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Measurement Models for Sexual Orientation in a Community Twin Sample

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Multivariate structural equation modeling techniques have been applied to examine the causes of individual differences in responses to several items concerning sexual orientation. To minimize potential ascertainment and response biases, the study sample involved a large ($N = 4901$) community-based cohort of Australian twins aged 18–52 who answered an anonymous questionnaire on sexual behavior and attitudes. The statistical power of the analysis was increased by the availability of multiple measures of sexual orientation (behaviors, attitudes and feelings), providing stronger evidence for the existence of additive genetic influences on this phenotype than in a previous analysis (Bailey *et al.,* 2000). Estimates of the heritability of homosexuality in this sample ranged between 50 and 60% in females but were significantly lower (heritability of approximately 30%) in males.

KEY WORDS: Homosexuality; sexual orientation; heritability; twins.

INTRODUCTION

Numerous studies of sexual orientation (Pillard and Weinrich, 1986; Pillard, 1990; Bailey and Bell, 1993; Bailey and Benishay, 1993; Pattatucci and Hamer, 1995) have found that both male and female homosexuality appear to be familial. Twin, sibling, and adoption studies suggest that this is due primarily to genetic rather than shared environment influences (Bailey and Pillard, 1991; Bailey *et al.*, 1993; Pillard and Bailey, 1998), with genes possibly accounting for at least half of the variance in sexual orientation. However, different etiologies have been hypothesized for male and female homosexuality, suggesting that if genetic factors contribute to homosexuality, they may differ between males and females (Bailey and Bell, 1993).

Homosexual and bisexual probands for previous twin studies of sexual orientation have generally been recruited via homosexual-oriented publications and organizations, which can lead to study participants being unrepresentative in important respects, such as self-selection for openness and overrepresentation of those with exclusively homosexual orientations. These potential volunteer biases are liable to affect twin concordances and heritability analyses (Kendler and Eaves, 1989). The current study uses a large population-based sample of Australian twins recruited from the Australian National Health and Medical Research Council (NHMRC) Twin Registry and, as such, reduces the volunteer biases inherent in the recruitment procedures of other studies. Previous analysis of this data set (Bailey *et al.*, 2000; Gangestad *et al.*, 2000) considered a sexual orientation variable constructed as the average of individual scores for the Kinsey-based sexual attraction and sexual fantasy scales. Bailey *et al.* found that familial factors influence psychological sexual orientation but that genetic and shared environmental contributions could not be disentangled without resort to covariates, namely, the Childhood Gender Nonconformity (CGN) and Continuous Gender Identity (CGI)

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scales, while Gangestad *et al.* explored whether sexual orientation and gender identity are taxonic in nature.

A further limitation of previous studies of sexual orientation is that they have focused on definitions derived from Kinsey *et al.* (1948). This approach neglects the possibility of obtaining additional information from questionnaire items via multivariate techniques. Here we use multivariate structural equation modeling techniques to maximize the information obtained from a number of distinct but closely related measures of sexual orientation and expand on the focus of Bailey *et al.* (2000) by including measures of both behavioral and psychological sexual orientation.

METHOD

Sample

Twins were drawn from the Australian NHMRC Twin Registry (ATR). The ATR is a volunteer register begun in 1978 and with about 25,000 pairs of all types and all ages enrolled and in various stages of active contact; we estimate that this represents 10–20% of living twins in Australia. Subjects for this study were recruited from two phases of a large, partly longitudinal twin-family study of alcohol use and abuse.

Phase 1

In 1989 an extensive Health and Lifestyle Questionnaire (HLQ) was mailed to 4269 pairs born in 1964–1971 (i.e., aged 18–25). Most of these twins had been recruited when at school some 10 years earlier, so it was not surprising that, despite extensive follow-up efforts, we were unable to reestablish contact with 1000 pairs. Those twins who were contacted but failed to return a completed questionnaire were followed-up by telephone up to five times, at which point they were asked to complete an abbreviated telephone interview to obtain basic demographic information. Both members of 2294 pairs (70% of contactable pairs) completed a questionnaire or abbreviated phone interview, plus a further 474 single twins, making an individual cooperation rate of 5074 of 6122 (83%) of those with whom contact was established. As the last item of a 16-page questionnaire, twins were asked the following item (Q66): “We have applied for funding to carry out an *anonymous* study of sexual behavior and attitudes. Would you be willing to receive a questionnaire with explicit questions on these topics? Yes/No.” Twins receiving the abbreviated telephone interview were asked the same item. Of the 2294 pairs who both responded to the HLQ, 1807 (79%) both said that they were willing to receive the sex questionnaire. Of the remaining 487 pairs and 474 single HLQ responders, a further 583 single twins indicated willingness to receive the sex questionnaire, for an overall individual response rate of 70%.

