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Genotype–Environment Interaction in Personality Development: Identical Twins Reared Apart

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The focus of this study is to identify specific genotype–environment (GE) interactions as they contribute to individual differences in personality in later life. In behavioral genetics, GE interaction refers to the possibility that individuals of different genotypes may respond differently to specific environments. A sample of 99 pairs of identical twins reared apart, whose average age is 59 years, has been studied as part of the Swedish Adoption/Twin Study of Aging (SATSA). Hierarchical multiple regression was used to detect interactions between personality and environmental measures after the main effects of genotype and environment were removed. Analyses yield evidence for 11 significant interactions that provide the first evidence for GE interaction in human development using specific environmental measures. Thus, in addition to the main-effect contributions of heredity and environment, GE interactions contribute to individual differences in personality as measured in the second half of the life course.

Although older individuals are often caricatured by stereotypes, differences among individuals during senescence are at least as marked as in any other developmental era. Individual differences in personality and personality development are also evident during the last half of the life course. It is reasonable to expect that descriptive and explanatory relationships in development involve complex interactions rather than simple main effects. For example, in early childhood, it has been speculated that an easy temperament might buffer a child against a difficult environment (Garmezy & Rutter, 1983). Similarly, in later life, stress may have a disproportionate effect on vulnerable individuals. Organismic specificity in reaction to environments is one of the major hypotheses that emerges from a thorough review of early experience in human development.

> Both from basic and applied data it has become increasingly clear that the relationship of early experience to development will be mediated by the nature of the organism on which the experience impinges. Unfortunately, virtually nothing is known about the specific organismic characteristics which mediate differential reactivity to the early environment. (Wachs & Gruen, 1982, p. 247)

It is reasonable to assume that similar developmental interactions occur in later life. The term *interaction* has many meanings, and rather than address systems theory or other conceptual approaches to interaction, the present article considers a specific category of statistical interaction—genotype–environment (GE) interaction. Although this is a restricted view of interaction, it has the merit of leading directly to empirical research that attempts to identify statistical interactions between genetic and environmental effects, thus going beyond the traditional approach of behavioral genetics, which stops with the estimation of genetic and environmental main effects.

Previous behavioral genetic research in adulthood, using both the twin and adoption methods, has shown that many dimensions of personality are influenced by both genotype and environment (Bouchard, 1984; Canter, 1973; Eaves & Young, 1981; Juel-Nielsen, 1965; Loehlin, 1976; Shields, 1962; Wilde, 1964). For some traits, such as extraversion and neuroticism, as much as half of the phenotypic variance can be accounted for by genetic influences (Floderus-Myrhed, Pedersen, & Rasmusson, 1980). A recent report from the Swedish Adoption/Twin Study of Aging (SATSA)—which includes twins reared apart as well as twins reared together—indicates genetic influence on extraversion and neuroticism, as well as other dimensions of personality during the second half of the life course (Pedersen, Plomin, Nesselroade, McClearn, & Friberg, 1988; Plomin, Pedersen, McClearn, Nesselroade, & Bergeman, 1988). Previous research, however, has focused primarily on the main-effect contributions of heredity and environment, without addressing the possible contribution of their interaction. The primary focus of

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this study is to identify specific GE interactions as they contribute to individual differences in personality during the second half of the life course.

In behavioral genetics, GE interaction refers to the possibility that individuals of different genotypes may respond differently to specific environments (Plomin, DeFries, & Loehlin, 1977). Alternatively, GE interaction can be described as the differential effects of environment on individuals. The concept represents an important perspective for understanding the effects of environmental influences on individual development. Rather than searching for environmental influences that equally affect all individuals, it considers environmental influences that may powerfully affect only a small group of individuals with certain genetic dispositions.

In nonhuman animals, studies of GE interactions have been facilitated by the availability of inbred strains of mice, which differ genetically between strains but are nearly identical genetically within strains. Rearing various inbred strains of mice in several distinct environments permits a direct test of genetic main effects, environmental main effects, and GE interactions. For example, in a series of studies involving thousands of mice, Henderson (1968, 1970, 1972) systematically explored GE interactions. Although significant GE interactions were detected, few showed consistency across studies (see review by Fuller & Thompson, 1978).

In research with human beings, it is not possible to select multiple copies of genotypes from pure inbred strains as in the case of mice, nor is it possible to subject them to environments as extreme as the deprived or enriched environments used in laboratory research on nonhuman animals. Nonetheless, the adoption design can provide a test of GE interaction, in that genetic propensities of adoptees can be estimated from the phenotypes of biological relatives. This genotypic estimate can be studied as it interacts with measured aspects of the environment to affect the adoptees' scores on the phenotype (Plomin et al., 1977). This approach, however, has as yet uncovered few examples of GE interaction (Plomin, 1986). One likely reason is that previous adoption studies have involved first-degree relatives–typically biological parents and their adopted-away offspring. Thus, the genotypic estimate is at best an estimate of one half of the adoptees' genotype, which greatly limits the power to detect genotype–environment interactions.

