verbal test scores			
MZ twins			
B	21.67	25.90	26.57
W	11.13	12.20	8.61
DZ twins			
B	20.86	15.68	11.31
W	20.15	20.27	18.92
A	9.83	18.19	25.70
C	13.89	7.81	−.27
E	13.18	11.73	7.34
Inductive reasoning test scores			
MZ twins			
B	9.10	23.12	24.87
W	11.62	14.49	10.79
DZ twins			
B	12.47	13.20	23.12
W	25.11	21.46	14.49
A	10.10	16.93	29.68
C	3.23	5.46	−6.88
E	15.83	13.76	8.73

SES socioeconomic status, *MZ* identical, *DZ* fraternal, *B* between, *W* within, *A* additive genetic, *C* shared environmental, *E* nonshared environmental

ICCs were not reported. Relations between environmental variables and pair similarity were mostly small and nonsignificant. Nevertheless, the effects that were significant were in the direction of smaller nonshared environmental effects in better environments, which is consistent with the pattern observed in the Scarr-Salapatek (1971), Fischbein (1980), and Turkheimer et al. (2003) studies: higher MZ twin correlations with increasing SES.

2.4 Recent Studies

2.4.1 The National Longitudinal Study of Adolescent Health (Add Health)

Rowe et al. (1999) reported an analysis from the first wave of the Add Health Study, which included 1,909 sibling pairs: MZ twins, DZ twins, full-siblings, half-siblings, and cousins reared together. Participants were administered the Peabody Picture Vocabulary Test at a mean age of 16. Parental education was used as a measure of SES. Rowe et al. (1999) employed DeFries-Fulker (DF) analysis (DeFries and Fulker 1985), a method for biometric decomposition in which pairs are double entered, and then one member of a pair is predicted from the other member, zygosity, and the interaction of zygosity with the other member. When correctly parameterized, the regression coefficient for the other member of the twin pair is equal to the standardized estimate of the variance attributable to the shared environment, and the coefficient for the interaction is equal to the heritability. An extended version of the DF model (LaBuda and DeFries 1990) also includes a two-way interaction between the other twin member and a moderator variable (parental education) and a three-way interaction among zygosity, the other member, and the moderator. The coefficients for these terms estimate linear changes in the shared environmental and additive genetic terms, respectively, as a function of the moderator. Although the DF analysis reported by Rowe et al. (1999) does not provide enough information for us to compute between- or within-pair variances or unstandardized ACE components, their Table 6 provides pair correlations for Low and High maternal education groups separately for three groups: high relatedness (MZ twins), moderate relatedness (DZ twins and full siblings), and low relatedness (half-siblings and cousins). MZ twin correlations were lower in the low maternal education group ($r = .55$) than in the high maternal education group ($r = .75$); for the least related pairs, the effect was reversed (Low Education $r = .32$, High Education $r = .10$); the correlations in the group of DZ twins and full-siblings did not differ by maternal education (Low $r = .32$, High $r = .37$).

We have access to the Add Health data and can compute the other parameters directly. We fit a model using Mplus similar to the one we employed for the NCPP data, in which the between- and within-pair variances were estimated for the six relationship groups (we added the unrelated pairs), and then parameterized in terms of their unstandardized ACE coefficients and modeled as an exponential function of parental education. Results are illustrated in Fig. 2.4a–c. To simplify the descriptive analysis, we followed Rowe et al.'s procedure of analyzing the data in three groups of genetic relatedness: high (MZ twins), moderate (DZ twins and full siblings), and low (half-siblings, cousins, and unrelated siblings). The between-pair variance of the MZ twins increases modestly with increasing parental education, while the between-pair variance of the low relatedness group decreases. Neither effect is significant. The opposite pattern obtains within pairs, with the MZ twins becoming more similar with increasing parental education (within-pair variance decreases) while the least related pairs become more different. Once again, the individual effects are not significant. Figure 2.5 illustrates the changes in the ICC, with the high relatedness group becoming more similar and the low relatedness group less so with increasing SES. The ACE parameterization, illustrated in the left panel of Fig. 2.6a, shows that the additive genetic variance increases as a function of increasing SES ($p = .071$), while the shared environmental variance decreases ($p = .022$). The standardized components, in the right panel of Fig. 2.6b, show a similar pattern.

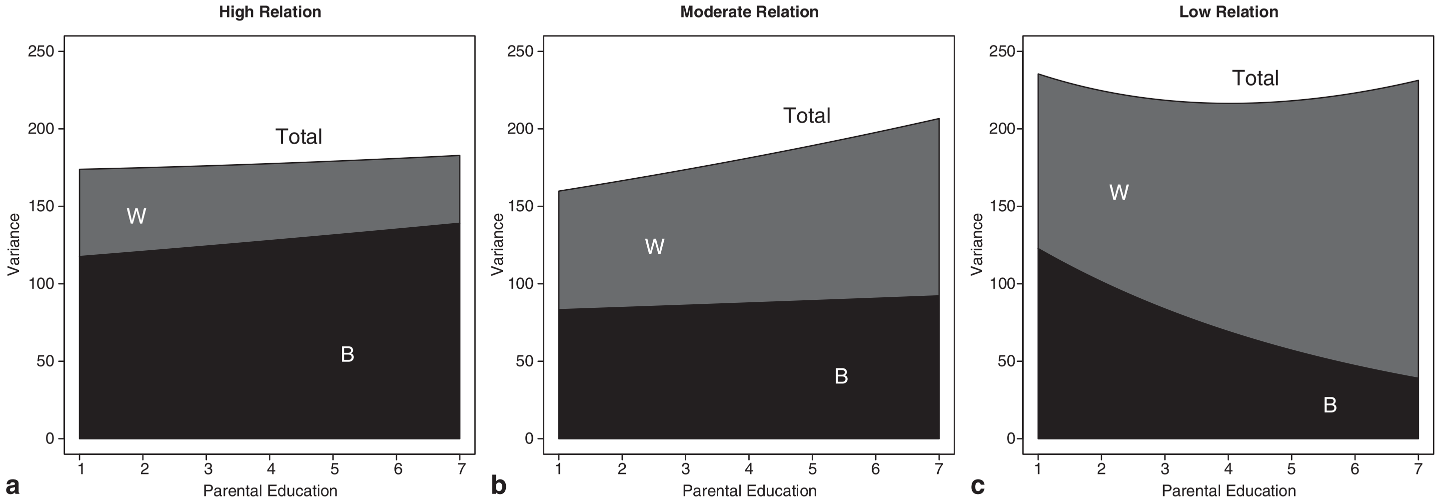

Fig. 2.4 Unstandardized between-(B), within-(W), and total variance in IQ for **a** highly related (monozygotic twins), **b** moderately related (dizygotic twins and full siblings), and **c** distantly related (half siblings, cousins, and unrelated siblings) sibling pairs in the National Longitudinal Study of Adolescent Health (Add Health). Parental education codes: *1* 8th grade or less, *2* did not graduate high school, *3* high school diploma or trade school, *4* trade school after high school, *5* some college, *6* college degree, *7* postgraduate education

http://www.springer.com/978-1-4614-7446-3

Behavior Genetics of Cognition Across the Lifespan
Finkel, D.; Reynolds, C.A. (Eds.)
2014, XV, 300 p., Hardcover
ISBN: 978-1-4614-7446-3