All twins who said “yes” were mailed the sex questionnaire between July 1991 and October 1992, regardless of their cotwin’s cooperation status. The sex questionnaire (beige-colored for males and mauve for females) was enclosed in a sealed inner envelope which was stamped “WARNING! Contents may offend. Do not open this envelope until you have read the cover letter.” This was placed in an outer envelope with several other enclosures including a cover letter, a consent form, a small reply-paid envelope for the consent form, and a large reply-paid envelope for the questionnaire. The reply-paid envelopes were stamped, the larger one with five different postage stamps, which in an unpublished study we found to increase return rates significantly, by about 10%. This was considered important given the minimal opportunities for follow-up in this study.

Cover Letter

The cover letter asked the twins to read it completely before opening any other materials. They were reminded of their agreement to receive an anonymous questionnaire about their sexual behavior and attitudes and asked not even to open the enclosed questionnaire if they now found this unacceptable. To guard against their responses being inadvertently read by others, they were exhorted, “Do not open this questionnaire until you intend to fill it out—you should allot 1 hour. Immediately after you fill out the questionnaire, you should put it in the return envelope and seal it. Mail the questionnaire as soon as you can after that. Do not fill out the questionnaire until you have sufficient privacy so that you are sure that no one will see your answers. Do not show your questionnaire to anyone else, no matter what their relationship to you.”

To protect anonymity while retaining information on which twins were pairs, essential for genetic analysis of the data, the following device was used: “Although we do not need to know your name, we do need some way to connect your responses to those of your twin. In order to accomplish this, as we have indicated on the first page of the questionnaire, you should please arrange with your twin to use the same ‘Made-up Number.’ This number can be any ten-digit number (though please don’t use obvious numbers like 0123456789 or 1111111111). It is important to check with your twin before you mail your questionnaire in order to make sure that you have both used the same number. If you do not do this, we will not be able to use your questionnaire."

Twins were also asked to complete a consent form with their name, date of birth, and signature and to return this separately in the small stamped envelope to indicate willingness to participate. In fact, this step was not strictly necessary since the twins had already indicated their consent to receive the questionnaire, and implied consent by return of the questionnaire is sufficient for ethical purposes. However, monitoring of return of the consent forms and follow-up of those who failed to return them was the only targeted mechanism we had to try to improve response, given that we had no way of identifying those who had and had not returned the questionnaires themselves. This was made quite explicit to twins: "If you decide that you have changed your mind and do not wish to complete the questionnaire, please indicate this on the consent form, and return it to us. Please realise that if you follow the directions and return the Consent Forms separately from your questionnaires, it will be impossible to connect your name with your questionnaire responses. It will only be possible to infer that you have returned your questionnaire. This will be useful to us in order that we can remind those who have not replied. If we have not received a consent form from you we shall phone you to ask if you have returned the questionnaire."

Zygosity

Zygosity of twins was established at the time of their completing the HLQ, from their response to standard items about physical similarity and being mistaken for each other. Such items have been shown by ourselves and others to be at least 95% accurate when judged against genotyping results (e.g., Martin and Martin, 1975; Kasriel and Eaves, 1976; Ooki *et al.*, 1990). We further improved on this by selecting for further investigation any pair whose answers are not completely consistent, within or between cotwins, with either monozygosity or dizygosity. These pairs were telephoned to detect the source of any confusion, and about 80% were readily decided at this stage. Those still equivocal were asked to send us photographs at several stages of their lives and most were then assigned with little hesitation by the project staff, leaving but a few genuinely doubtful cases. Where possible, blood was subsequently obtained for genotyping these few uncertain pairs. We also genotyped 419 pairs (320 same-sex pairs) whose zygosity had been assigned using the above procedures, with 11 independent highly polymorphic short tandem repeat markers ($P\ DZ \mid Conc < 10^{-3}$). Only four errors were found (1.3% of same-sex pairs)—all MZ pairs who had previously been called DZ.