Monozygotic (MZ) twins who are separated early in life and reared apart provide an enriched test for GE interaction in humans because the twins are genetically identical. This method, however, is limited by both the rarity of identical twins reared apart and studies that include specific measures of the rearing environment. An unprecedented opportunity has emerged in Sweden for the study of individual differences in aging. A large sample of elderly twins who were reared apart has been identified in the Swedish Twin Registry and is participating in the ongoing Swedish Adoption/Twin Study of Aging (SATSA; McClearn, Pedersen, Plomin, Nesselroade, & Friberg, 1987; Pedersen, Friberg, Floderus-Myrhed, McClearn, & Plomin, 1984).

To the extent that a trait is heritable—that is, to the extent that there is genetic influence, on average, in the population—the genetic propensity of one twin can be estimated from the phenotype of the reared-apart co-twin. Although we are actually comparing phenotypes for reared-apart individuals (in the absence of selective placement), any similarity between them is due to genetic influences. Thus, the co-twin's phenotype is the best available estimate of the twin's genotype. This genotypic estimate can then be studied as it interacts with measured aspects of the environment to affect scores on the phenotype of interest. For the purposes of illustration, the phrases *high G* and *low G* are used to denote extremes of genetic influence for a particular trait, and are intended as population concepts referring to genotypic differences among individuals: High G refers to individuals with a genotypic propensity to score high on a given trait, and low G refers to individuals with a hereditary tendency to score low on the trait of interest.

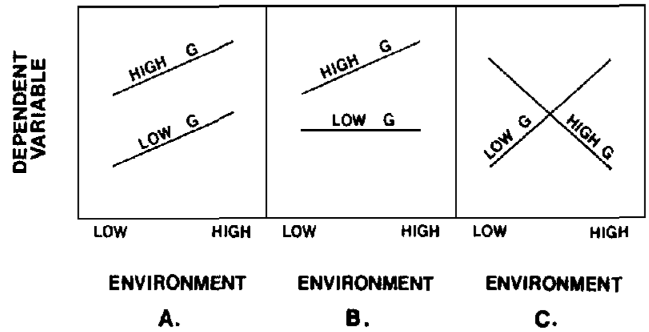

Figure 1. Some hypothetical examples of genotype–environment interaction. (Figure 1a shows main effects with no interactions; in this case, main effects and interactions are independent. In the last Figure 1c, the opposite is true—interactions occur without main effects. Such reversed effects are rare. Figure 1b is the most likely type of interaction—an environmental factor has an effect only for certain genotypes.)

Figure 1 illustrates some hypothetical examples of GE interaction that make the point that main effects and interactions are independent. For example, main effects can occur without interaction, as in Figure 1a. Interactions can also occur without main effects, as in Figure 1c; however, disordinal interactions of this sort are rare. The most likely type of interaction, an ordinal interaction, is illustrated in Figure 1b: An environmental factor has an effect only for certain individuals.

To illustrate analyses of GE interactions, consider a 2 × 2 design involving the extraversion scores of twins. The score of one reared-apart identical twin is an estimate of the genotype of the other identical twin; thus, a genetic main effect will be observed if twins whose twin partners score high on an extraversion scale also score high on the extraversion scale, regardless of the environment in which they were reared. Similarly, an environmental main effect will be observed if low versus high control of the rearing home affects extraversion level, regardless of genetic propensities toward extraversion. Whether or not such genetic and environmental main effects are observed, GE interaction can emerge; as mentioned before, however, disordinal interactions of this sort are rare. The most likely type of interaction, an ordinal interaction, occurs when an environmental factor has an effect only for certain individuals.

No general theories of GE interaction have been proposed—indeed, it is likely that the process underlying GE interaction will differ for different combinations of behavioral and environmental measures. Nonetheless, we suggest three possible types of ordinal GE interactions.

