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Gene-Environment Correlation

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Synonyms

$2Cov_{GE}$; Cov_{GE}; Gene-Environment Covariance; rGE

Definition

In population and behavioral genetics, gene-environment correlation occurs when genetic variance and environmental variance are correlated in a heritability analysis. This happens when there is an association between an individual's genetic background and their environment, resulting in an association between environmental and genetic differences at a population level.

Introduction

Heritability (H^2) is a statistical parameter that estimates how much variation in a trait or phenotype within a population is due to genetic differences between individuals in that population. To arrive at an estimate, variation is encompassed in the statistical term variance. H^2 is summarized as the proportion of genetic variance (V_G) (as opposed to environmental variance (V_E)) that accounts for phenotypic variance (V_P) (Eq. 1):

$$H^2 = \frac{V_G}{V_P} \tag{1}$$

For instance, if one were measuring the phenotype IQ and arrived at $H^2 = 0.8$, then 80% of the variance in IQ is explained by variance in genetics within that population. The other 20% is accounted for by environmental variance between individuals.

This statistic relies on the assumption that V_G and V_E act additively to produce V_P, so that there is no statistical interaction or correlation between the two terms (Eq. 2):

$$V_P = V_G + V_E \tag{2}$$

However, there are situations where the additivity of the heritability model breaks down, such as the occurrence of gene-environment correlation. This takes place when variation in genotypes within a population is statistically associated with variation in environments. When this occurs, an additional variable must be added to the heritability equation to account for the correlation (Eq. 3):

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$$V_P = V_G + V_E + Cov_{GE} \quad (3)$$

There are three ways in which genetic and environmental variance can be correlated: through active, passive, and reactive means (Plomin et al. 1977).

Passive Gene-Environment Correlation

Biological parents impart both a developmental environment and their genes to their offspring, which can lead to a correlation between particular genotypes and environments within a population. This is termed passive gene-environment correlation. For example, intelligent parents tend to contribute an intellectually stimulating environment and a genetic endowment which both allow for better development of intelligence in their children. A child's genotype is correlated with the genotype of their parents due to the principles of genetic inheritance. Thus, if a parent's genotype is associated with a particular environment, then a correlation between their children's genotype and that environment also emerges. At a population level, different genotypes will be nonrandomly associated with different environments, meaning that genetic variance and environmental variance are correlated.

This type of correlation is termed "passive" because the shaping of the child's environment is in no way due to the consequences of his or her own genotype, but is instead due to the actions and causal influences of their parents.

Significant passive gene-environment correlations have been uncovered for behavioral problems, temperament, and language development (Plomin et al. 1985). This is estimated by comparing the correlations between environmental conditions and phenotypes of children in adoptive and nonadoptive families (Plomin et al. 1977). Epidemiological associations have also been used to infer passive gene-environment correlation. Moffitt (2005) has speculated that passive G-E correlation contributes to variation in child aggressiveness through a correlation of genotypes which predisposes aggressive behaviors and a "bad parenting" environment. Rutter et al. (2006) have suggested that it could contribute to the heritability of psychiatric disorders. However, empirical work in this area is still limited. While it has been demonstrated that more aggressive children often become bad parents themselves (Caspi et al. 2001 as cited in Moffitt 2005), and there are associations between parental psychopathy and the environments that they provide (Rutter et al. 2006), studies have not yet been conducted that directly test the prevalence of passive G-E correlation for these phenotypes.

Reactive Gene-Environment Correlation

Reactive G-E correlation occurs when an individual's developmental environment is altered by others as a result of the subject's initial genetic difference. For example, if hair color differences are generated by genotypic differences, and individuals are treated differently based on the color of their hair, then different genetic groups will experience different environments as the result of varying societal reactions. This leads to a correlation between genotypes and environments and can result in phenotypic differences between the groups for other phenotypes, such as educational performance. This type of gene-environment correlation is thought to account for the disparity in IQ scores between different racial groups, as societal prejudice and disadvantageous environments are correlated with populations with particular racial backgrounds (Block 1995). If variation in genotypes accounts for skin color differences, and society treats people of different skin colors in a different way, then each genotypic group experiences a different environment, correlated with their genotype. As a result of these environmental reactions, other phenotypes are likely to be affected, such as educational performance and IQ test scores. When gene-environment correlations go unrecognized, these phenotypic differences will emerge as differences between genetic groups and hence are attributed to genetic differences (V_G) and counted toward the heritability statistic. Reactive gene-environment correlation has been employed as a criticism of the heritability statistic for making unrepresentative claims about phenotypic differences (Block 1995).

Active Gene-Environment Correlation

Active gene-environment correlation occurs when individuals with particular genotypes have a tendency to shape their own environment in a certain way. As with the reactive cases, differences in the environment can then have downstream effects on other phenotypes. For example, children with a small genetic advantage in intelligence might modify their environment in a way to intellectually stimulate themselves throughout development, by seeking out books, taking extra classes, and working on problems. This results in environmental differences which are correlated with different genotypic groups within a population. Consequently the group of children with advantageous environmental experiences are likely to reach a stage of measurable intellectual advantage, expressed as significant IQ differences (example adapted from Jencks et al. 1972).

It is not possible to separate active and reactive forms of G-E correlation experimentally or to estimate it directly in human studies. There is good evidence that children actively shape their environment (Ambert 1997), and there is also evidence that some self-mediated environmental alterations are based on genetic differences. For example, differences in stressful life events as well as socioeconomic, educational, and occupational status have all been shown to be somewhat genetically mediated (Plomin et al. 2008). Rutter and Silberg (2002) have proposed that active, reactive, and passive correlation contribute significantly to the heritability of psychiatric disorders. For instance, aggressively prone offspring are likely to promote harsher treatment from others, compounding their development along a psychiatric trajectory. This work has been extended by Jaffee and Price (2007) who have identified particular allelic variations and their associations with environments, such as parental rejection. These associations are then predictive of later psychiatric illness, indicating that genetic variation may account for active, reactive, and/or passive forms of correlation with parental engagement. Similarly, Meek et al. (2013) have suggested that heritability estimates for autism may be largely accounted for by active and reactive G-E correlations. Children who begin as mildly autistic are likely to select environments lacking in social stimuli (active), and others around them react to them in a way which compounds both their autistic phenotype (reactive) and their subsequent environmental selection (further compounding the active correlation pathway).

Conclusion

Gene-environment correlation occurs when different genotypes assort nonrandomly to different environments. It is recognized as a potential confound to estimating the heritability of personality traits in behavioral genetics as it prevents an estimation of the effects of genetic variance alone. Gene-environment correlation can be separated into passive, active, and reactive forms. While passive forms are detectable through the use of adoption studies, uncovering the active and reactive forms of gene-environment correlation is methodologically difficult. It has been proposed the gene-environment correlation accounts for some of the differences observed for autism, childhood aggression, temperament, psychiatric illness, intelligence, and language development.

Cross-References

- ▶ Adoption Studies
- ▶ Aggression
- ▶ Autism
- ▶ Behavioral Genetics
- ▶ Environmental Conditions and the Development of Personality
- ▶ Heritability of Personality Traits
- ▶ Intelligence
- ▶ Population Genetics
- ▶ Temperament

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