To make use of the zygosity information from the HLQ in the sex study, the zygosity diagnosis for all participants was premarked on their anonymous questionnaire form prior to mailing: "Based on your responses to past questionnaires, we have classified you and your twin as: Identical twins/Non-identical twins. Do you agree with our assessment? Yes/No." The objective of the latter question was to discourage the respondent from interfering with the assignment we had made.

Follow-up

About 2 weeks after the initial mailing, all twins were sent a reminder letter. Consent forms were logged as they were returned, and subsequently all twins who had not returned a consent form were followed up by telephone, with a noticeable effect on the response rate. Because we received many queries from twins asking whether they should complete the questionnaire if their cotwin had decided not to participate, we sent a further letter urging such "singles" to cooperate. In general, we applied exactly the same follow-up criteria and procedures to all subjects, regardless of their cotwin's cooperation status.

Phase 2

Because the first phase of the study on the younger cohort had gone so smoothly, with only a few minor complaints, we decided to extend the study to an older twin cohort who had taken part in questionnaire studies in 1980 and in 1988. The 2035 pairs who had both completed the 1988 follow-up questionnaire and were born after 1941 were sent a letter in March 1992 asking, in wording almost exactly identical to Q66 from the HLQ for the younger cohort, whether or not they were willing to receive the sex questionnaire. Those who failed to respond to this letter were followed up with a single telephone call. Thereafter, procedures were exactly the same as described above for the younger cohort. Mailing of questionnaires to the older cohort was between April and August 1992.

Pairing of Returned Questionnaires

Our system for ensuring anonymity while retaining twin pairing information worked fairly well. However, we became aware of a number of cases where both twins had returned completed questionnaires but had failed to match their self-created identity numbers correctly so they could not be paired and were therefore classified as two singles. Leaving these unidentified could lead to biases by reducing the number of true pairs and thus lowering power. At the conclusion of the study, therefore, we conducted a number of analyses to identify true pairs from among the singles. Using sex, zygosity, and reported family structure information, all singles could be classified into the five sex–zygosity classes. Within each class singles were then ordered by age. Each list was then scanned by eye to look for matches taking account of self-reports of birth order, birth weight of self and cotwin, placentation, and family structure. All "matches" identified were checked by three members of the project staff, and only those unanimously agreed on were allowed. Sixty-two such matches were made and were removed from the singles lists to the appropriate pair classes. Most of these proved to differ in their IDs by simple mutations—usually inversions, deletions, or point mutations. It is unlikely that more than a few genuine pairs remain among the singles.

A total of 1908 complete pairs (980 MZ, 928 DZ) and 1085 singles actually completed the questionnaire (54% of all potential individual participants, 44% of all possible twin pairs). The respondent group consisted of 3077 females and 1824 males, with an age range of 19 to 52 years (mean age, 30.9 ± 8.4 years). However, the number of item responses obtained varies somewhat between individuals due to missing values.

Measures of Sexual Orientation

Ten items pertaining to psychological and behavioral sexual orientation were included in the questionnaire. Sexual orientation is generally measured using the Kinsey scale (Kinsey *et al.*, 1948), a 7-point scale which ranges from 0 (exclusively heterosexual) to 6 (exclusively homosexual). This section of the questionnaire included the following.

- Separate Kinsey scale items to assess present sexual feelings (the degree to which survey participants are attracted to persons of the same or opposite sex), sexual behavior during the past year (relative frequency of same-sex and opposite-sex partners), and present sexual fantasies (the relative proportion of participants' fantasies about people of the same or opposite sex)
- An item asking whether respondents considered themselves to be heterosexual, bisexual, or homosexual
- Questionnaire items concerning whether the respondent had ever been attracted to a person of the opposite sex and ever attracted to a person of the same sex (yes/no response set)
- Items on participants' attitudes to the idea of having sex with people of the opposite sex and people of the same sex (5-point scales ranging from "very sexually exciting" to "disgusting")
- Items asking respondents to indicate the number of opposite-sex and same-sex partners during their entire lifetime (8-point response sets: "none/1 only/2/3–5/6–10/11–20/21–50/over 50"). For the purposes of determining number of sexual partners, "sexual contact" was defined on the questionnaire as any activity which made the respondent sexually excited and in which their genitals made contact with any part of the other person.