As illustrated in Figure 2a, a Type-1 GE interaction occurs

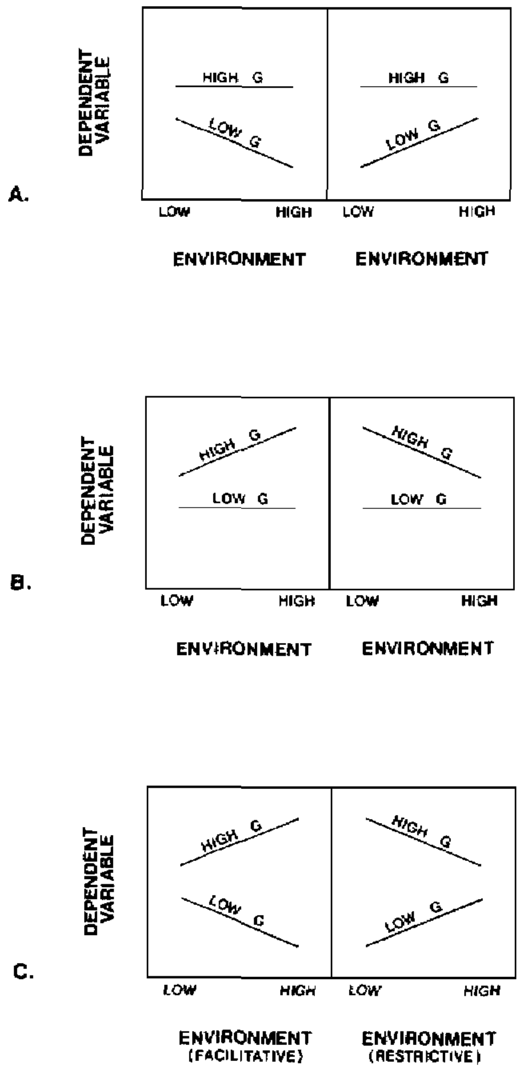

Figure 2. Examples of three types of ordinal genotype–environment (GE) interactions. (Figure 2a illustrates Type-I GE interactions; Figure 2b, Type-II GE interactions; and Figure 2c, Type-III GE interactions.)

when the environment has a greater impact on individuals with a genotype to score low for a given trait. That is, genotypes to score high (high G) on a certain trait express high phenotypic scores regardless of the characteristics of the rearing environment. For example, individuals genetically predisposed toward extraversion may be extraverted regardless of their family's social control, whereas individuals predisposed toward low extraversion may be affected by the family's level of control.

The second possible type of GE interaction occurs when the environment affects individuals with a genotype to score high for a given trait, but not low-G individuals. Thus, the resulting interaction, depicted in Figure 2b, will be a Type 1 interaction upside down. In our extraversion example, a genotype to score high on the extraversion trait (high G) could be either exacerbated or diminished by families high in control, whereas individuals with a genetic tendency for low extraversion scores (low G) might be little affected by control.

The difference between a Type-1 and a Type-2 GE interaction can be definitional. That is, by redefining the terms *high G* and *low G* from a genotype to score high or low for a particular trait, like extraversion, to differentiate it into a bipolar relation—such as introversion versus extraversion—a Type I and a Type II may be indistinguishable. That is, our example could be phrased in terms of high G for introversion, not a low G for extraversion. We feel it is important conceptually, however, to distinguish between the possibilities that, for a given trait, environmental factors might affect one end of the distribution more than the other.

A third type of GE interaction occurs when the environment influences both high-G and low-G individuals, but in opposite directions. Type III interactions have been suggested in the GE interaction research of Henderson (1968, 1970, 1972), in which different inbred strains of mice were reared in different environments. In his research, Type-III GE interactions emerged in that genetic differences between strains were masked in high controlling environments and emerged in more permissive environments. That is, a restrictive environment reduces the overall magnitude of genetic effects and suppresses genetic variation, whereas a less restrictive environment allows genetic differences to emerge, as illustrated in Figure 2c. For example, in highly controlling families, genetic differences between individuals' extraversion may be muted in contrast to less controlling families.

In summary, the focus of this study, therefore, is not genetic or environmental main effects, but rather the possible interaction between early rearing environment and genetic influences on personality development as measured in later life. In addition to identifying examples of specific GE interactions, we are also interested in exploring whether general principles of GE interaction can be formulated.

Method

Subjects

The subjects in the present study were 99 pairs of identical twins reared apart (MZA), identified in the Swedish Twin Registry as part of the Swedish Adoption/Twin Study of Aging (SATSA). Recruitment and characterization of the entire SATSA sample is described elsewhere (McClearn et al., 1987; Pedersen et al., 1984). In brief, the Swedish Twin Registry contains information on both members of nearly 25,000 pairs of like-sex twins born in Sweden between 1886 and 1958. A total of 750 intact pairs (346 reared apart and 404 reared together) from these constitute a subregistry, SATSA.

