The Analysis of Marital Interaction in Cross-Sectional Twin Data

A.C. Heath

Department of Human Genetics, Medical College of Virginia, Richmond, USA

Abstract. The effects on twin data of social interaction between spouses is examined. When social interaction leads to an increase in marital resemblance (eg through reciprocal imitation), the variance of married individuals is increased, compared to the variance of unmarried individuals. Furthermore, the expected correlations between concordant married twin pairs will be lower than the expected correlations between concordant unmarried twin pairs, with the discordant twin correlations being intermediate in value. It is therefore possible, in principle, to detect the effects of marital interaction without using either longitudinal data or data on spouse pairs. However, to be detectable in twin data, marital interaction must be strong, or must exhibit marked asymmetry of effects between males and females. Genotype × environment interaction can also produce heterogeneity of correlation between concordant married, discordant, and concordant unmarried twin pairs, when genetic and environmental effects interact with marital status. However, this will usually produce increased estimates of the genetic component of variance in unmarried twins, whereas marital interaction produces increased genetic variance in married twins.

Key words: Marital interaction, Mate selection, Genotype × environment interaction

INTRODUCTION

In data on twin pairs reared together, the genetical consequences of assortative mating, and the effects of shared family environment, are confounded. Failure to allow for the

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effects of assortative mating will lead to an overestimate of the contribution of family environment to twin resemblance. Twin data are therefore commonly supplemented by data on spouse pairs to provide an estimate of the importance of assortative mating [4]. The correlation between spouse pairs may however be a consequence of social interaction between spouses, rather than, or in addition to, assortative mating. If spouses are correlated in their drinking habits, for example, this may arise because there are reciprocal environmental effects of husband's drinking behavior on wife's drinking behavior, and vice versa; or because individuals prefer to marry others with similar drinking habits. Failure to allow for the contribution of social interaction to spousal resemblance can therefore lead to an overestimate of the importance of assortative mating, and a consequent underestimate of the importance of family environment.

In principle, provided that either longitudinal data on spouse pairs, or data on spousal similarity as a function of duration of cohabitation, are available, the effects of mate selection and social interaction can be resolved. In practice, however, marital correlations are often based on a sample of unknown age structure, or one for which duration of cohabitation is unknown [10]. In this paper, therefore, we consider whether social interaction between spouses has any consequences which can be detected in cross-sectional data on twin pairs.

MODEL

The Figure represents our assumptions about social interaction between spouses in a path
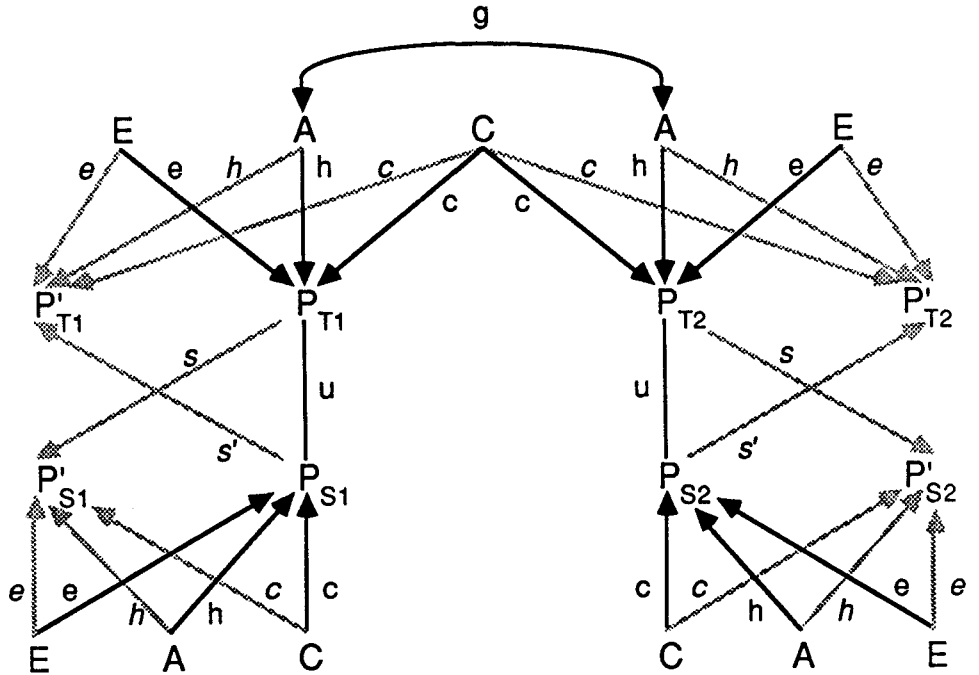