Statistical Methods

Univariate Analysis

Data were analyzed using SAS 6.11 (SAS Institute, 1995), PRELIS 2.20 (Jöreskog and Sörbom, 1998), and Mx 1.47c (Neale, 1999). Correlations between variables are calculated on the assumption that underlying each variable is a continuum of liability which is normally distributed in the population. However, while significant twin correlations establish the fact that there is familial aggregation for the measures of interest, they do not distinguish between the possible mechanisms by which this arises. Structural equation modeling is used to make this distinction, by considering which combination of additive genetic (A), nonadditive genetic (D), shared environment (C), and unique environment (E) effects provides the most parsimonious explanation for the observed pattern of MZ and DZ twin correlations. Differences in gene expression or environmental effects between males and females ("sex limitation") may also be modeled. Univariate analyses were conducted using maximum-likelihood methods for raw ordinal data recently implemented in Mx 1.47c (Neale, 1999). Each of these models was then simplified by determining whether removal of successive individual parameters results in a significant decrease in the fit of the model to the data.

Multivariate Techniques

Extension to multivariate analysis allows the determination of not only the sources of covariation but also the pattern or structure in which these differentially influence the covarying measures. However, computational demands prevented the use of raw data methods for multivariate analysis. To maximize the number of twin pairs available for structural equation modeling, imputation methods in PRELIS 2.20 (Jöreskog and Sörbom, 1992) were used to impute missing item responses where possible, within individuals by sex. This approach obtains the substitute value from other cases with similar response patterns but no missing values, provided that the variance of the value for these other cases is acceptable. In total, 262 responses were imputed (0.8% of the total item responses), increasing the number of individuals with "complete" data from 4413 to 4675 (a gain of 5.9%).

Structural equation modeling using Mx (Neale, 1999) was used to test two hypotheses: the first of these is that there are common genetic and environmental factors influencing the observed variables ["independent pathway model" (Kendler *et al.*, 1987)], while the second hypothesis is that there is a common latent construct (homosexuality) underlying the observed variables ["common pathway model" (Kendler *et al.*, 1987)]. Principles of parsimony as detailed above were used to simplify models, with the best-fit models chosen by minimizing the Akaike (1987) information criterion (χ^2 – 2 × degrees of freedom).

RESULTS

Response Frequencies

Of the 3077 females who responded to the questionnaire, 2940 (95.5%) rated themselves as heterosexual, with 82 (2.6%) rating themselves as bisexual and 21 (0.7%) as homosexual. In comparison, 1682 (93.8%) of males rated themselves as heterosexual, with 57 (3.2%) and 55 (3.1%) of respondents considering themselves to be bisexual and homosexual, respectively. Ninety-four and eight-tenths percent of female respondents and 96.3% of male respondents reported having been sexually attracted to a person of the opposite sex, whereas only 10.2% of females and 11.2% of males had been attracted to a person of the same sex. Response frequency percentages obtained for males and females for other items with more than three response categories are summarized in Table I, separated into results for those whose twin also participated in the study ("paired") and those whose twin did not participate ("single"). Of the 10 items (including those mentioned above), only number of opposite-sex partners appeared to be significantly affected by cotwin participation bias (males: $p < 0.001$), with males whose cotwins did not participate in the survey recording higher numbers of opposite-sex partners than males whose cotwins did participate in the study. Statistically significant correlations with age were observed for attitude to heterosexual sex (females: $r = -0.18$) and attraction to opposite sex (males: $r = 0.15$). Although these correlations are significant, age accounts for a small proportion of variance (<4%) in this sample of 18 to 52 year olds and is considered no further.

Univariate Analysis

Univariate structural equation modeling for the 10 measures of psychological and behavioral sexual orientation demonstrated statistically significant familial effects for all 10 measures, although the effects were not always significant in both sexes. Additive genetic effects, in particular, were found for orientation of sexual fantasies, attitude to heterosexual sex and attitude to homosexual sex (statistically significant in women only), and number of partners of the opposite sex (significant for men and women). Significant shared environment effects were distinguishable in only one variable for females ("ever sexually attracted to a female"), while no significant nonadditive genetic effects were found for any variable.

In many cases, it was not possible to determine whether the observed familial effects arose from genetic or environmental influences (i.e., only the sum of genetic and shared environmental influences was significant). Except for attraction to a person of the same sex, all models could be reduced without a significant loss of model fit to substantially simpler AE models where additive genetic influences accounted for between 34 and 53% of the variation, with no significant differences observed between men and women.