In the fall of 1984, a short form of the Eysenck Personality Inventory (Floderus, 1974), the Karolinska Scales of Personality (KSP; Schalling, Edman, & Asberg, 1983), and a modified version of the Family Environment Scale (FES; Moos & Moos, 1981) were included in the battery of questionnaires sent to the SATSA twins. Analyses described in the present report are based on pairwise responses from 99 pairs of identical twins reared apart.

The zygosity of twins in the Swedish Twin Registry was diagnosed on the basis of physical similarity in childhood. Although this method is accurate for twins in general, twins who have been reared apart are unable to answer questions about their childhood similarity. For this reason, a new zygosity questionnaire was developed that added questions concerning adult eye color, hair color, hair texture, hair curliness, and several questions concerning overall physical similarity (strangers confuse twins, friends confuse twins, family members confuse twins, and twins are as similar as peas in a pod), and the twins' own beliefs concerning zygosity. A discriminant function of these items was applied to twins reared apart, using as a criterion the Swedish Twin Registry diagnosis of zygosity for twins reared together. To facilitate this, the twins reared apart were also asked about their similarity of appearance upon reunion. This procedure diagnosed 99 pairs of twins reared apart as identical.

Within the next few years, blood will be obtained from all of the SATSA twins that will permit single-gene analysis of blood types, serum proteins, and red-cell enzymes that can exclude a diagnosis of identical twin and can be used to validate the present procedures for diagnosing zygosity. However, physical similarity indices consistently show greater than 90% accuracy when validated against analyses of single-gene markers in blood (Plomin, DeFries, & McClearn, 1980), and a similar approach has been used in other studies (Mangus, Berg, & Nance, 1983). Thus, reasonable confidence can be placed in the present procedures for diagnosing zygosity.

The average age of the twins at the time of testing was 58.6 years (SD = 13.6 years); 60% of the twins are women, which conforms to the expected increase in women during the last half of the life span. The SATSA twins are generally representative of twins in the Swedish Twin Registry, except for age. The SATSA twins are older because most reared-apart twins were born in the first three decades of this century when economic depression and epidemics increased the likelihood of separation. The average age of separation was 2.8 years; 48% of the pairs were separated during the first year of life, and 82% were separated by 5 years.

If reared-apart twins are reared in correlated environments, their resemblance on the personality measures could reflect shared environment as well as shared heredity. In adoption research, this issue is known as selective placement, which can inflate estimates of both genetic influence and the influence of shared environment. If shared environment is not important, however, selective placement will not affect estimates of genetic influence. To directly address selective placement effects on personality and measures of the rearing environment, model-fitting analyses of the SATSA data were used, with results that showed little effect for selective placement on personality variables (Pedersen et al., 1988; Plomin, Pedersen, et al., 1988) and on the FES measures of early rearing environment (Plomin, McClearn, et al., 1988).

Measures

Personality. Items included in the SATSA questionnaires for extraversion and neuroticism variables are based on a short form of the Eysenck Personality Inventory (EPI, Form B; Floderus, 1974) which is widely used in Scandinavian twin registries (Floderus-Myrhed et al., 1980; Koskenvuo, Langinvainio, Kaprio, Rantasalo, & Sarna, 1979; Tarkkonen, Koskenvuo, Kaprio, Langinvainio, & Floderus-Myrhed, 1981). The dimension of neuroticism, or emotional stability, describes at one extreme people who tend to be moody, touchy, anxious, and restless. At the other extreme are people who are characterized as stable, calm, carefree, even-tempered, and reliable. Extraversion describes, at one end, people who are sociable, like parties, have many friends, crave excitement, and tend to be impulsive. At the other end are people who are quiet, retiring, and are reserved and distant except to intimate friends (Eysenck & Eysenck, 1975).

A total of 18 items have been selected from the inventory, 9 for each dimension (neuroticism and extraversion). Each scale is based on the sum of 0 and 1 (no/yes) responses to the items. Internal consistency as measured by Cronbach's alpha was 0.66 and 0.75 for extraversion and neuroticism, respectively. This is consistent with the alphas based on the entire Swedish Twin Registry (Floderus-Myrhed et al., 1980) and are somewhat lower than those reported for the full scales in the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975).

The Impulsivity and Monotony Avoidance scales from the KSP (Schalling et al., 1983) were also administered. Impulsivity items predominantly reflect acting on the spur of the moment and rapid decision making. For example, items include, "I often rush into new things" or "When I make decisions, I usually do it quickly" (Schalling et al., 1983). The Monotony Avoidance scale is related primarily to Zuckerman's (1971) boredom susceptibility and disinhibition dimensions of sensation seeking. It is characterized by such items as, "I am drawn to places where exciting things happen" or "I have an unusually great need for change." For these two measures, scale scores were calculated as the sum of responses to each of 10 items based on a 5-point Likert format. Cronbach's alpha was 0.72 for Impulsivity and 0.76 for Monotony Avoidance.