Figure. Resemblance of twin pairs and their spouses under phenotypic assortative mating and social interaction.

model [11], which summarizes the causes of resemblance of married twin pairs and their spouses. Prior to marital interaction, an individual's phenotypic deviation, P, is determined by his additive genetic value, A, his familial environmental value, C, and a random environmental deviation, E. Parameters h, c and e are used to represent the path regression of P on A, C and E respectively. Subscripts T1, T2, S1 and S2 are used to distinguish the phenotypes of first and second-born twins and their spouses. Mate selection is assumed to precede the start of social interaction, and is assumed to be based upon phenotypic assortative mating [6], represented, using copath notation [3], by copaths u from twins' phenotypes to the phenotypes of their spouses. The correlation between the additive genetic values of twin pairs, g, will be either 1 in the case of monozygotic (MZ) twin pairs, or $0.5 (1 + uh^2)$ in the case of dizygotic (DZ) twin pairs.

Under marital interaction, an individual's phenotypic deviation (P') is influenced by an extra source of variability, the phenotypic deviation of his/her spouse. We introduce paths s and s' to represent the path regressions of wife's phenotype on husband's phenotype, and vice versa. Different parameters are used for the two sexes to allow for the possibility of "asymmetric" marital interaction, as might occur if the influence of husbands' drinking behavior on the drinking habits of their wives is greater than the influence of wives' drinking behavior on their husbands. The change in wife's phenotype induced by the environmental impact of husband's phenotype will in turn lead to a further change in the husband's phenotype, and vice versa (see, for example, the discussion of reciprocal interaction in [11]). However, for reasonable values of s and s' (in particular, s, $s' < 1$), the phenotypic values will rapidly stabilize at new equilibrium values. In this paper we will focus on correlations between twin pairs in this equilibrium state.

DERIVATION OF EXPECTED STATISTICS

The tracing rules for deriving expected correlations from a path diagram [11] do not apply when there is reciprocal interaction between variables, as will be the case under marital interaction. However, Wright's basic equation of path analysis [11: p. 301] can still be applied, provided that we can assume, without mathematical inconsistency, that all measured and latent variables are standardized to have zero mean and unit variance after marital interaction. Under these conditions [11], the expected correlation between two standardized variables X_i and X_j is given by $r_{ij} = \Sigma p_{ik} r_{kj}$, where p_{ik} is the path regression of X_i on a latent variable X_k, which is one of n immediate determinants of X_i, and r_{kj} gives the correlation of variable X_k with X_j. In complex diagrams, r_{kj} will itself be derived as a function of other paths in the diagram, by repeated application of Wright's basic equation. In the case of reciprocal interaction between variables, application of Wright's basic equation will generate a set of simultaneous equations which must be solved to derive expected correlations between the variables [11].

Under marital interaction, there will be differences in phenotypic variance between married and unmarried individuals. For the case of random mating, it is not difficult to work with standardized latent variables and standardized phenotypic deviations after marital interaction, leaving phenotypic deviations before marital interaction as unstandardized variables. When there is assortative mating, however, the advantage of using standardized variables disappears. Instead, we have followed the general approach which

Carey [2] outlines for the case of sibling interaction, which applies equally for the analysis of marital interaction. If S is the expected covariance matrix of male like-sex twin pairs of a given zygosity type, and their spouses, prior to marital interaction, then the expected covariance matrix after marital interaction is given by

$$E = (I - X)^{-1} S (I - X')^{-1}$$

where the matrix X contains the social interaction parameters s and s' representing the environmental effects of male twins on their spouses, and vice versa, and X' denotes the transpose of that matrix. Specifically, if the first and second rows and columns of S correspond to the first and second twins, and the third and fourth to the spouses of the first and second twins, then we will set $X_{1,3} = X_{2,4} = s'$, $X_{3,1} = X_{4,2} = s$, and set all other elements of X to zero. These two alternative approaches lead to identical equilibrium expected correlations, at least in the cases of random mating for which we have compared them.