Multivariate Analysis

Complete data were obtained for 603 female and 290 male MZ twin pairs and 340 female, 172 male, and 344 opposite-sex DZ twin pairs. Due to the high item intercorrelations and the resulting numerical algorithm problems, it was not possible to incorporate all items from the questionnaire in the multivariate analysis. We wanted to include a range of variables encompassing both psychological and behavioral sexual orientation and were again constrained in our selection by the numerical difficulties arising from highly intercorrelated items. Consequently, three items were selected—the Kinsey-scale present sexual feelings item ("Feelings"),

Table I. Response Frequencies (%) for Sexual Orientation Variables for Twins in Complete Pairs (2456 Females and 1360 Males) and Single Twins (621 Females and 464 Males)

	Kinsey scale-based rating						
	Exclusively heterosexual →						Exclusively homosexual
	0[a]	1	2	3	4	5	6
Feelings							
Female							
Paired	85.8	8.4	2.2	1.0	0.3	0.4	0.5
Single	83.4	9.7	1.8	1.6	0.8	0.6	0.6
Male							
Paired	86.9	6.4	1.1	0.6	1.0	1.0	2.0
Single	88.1	3.0	1.5	1.3	0.6	0.6	2.6
Behavior							
Female							
Paired	95.2	0.7	0.1	0.1	0.0	0.1	0.8
Single	92.6	1.4	0.2	0.2	0.0	0.0	1.6
Male							
Paired	94.8	0.4	0.2	0.1	0.2	0.3	2.4
Single	92.3	0.4	0.9	0.2	0.4	0.2	2.6
Fantasies							
Female							
Paired	83.1	11.0	1.6	0.7	0.4	0.7	0.7
Single	83.4	9.3	1.8	1.0	0.5	0.6	0.6
Male							
Paired	87.7	5.2	1.2	0.4	0.6	0.9	2.7
Single	87.3	2.8	1.5	0.9	0.4	0.6	3.7

	Attitudes				
	Disgusting	Slightly unpleasant	Neutral	Somewhat exciting	Very sexually exciting
Heterosexual sex					
Female					
Paired	0.2	0.6	5.4	30.3	62.0
Single	0.5	1.6	6.0	30.9	58.8
Male					
Paired	0.7	1.3	1.7	10.7	84.8
Single	0.9	1.1	2.4	11.2	82.1
Homosexual sex					
Female					
Paired	61.4	13.8	13.7	6.2	2.2
Single	62.5	12.7	12.6	5.8	2.6
Male					
Paired	75.7	10.7	5.6	2.4	4.0
Single	76.5	9.3	4.1	3.0	4.3

	Partners							
	0	1	2	3–5	6–10	11–20	21–50	>50
Opposite-sex								
Female								
Paired	3.6	20.6	12.9	26.9	18.7	10.1	3.9	1.0
Single	3.5	18.8	11.1	31.9	18.4	8.4	3.4	1.4

(continued)

Table I. (Continued)

	Partners							
	0	1	2	3–5	6–10	11–20	21–50	>50
Male								
Paired	5.0	12.6	9.0	22.8	18.4	16.2	11.5	3.0
Single	5.0	11.6	6.3	16.4	16.4	20.3	14.9	6.3
Same-sex								
Female								
Paired	88.4	4.2	1.0	1.3	0.5	0.3	0.1	0.0
Single	87.0	3.4	1.1	1.4	1.0	0.5	0.2	0.2
Male								
Paired	81.3	7.1	2.2	2.1	1.0	0.8	0.8	1.1
Single	81.9	5.4	1.1	2.4	1.3	1.3	0.9	1.5

[a] Includes respondents who had not been sexually active in the past year (Behavior) and respondents who stated that they did not have sexual fantasies (Fantasies).

attitude to homosexual sex ("Attitude"), and lifetime number of same-sex partners ("Partners").