Rearing environment. The FES (Moos & Moos, 1981), altered to obtain retrospective perceptions of family environment in childhood, was used to assess early rearing environment. The present application, shortened from 90 to 45 items, is described in detail elsewhere (Plomin, McClearn, et al., 1988). The following eight scales were defined according to the original FES scoring system: Cohesion, Expressiveness, Conflict, Achievement Orientation, Culture–Intellectual Orientation, Active-Recreational Orientation, Organization, and Control. In addition to primary scales, the FES assesses three higher order dimensions: relationship (cohesion, expressiveness, low conflict), personal growth (achievement, culture, active), and system maintenance (organization, control). The scales were summed appropriately with equal weight, reversing the score for Conflict, to create the three second-order FES scores.

A second measure of early rearing environment is socioeconomic status (SES). In order to improve upon education and occupation as indices for SES, the twins were asked more detailed questions concerning their rearing family. In addition to highest level of education and occupation achieved by either parent, the following information was obtained: Density of the home (number of rooms divided by the number of persons); family had a summer cottage; family had a boat; family's economy compared with others at that time; and how well family's money met needs. The cottage and boat items were summed to produce one score, and the six items were submitted to a principal component analysis. All items loaded highly on a first unrotated principal component, which accounted for 36% of the total variance. Thus, the six items were standardized and summed with equal weight to produce an index to be used in analyses of SES.

Design

Full use of the data from a study of separated identical twins entails the analysis of variables in a continuous, rather than dichotomous manner. Thus, this study used hierarchical multiple regression (HMR; Cohen & Cohen, 1975) instead of 2 × 2 analysis of variance (ANOVA) in which variables are arbitrarily dichotomized as in the previous illustration (Figure 2). In overview, the HMR predicts one twin's score on a personality variable from the other twin's score, an FES measure of the environment, and the two-way product of these variables. More specifically, the basic HMR model may be summarized as follows:

$$Y = \underbrace{B_1X_1 + B_2X_2}_{\text{Step 1}} + \underbrace{B_3X_1X_2}_{\text{Step 2}} + C.$$

Y is one twin's (Twin A) expected personality score; X_1 is the other twin's (Twin B) score on the same personality variable; X_2 is an environmental score from the FES (Twin A). The GE interaction is represented by the product X_1X_2 from which the main effects have been partialed, as is typical in analyses of statistical interaction. B_1 is the partial regression of Y on X_1 (a measure of genetic resemblance); B_2 is the partial regression of Y on X_2 (a measure of the effect of environment). The significance of the main effects and the interactions are tested sequentially. Thus, B_1 and B_2 are estimated from the data on Y, X_1, and X_2 during Step 1; the two-way interaction, B_3, is added during Step 2. The increment of the squared multiple regression, due to the product during the second step, is attributed to GE interaction and may be tested for statistical significance. The two-way interaction is indicative of a conditional relation in that the effect of the environment on personality depends on one's genotype.

Results

Descriptive Statistics

Means and standard deviations for all measures by gender are shown in Table 1 (personality measures) and Table 2 (environmental measures). Results of ANOVA for gender and age (in 5-year age bands) for the entire sample are reported elsewhere (Pedersen et al., 1988; Plomin, McClearn, et al., 1988). To correct for main-effect influences of gender and age, all variables were corrected using a standardized residual from a multiple regression of each measure on age, gender, and the Age × Gender interaction (McGue & Bouchard, 1984).

Correlations

As in the case of the Swedish Twin Registry, extraversion and neuroticism are negatively correlated (−.31; Floderus-Myrhed et al., 1980). Extraversion is positively correlated with both impulsivity (.29) and monotony avoidance (.44); neuroticism, however, shows no correlation with these variables. Monotony avoidance and impulsivity correlate .44.

Hierarchical Multiple Regression

Hierarchical multiple regression analyses were applied to the SATSA MZA data in order to assess genotype–environment interactions. As explained earlier, the HMR predicts one twin's (Twin A) personality score from the other twin's (Twin B) personality score (the measure of genotype), an environmental score (Twin A), and the two-way product of these variables. HMR analyses were conducted for the EPI scales of Extraversion and Neuroticism, and the KSP measures of impulsivity and monotony avoidance. The eight FES scales of Cohesion, Expressiveness, Conflict, Achievement Orientation, Culture–Intellectual Orientation, Active-Recreational Orientation, Organization, and Control, the second-order factors of Relationship, Personal Growth, and System Maintenance, as well as SES, were used as environmental measures.[1]

Table 1
Means and Standard Deviations by Gender for the Personality Measures

Personality trait	*n*	*M*	*SD*
Extraversion			
Men	100	4.99*	2.12
Women	94	4.14	2.36
Neuroticism			
Men	100	2.46*	2.28
Women	94	3.48	2.63
Impulsivity			
Men	98	26.81*	5.58
Women	94	24.84	6.86
Monotony avoidance			
Men	98	25.57*	6.43
Women	94	22.67	5.86

* $p < .05$.