EXPECTED VARIANCES AND COVARIANCES OF TWIN PAIRS

Table 1 gives algebraic expressions for the expected variances of married and unmarried individuals, and for the expected covariances of twin pairs, conditional upon the marital status of 1st and 2nd twins. In twin pairs discordant for marital status, it is assumed that twins are reordered so that the married twin is always designated as the 1st twin, the unmarried twin as the 2nd twin. To simplify expressions, we have ignored sex-differences in phenotypic variance prior to marital interaction. We have also defined parameters h^2 and c^2 so that these give the proportions of the total phenotypic variance, V, prior to marital interaction, which is attributable to additive gene action and shared environmental effects.

Since there are no traits for which a negative correlation between spouses has been found consistently, we focus our attention on marital imitation ($0 > s, s' > 1$) and positive assortative mating ($0 > u > 1$). This corresponds to the case, for example, where heavy drinking by one spouse increases, environmentally, the probability of heavy drinking by the other spouse, and vice versa; and where there is also an increased tendency for individuals with similar drinking habits to marry. From Table 1, it will be seen that under these conditions we expect to observe an increase in the variance of married individuals compared to unmarried individuals, and also an increase in the covariance of concordant married twins, and to a lesser degree discordant twins, compared to concordant unmarried twin pairs. However, since $(1 + s^2 + 2us) > (1 + us)^2$ when $u < 1$, marital interaction will produce a larger increase in variance than in twin covariance. Twin correlations will therefore be highest in unmarried pairs, intermediate in discordant pairs, and lowest in married pairs. Asymmetric marital interaction, when $s \neq s'$, will give rise to sex differences in variance in married individuals, and sex-differences in twin covariances and correlations in concordant married and discordant twin pairs, even in the absence of such heterogeneity prior to marital interaction.

Even in the absence of marital data, then, we should in theory be able to detect the effects of marital interaction by analysing the variances and covariances of twin pairs conditional upon marital status. We would expect to obtain increased estimates of the

Table 1 · Expected variances and covariances of twin pairs at equilibrium under marital interaction and phenotypic assortative mating

Variance, unmarried	V
married male	$\dfrac{V\,(1 + s'^2 + 2us')}{(1 - ss')^2}$
married female	$\dfrac{V\,(1 + s^2 + 2us)}{(1 - ss')^2}$
Covariance, concordant unmarried pairs: $(gh^2 + c^2)\,V$	
discordant pairs:	
male twin married	$\dfrac{(gh^2 + c^2)\,(1 + us')\,V}{(1 - ss')}$
female twin married	$\dfrac{(gh + c^2)\,(1 + us)\,V}{(1 - ss')}$
Covariance, concordant married pairs:	
male like-sex	$\dfrac{(gh^2 + c^2)\,(1 + us')^2\,V}{(1 - ss')^2}$
female like-sex	$\dfrac{(gh^2 + c^2)\,(1 + us)^2\,V}{(1 - ss')^2}$
unlike-sex	$\dfrac{(gh^2 + c^2)\,(1 + us)\,(1 + us')\,V}{(1 - ss')^2}$

additive genetic and familial and unique environmental components of variance for married individuals, compared to unmarried individuals. When mate selection is based upon phenotypic assortative mating, as we assume here, the ratios of the additive genetic and familial environmental components of variance in married and unmarried individuals should be the same. Under more complex models of mate selection, perhaps allowing for effects of social background as well as phenotype on mate selection [8], however, this latter prediction will no longer hold.