Cross-twin cross-trait polychoric correlations for females and males estimated for these three variables using PRELIS 2.20 are shown in Table II. Twin 1–twin 2 correlations for each of the four variables are highlighted in boldface. For females it can be seen that the correlations for MZ twins are greater than those for their DZ counterparts for Feelings (0.45 versus 0.29), Attitude (0.55 versus 0.29), and Partners (0.55 versus 0.00), indicating that additive genetic effects are an important source of familial resemblance for sexual orientation. Closer inspection of Table II reveals that in most instances the interitem cross-trait correlations observed for MZ twins are somewhat less than twice those for DZ twins, suggesting a possible common environment effect. Even stronger genetic control of familial aggregation is suggested in males, with DZ twin correlations generally much less than half the corresponding observed MZ twin correlations. In this case, it could be expected that there are nonadditive genetic effects affecting sexual orientation. Opposite-sex twin correlations are slightly less than those observed for DZ female twin pairs but approximately the same as those observed for DZ male pairs, suggesting that at least some of the familial factors influencing sexual orientation in males are also pertinent in females.

To test hypotheses about the relationship among the three variables of major interest, several structural equation models were fitted to the data. It should be noted that due to some extremely high interitem correlations for males (Table II), resulting in a nonpositive definite observed correlation matrix, a ridge constant of 0.069 was added to the main diagonal of the observed correlation matrix to facilitate these analyses. However, in the weighted least-squares calculation, this is immediately removed as a specific constant so it is unlikely to bias factor loadings more than trivially. The first of the models presented, an independent pathway model, is based on the hypothesis that there are common genetic and environmental factors influencing the observed variables. The best-fitting full independent pathway model shown in Table III was one in which common additive genetic, shared environment, and unique environment effects were modeled for women, and additive genetic, nonadditive genetic, and unique environment effects were modeled for men ($\chi^2_{46} = 65.793$, $p = 0.029$). Additional effects specific for each variable were also included, although the shared environment specific effects were not significant for females ($\Delta\chi^2_3 = 0.346$, $p = 0.951$) and the nonadditive genetic specific effects were not significant for males ($\Delta\chi^2_3 = 0.514$, $p = 0.916$). Removal of the common nonadditive genetic effects for males ($\Delta\chi^2_3 = 1.583$, $p = 0.663$) and shared environment effects for females ($\Delta\chi^2_3 = 1.890$, $p = 0.596$) also did not result in any significant reduction in the fit of the model. The additive genetic effect hypothesized to be common to all three variables was statistically significant for all variables ($\Delta\chi^2_6 = 128.006$, $p = 0.000$), explaining between 61 and 86% of all additive genetic influence on the measures. The final reduced model consisted of only additive genetic and unique environment effects, shown in Table III and Fig. 1, and provides a good fit to the data ($\chi^2_{60} = 70.126$, $p = 0.174$). No evidence was found to suggest that the additive genetic effects influencing men and women were different (nonscalar sex limitation: $\Delta\chi^2_1 = 1.198$, $p = 0.274$), although relative proportions of genetic and environmental effects

Table II. Cross-Twin, Cross-Trait Polychoric Correlations for Variables Related to Sexual Feelings, Attitude to Having Sex with Persons of the Same Sex, and Number of Same-Sex Partners: Monozygotic (MZ) Twin Results Are Above the Main Diagonal, with Dizygotic (DZ) Twin Results Below the Main Diagonal

	MZ female correlations (603 pairs)					
	Feelings$_{T1}$	Attitude$_{T1}$	Partners$_{T1}$	Feelings$_{T2}$	Attitude$_{T2}$	Partners$_{T2}$
Feelings$_{T1}$	*1.00*	0.72	0.73	**0.45**	0.35	0.25
Attitudes$_{T1}$	0.68	*1.00*	0.72	0.47	**0.55**	0.42
Partners$_{T1}$	0.66	0.60	*1.00*	0.39	0.40	**0.55**
Feelings$_{T2}$	**0.29**	0.17	0.13	*1.00*	0.76	0.68
Attitude$_{T2}$	0.24	**0.29**	0.19	0.78	*1.00*	0.65
Partners$_{T2}$	0.26	0.25	**0.00**	0.35	0.37	*1.00*
	DZ female correlations (340 pairs)					

	MZ male correlations (290 pairs)					
	Feelings$_{T1}$	Attitude$_{T1}$	Partners$_{T1}$	Feelings$_{T2}$	Attitude$_{T2}$	Partners$_{T2}$
Feelings$_{T1}$	*1.00*	0.93	0.83	**0.50**	0.41	0.28
Attitudes$_{T1}$	0.84	*1.00*	0.73	0.42	**0.43**	0.25
Partners$_{T1}$	0.74	0.70	*1.00*	0.25	0.30	**0.40**
Feelings$_{T2}$	**0.01**	0.04	–0.23	*1.00*	0.94	0.86
Attitude$_{T2}$	0.15	**0.07**	0.12	0.76	*1.00*	0.79
Partners$_{T2}$	0.08	0.10	**0.02**	0.79	0.87	*1.00*
	DZ male correlations (172 pairs)					