Table 2
Means and Standard Deviations by Gender for the Environmental Variables

Environmental measure	*n*	*M*	*SD*
Cohesion			
Men	90	17.73	4.24
Women	90	18.45	3.88
Expressiveness			
Men	88	15.44	3.57
Women	82	16.00	4.05
Conflict			
Men	88	18.33	3.51
Women	90	19.03	3.46
Achievement			
Men	88	13.65	3.38
Women	84	14.54	3.17
Culture			
Men	88	11.88	4.79
Women	86	11.47	4.46
Activity			
Men	90	12.22	4.11
Women	86	12.30	4.17
Organization			
Men	88	18.07*	3.36
Women	90	20.56	3.61
Control			
Men	88	16.61*	4.40
Women	90	18.29	3.68
Relationship			
Men	88	51.71	7.27
Women	80	52.90	7.80
Personal growth			
Men	88	37.77	9.81
Women	80	38.51	9.20
System maintenance			
Men	88	34.65*	7.04
Women	88	38.72	6.53
Socioeconomic status			
Men	76	3.25*	3.03
Women	74	2.36	2.40

* $p < .05$.

Results for significant GE interaction are shown in Table 3. In all, 11 analyses (of 48) showed significant GE interactions at the $p < .05$ level. Because this is a conservative method for detecting interactions (Cronbach, 1987), interactions significant at $p < .10$ level were also interpreted. In general, the GE interactions accounted for less than 7% of the total variance. Given an overall squared multiple correlation of .2, and the current sample size, interactions that account for 5% of the variance can be detected with 80% power.

In order to interpret these interactions, and for ease of graphic representation, the genotypic and environmental scores were divided at the median, and 2 × 2 ANOVA were conducted. As can happen, because of the loss of information when dichotomizing variables into high and low, some interactions are no longer significant. Note, then, that the magnitude of the effect is conveyed wholly in the interaction effect sizes and not by the apparent slope of the lines in the following figures. The purpose

[1] Tables showing detailed results from all hierarchical multiple regression analyses are available from the first author.

Table 3
Significant Genotype–Environment (GE) Interactions in the SATSA MZA Data

GE Interaction	$F(1, 134)$	p	Variance (%)[a]
Extraversion × Control	8.73	<.01	6
Extraversion × Organization	7.50	<.01	5
Extraversion × System Maintenance	9.42	<.01	6
Neuroticism × Socioeconomic status	4.13	<.05	3
Neuroticism × Active	6.89	<.01	5
Neuroticism × Personal Growth	3.51	<.06	2
Impulsivity × Socioeconomic Status	9.99	<.01	6
Impulsivity × Active	6.74	<.01	4
Impulsivity × Conflict	5.17	<.05	3
Impulsivity × Personal Growth	4.59	<.05	3
Monotony Avoid × Control	3.13	<.08	2
Monotony Avoid × Organization	4.37	<.05	3
Monotony Avoid × Achievement	3.23	<.08	2
Monotony Avoid × System Maintenance	4.47	<.05	3

Note. SATSA = Swedish Adoption/Twin Study of Aging; MZA = monozygotic twins reared apart.
[a] Percentage of total variance explained by the interaction term.

of the figures is to provide a tool for the graphic illustration of the direction of the effects.

Eysenck Personality Inventory. For the EPI measure of extraversion, three significant GE interactions were found. All three were associated with control-related dimensions of the FES: control, $F(1, 134) = 8.73$; organization, $F(1, 134) = 7.50$; and system maintenance (the second-order factor that is composed of the Control and Organization scales), $F(1, 134) = 9.42$. The Control scale is exemplified by "We had to follow the rules strictly in our family," whereas Organization is characterized by "We were usually very neat and proper." The interactions (depicted in Figure 3) reflect the Type I interpretation. In general, the illustrations indicate that a genotype for high extraversion (depicted as high G) is not affected by a controlling or restrictive environment. In contrast, the environment has a differential affect on individuals with a genotype for low extraversion scores (low G). That is, low-G individuals reared in a low controlling environment express extraversion scores that are significantly higher than for low-G individuals reared in an environment perceived as highly controlling. These GE interactions accounted for approximately 6% of the variance.