EFFECTS OF MARITAL INTERACTION IN TWIN DATA

Table 2 illustrates the effects of social interaction between spouses on the correlation between twin pairs, when there is no sexual asymmetry, ie, $s = s'$, for given levels of assortative mating and social interaction. Numerical values for twin correlations are tabulated for the case where $h^2 = c^2 = 0.36$. To facilitate comparison of the effects of

different intensities of assortative mating and social interaction, we have considered only values of the assortative mating parameter u and the marital interaction parameter s (not tabulated) which result in an observed marital correlation (after social interaction) of 0.2, 0.4 or 0.6. The effects of marital interaction on the twin correlation are greatest when the resultant marital correlation is high, and the contribution of assortative mating to that correlation is small or zero. Even under these most favourable conditions, the effects of marital interaction must be very strong in order to generate differences in correlation between concordant married, discordant and concordant unmarried twin pairs which can be detected with realistic sample sizes.

Table 2 - Changes in twin correlations under symmetric marital interaction

Assortative mating	Observed marital correlation	MZ twin correlations			DZ twin correlations		
		Concord. married	Discord.	Concord. unmarried	Concord. married	Discord.	Concord. unmarried
0	0.2	0.713	0.716	0.720	0.535	0.537	0.540
	0.4	0.690	0.705	0.720	0.517	0.529	0.540
	0.6	0.648	0.683	0.720	0.486	0.512	0.540
0.2	0.2	0.720	0.720	0.720	0.553	0.553	0.553
	0.4	0.712	0.716	0.720	0.547	0.550	0.553
	0.6	0.685	0.702	0.720	0.526	0.540	0.553
0.3	0.4	0.718	0.719	0.720	0.558	0.559	0.559
	0.6	0.700	0.710	0.720	0.544	0.551	0.559

Table 3 gives numerical values for MZ twin correlations when there is asymmetric marital interaction. We illustrate only the case where mating is random, and select values of s', for given values of s, such that the resultant marital correlation after marital interaction is 0.6. Once again we have assumed $h^2 = c^2 = 0.36$, implying a twin correlation in concordant unmarried twins of both sexes of 0.72. We consider only the cases where $s < s'$, implying that wives have a greater environmental impact on their husbands than do husbands on their wives. From Table 3 we see that strong asymmetric marital interaction can give rise to large differences in twin correlation between concordant married, discordant and concordant unmarried twin pairs.

Table 3 - Changes in MZ twin correlation under asymmetric marital interaction and random mating

Observed marital correlation	Male social interaction parameter, s	Concord. married pairs		Discordant pairs	
		Male	Female	Male	Female
0.6	0.1	0.527	0.713	0.616	0.716
0.6	0.2	0.586	0.692	0.650	0.706
0.6	0.3	0.634	0.661	0.676	0.690
0.6	=s'	0.648	0.648	0.683	0.683

Table 4 illustrates the differences in variance predicted between married and un-married individuals when there is social interaction between spouses. Once again we observe that when marital interaction is symmetric, very strong effects of marital inter-action are necessary to produce differences in variance that can be detected with reason-able sample sizes. Strongly asymmetric marital interaction can produce quite large changes in variance.

Table 4 - **Changes in phenotype variance under marital interaction (when variance of unmarried indi-viduals is standardized to unity)**

Assortative mating	Observed marital correlation	Male social interaction parameter, s	Variance of married males	Variance of married females
0	0.2	$= s'$	1.031	1.031
	0.4	$= s'$	1.141	1.141
	0.6	$= s'$	1.406	1.406
	0.6	0.3	1.433	1.377
	0.6	0.2	1.502	1.272
	0.6	0.1	1.547	1.144
0.2	0.4	$= s'$	1.082	1.082
	0.6	$= s'$	1.300	1.300
0.3	0.6	$= s'$	1.170	1.170

RESOLVING THE EFFECTS OF MARITAL
AND GENOTYPE × ENVIRONMENT INTERACTION

From Tables 2-4 it will be apparent that strong effects of marital interaction can be de-tected in twin data even in the absence of any spousal data (apart from knowledge of marital status). However, if we do find significant heterogeneity of estimates of genetic and environmental components of variance between married and unmarried twins, this cannot necessarily be interpreted as evidence for marital interaction. As has been shown elsewhere, genotype × environment interaction can also give rise to such differences in components of variance [5,9]. This will occur whenever there is a significant interaction of genetic and environmental effects with marital status. Such an interaction might be expected if the absence of a steady marriage-like relationship is a "vulnerability" factor [cf 1] which increases the impact of inherited liability to symptoms of depression or to heavy drinking, for example [9].