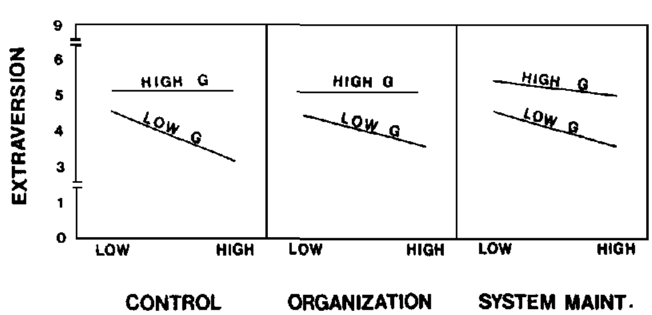

Figure 3. Genotype–environment interactions with Eysenck Personality Inventory extraversion.

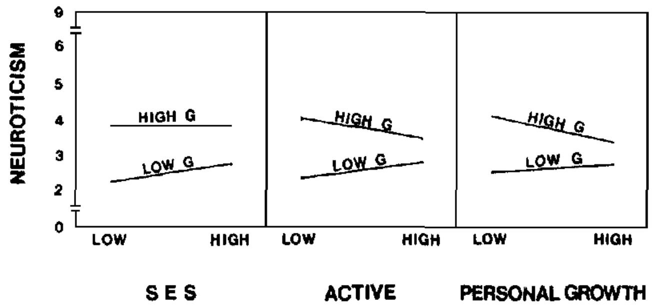

Figure 4. Genotype–environment interactions with Eysenck Personality Inventory neuroticism.

The EPI measure of neuroticism showed significant GE interactions with SES, the FES Active scale, and the second-order factor of Personal Growth: $F(1, 134) = 4.13$, $F(1, 134) = 6.89$, and $F(1, 134) = 3.51$, respectively. Illustrations using ANOVA are shown in Figure 4. The interpretation of the GE interaction between neuroticism and SES is also similar to the Type I interpretation. That is, individuals with a genotype for low neuroticism (low G) score higher on the Neuroticism scale when reared in a high-SES environment versus being reared in a low-SES environment. On the other hand, individuals with a genotype for high neuroticism scores (high G) showed no differences across levels of SES.

The GE interactions between neuroticism and the FES Active Scale, as well as the interaction with personal growth, reflect Type III interaction in that both high-G and low-G individuals are affected by rearing environment, but in the opposite direction. The Active scale measures such things as "Members in our family often went out and enjoyed themselves" and "We often went to the cinema, sports events." Personal Growth is the second-order factor composed of the Active scale, as well as Achievement and Culture. One possible description of the GE interaction between neuroticism and the Active scale, and similarly with Personal Growth, is that individuals with a high G for neuroticism score lower on the EPI Neuroticism scale when the environment is perceived as high in activity or when FES Personal Growth is high, whereas those with a low G show an increase in their neuroticism scores.

Karolinska Scales of Personality. Analyses from the KSP measures of impulsivity and monotony avoidance resulted in eight significant interactions, four for each scale. For Impulsivity, significant interactions emerged with SES, $F(1, 134) = 9.99$; Active, $F(1, 134) = 6.74$; Conflict, $F(1, 134) = 5.17$; and Personal Growth, $F(1, 134) = 4.59$. Illustrations of these results are shown in Figure 5. For SES, Active, and Personal Growth, one interpretation of these results, reflecting Type I, is that the environment has the greatest effect on those individuals with a genotype for low scores on these measures. That is, those individuals with a high G for impulsivity exhibit it regardless of the rearing environment. On the other hand, those individuals with a low G are differentially affected, with environments high in SES, Activity, and Personal Growth resulting in individuals who score much higher on the Impulsivity scale than those reared in environments low in these measures.

For the environmental measure of Conflict (i.e., "Family members quarreled a lot"), a Type II interaction emerges. Re-

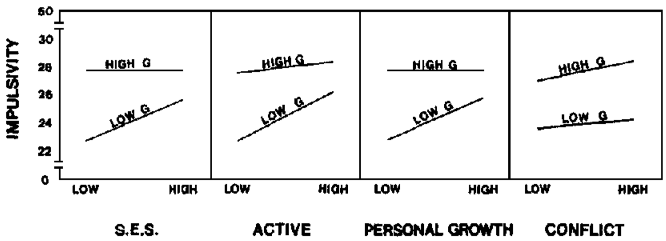

Figure 5. Genotype–environment interactions with Karolinska Scales of Personality impulsivity.

sults suggest that a high G for impulsivity is exacerbated by an environment high in conflict, whereas individuals with a genetic tendency for low impulsivity scores (low G) are not affected by conflict in the rearing environment.