We can recast the expected covariances between concordant unmarried, discordant, and concordant married twin pairs (see Table 1) in the form t, tk and tk^2, where $t = (gh^2 + c^2)V$, and $k = (1 + us)/(1 - s^2)$. (For simplicity, we ignore sex differences here, since generalization to allow for sex-dependent effects is straightforward). Under geno-type × environment interaction, when the impact of genotype and family background are increased to the same degree under one condition of environmental exposure (eg, absence of a steady marriage-like relationship), we can likewise express the expected co-variances between concordant exposed, discordant, and concordant unexposed twin

pairs as t, tk and tk^2, where t = h^2 + c^2, and the genetic and family environmental components of variance are decreased from h^2 to k^{2}h^2 and to c^2 from k^{2}c^2 in unexposed (ie, married) twins [5,9]. Under marital interaction, we will have variances of the form V and $_j$V, where

$$j = \frac{(1 + s^2 + 2us)}{(1 - s^2)^2} \ .$$

Under genotype × environment interaction, we will have ecpected variances of the form V and $_j$V for exposed and unexposed individuals, where V = h^2 + c^2 + e^2 and jV = = k^{2}h^2 + k^{2}c^2 + me^2.

Despite the formal similarity of the expectations for variances and covariances of twin pairs under marital interaction and under genotype × environmental interaction, under most circumstances we are unlikely to confuse their effects. Under marital interaction, genetic and familial environmental components of variance are increased in married individuals, but the unique environmental component of variance is increased to an even greater degree. Under genotype × marital status interaction, we would usually expect to observe an increase in the genetic (and possibly also the familial environmental) components of variance in unmarried individuals [eg, 9]. Under phenotypic assortative mating or random mating, marital interaction will increase genetic and familial environmental components of variance to the same degree. Under genotype × environment interaction, there is no reason why these components should change to the same extent. Finally, whereas marital interaction will generate a positive correlation between spouses (assuming 0 < s, s', u < 1), under genotype × marital status interaction the correlation between spouses will be zero, if mating is random.

CONCLUSIONS

Attempts are sometimes made to allow for the genetical consequences of assortative mating when analysing twin data, using data from a separate sample of spouse pairs [4,10]. Such efforts are often criticized because they assume that spousal resemblance is solely due to assortative mating. If social interaction between spouses is an important determinant of spousal resemblance, such an assumption will lead to an underestimation of the importance of family environment. In this paper, we have explored the consequences of marital interaction, to determine whether there is any possibility of detecting its influence in twin data.

When marital interaction is strong, leading to a high spousal correlation, it is expected to have consequences which can be detected in twin data with realistic sample sizes. The variance of married individuals will be increased, compared to the variance of unmarried individuals. The covariances of twin pairs will be greatest in concordant pairs, intermediate in discordant pairs, and least in concordant unmarried pairs. The correlations between twin pairs will be greatest in concordant unmarried pairs, intermediate in discordant pairs, and least in concordant married pairs. When there is asymmetric social interaction between spouses, this will give rise to sex-differences in the phenotypic variance between married males and married females and to differences in twin correlation between male

like-sex, female like-sex and unlike-sex married or discordant twin pairs, even in the absence of such sex-differences in unmarried twins. Under certain unlikely circumstances, the effects of genotype × marital status interaction can mimic those of marital interaction. Even under these conditions, however, as we show elsewhere [7], the effects of genotype × environment interaction and marital interaction can still be resolved, provided that data on the spouses of twin pairs, as well as the twins themselves, are available.

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Correspondence: Dr. A.C. Heath, Department of Human Genetics, Box 33, MCV Station, Richmond VA 23298, USA.