The results of GE interaction analyses for Monotony Avoidance are depicted in Figure 6. Significant GE interactions were found with control-related dimensions: Control, $F(1, 134) = 3.13$; Organization, $F(1, 134) = 4.37$; and System Maintenance, $F(1, 134) = 4.47$, as well as the Achievement scale, $F(1, 134) = 3.23$. In interactions between Monotony Avoidance and Organization, and less clearly, System Maintenance, the influence is on individuals with a low G (Type I interaction). As might be expected, a rearing environment high in organization and system maintenance results in lower scores on the Monotony Avoidance scale for those individuals. For Control, high G individuals are primarily affected reflecting a Type II interaction: For individuals with a high G, an environment perceived as highly controlling decreases Monotony Avoidance scores for those individuals.

In the interaction between monotony avoidance and the FES Achievement scale, there is an increase for both high-G and low-G individuals raised in an environment perceived as high on FES achievement; however, there is a greater increase for the high-G individuals (Type II interaction). The Achievement scale measures such things as "In our family it was considered important to get somewhere in life" and "We always strove to do things a little better the next time."

Discussion and Conclusions

Although it is reasonable to assume that genotypic expression can be differentially influenced by early rearing environment, GE interaction has rarely been considered in human research. The Swedish Adoption/Twin Study of Aging provides an opportunity to investigate individual differences in an elderly population never before available in human research: Monozygotic twins, separated early in life, and reared apart, provide a natural experimental situation to compare the performance of identical genotypes reared in separate environments.

One problem contributing to the complexity of interactional analyses is that no formal theory exists to guide the selection of the variables to be included in these analyses. For this reason, we have attempted to outline three possible types of ordinal GE interactions.

One type suggests that the environment has a greater impact on individuals with a genotype for low scores for a given trait. The present research provided some examples of Type I-GE interactions, such as extraversion as it interacts with familial control. Individuals with a genotype for high-extraversion scores (high G) express the trait regardless of the amount of control or organization in their rearing environment; for individuals with a genotype for low extraversion (low G), a perceived family environment high in control or organization resulted in lower extraversion scores. The impulsivity data showed a similar pattern with SES, Activity, and Personal Growth. Environments high in these variables resulted in increased scores on the Impulsivity scale for individuals with a low G for this trait.

A second type of GE interaction is essentially a Type I interaction upside down. That is, the environment affects individuals with a genotype to score high for a given trait, but not low-G individuals. Examples of Type II interactions were also illustrated: A high G for impulsivity is exacerbated by an environment high in conflict. On the other hand, an environment perceived as highly controlling decreases monotony avoidance scores for individuals with a high G for this trait, but shows little influence on individuals with a low G for the trait.

The third type of GE interaction occurs when the environment influences both high G and low G, but in opposite directions. Most of the evidence for this type has come from mouse research, and the support is for a particular variety of Type III interactions: Genetic effects are masked in high controlling environments and emerge in more permissive environments. That is, a restrictive environment may reduce the overall magnitude of genetic effects and suppress genetic variation, whereas a less restrictive environment will allow genetic differences to emerge. An example of Type III interactions was the interaction between neuroticism and familial activity and personal growth. This Type III interaction could be construed to be similar to the interactions in the mouse research—that is, genetic effects are masked in controlling environments—if familial push toward personal growth (which includes, along with activity, a push towards achievement and independence) is viewed as control. Thus, genetic differences between high G and low G differ in the less controlling family environment but not in the more controlling families.

Although developmentalists are only beginning to systematically explore interactions across the lifespan, few consistent interactions have emerged. The hierarchical multiple regression analyses of the SATSA personality traits provide some of the first evidence for GE interaction using specific environmental measures. Although the percentage of variance explained by GE interaction is small, the concept is still important: Perceptions of early rearing environment interact with genetic factors

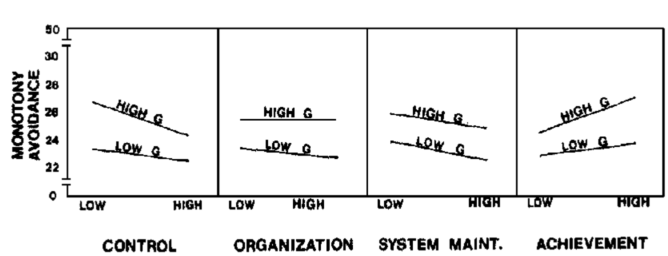

Figure 6. Genotype–environment interactions with Karolinska Scales of Personality monotony avoidance.

to affect personality during the second half of the life course. Not only is development an interactive process at any point in time, but also an interactive process across the life span.

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