	Feelings$_{F}$	Attitude$_{F}$	Partners$_{F}$	Feelings$_{M}$	Attitude$_{M}$	Partners$_{M}$
Feelings$_{F}$	*1.00*					
Attitudes$_{F}$	0.86	*1.00*				
Partners$_{F}$	0.72	0.59	*1.00*			
Feelings$_{M}$	**0.01**	0.16	0.03	*1.00*		
Attitude$_{M}$	0.13	**0.08**	0.10	0.86	*1.00*	
Partners$_{M}$	0.11	0.16	**0.14**	0.78	0.72	*1.00*
	DZ opposite-sex pair correlations (344 pairs)					

could not be equated between the sexes (common effects sex limitation: $\Delta\chi^2_{12} = 61.659$, $p = 0.000$), with additive genetic effects being of greater importance in women (53–57% of the variance) than men (31–34% of the variance).

A more restrictive common pathway model was also fitted to the data, with the full common pathway model providing an acceptable initial fit to the data ($\chi^2_{54} = 70.966$, $p = 0.061$). Nonadditive genetic and shared environmental effects (both common and specific to the individual observed variables) were not found to be significant ($\Delta\chi^2_8 = 4.394$, $p = 0.820$). Both the full and the reduced common pathway models are shown in Table III, and the reduced model is shown in Fig. 2. It can be seen that the latent variable ("homosexuality") underlying the observed variables in this model has a heritability of 0.58 (i.e., 0.76^2) for females (95% confidence intervals, 0.48–0.69) and 0.30 for males (95% confidence intervals, 0.15–0.46). As demonstrated in Fig. 2, this latent variable has an important phenotypic influence on all three observed variables, accounting for between 63 and 89% of the total variance in females and between 74 and 95% of the total variance in males. Significant specific additive genetic influences not accounted for by the latent variable were found in women for all three observed variables, but they were not statistically significant in men. As in the independent pathway model, no evidence was found for different sets of genes influencing sexual orientation in men and women ($\Delta\chi^2_1 = 0.491$, $p = 0.483$).

Table III. Aggregate Proportions of Variance (with 95% Confidence Intervals) Accounted for by Genetic and Environmental Effects for Three Measures of Sexual Orientation: The Full and Most Parsimonious Independent Pathway and Common Pathway Models Are Shown

	Proportion of variance						Model fit			
Model	A_f	C_f	E_f	A_m	D_f	E_m	χ^2	df	p	AIC
Full independent pathway							65.793	46	0.029	−26.21
Feelings	0.32	0.20	0.48	0.13	0.22	0.65				
	(0.05–0.64)	(0.00–0.45)	(0.35–0.62)	(0.00–0.47)	(0.00–0.52)	(0.44–0.86)				
Attitude	0.46	0.09	0.45	0.26	0.11	0.63				
	(0.17–0.64)	(0.00–0.35)	(0.36–0.54)	(0.00–0.48)	(0.00–0.48)	(0.46–0.80)				
No. partners	0.52	0.01	0.47	0.19	0.16	0.65				
	(0.23–0.69)	(0.00–0.25)	(0.30–0.63)	(0.00–0.50)	(0.00–0.53)	(0.43–0.85)				
Reduced independent pathway							70.126	60	0.174	−49.87
Feelings	0.53	—	0.47	0.31	—	0.69				
	(0.39–0.67)		(0.33–0.61)	(0.10–0.49)		(0.51–0.90)				
Attitude	0.57	—	0.43	0.34	—	0.66				
	(0.48–0.65)		(0.35–0.52)	(0.15–0.49)		(0.51–0.85)				
No. partners	0.53	—	0.47	0.31	—	0.69				
	(0.37–0.69)		(0.31–0.63)	(0.08–0.50)		(0.50–0.92)				
Full common pathway							70.966	54	0.061	−37.03
Feelings	0.52	0.08	0.39	0.12	0.23	0.61				
	(0.23–0.70)	(0.00–0.36)	(0.28–0.53)	(0.00–0.46)	(0.00–0.49)	(0.44–0.82)				
Attitude	0.46	0.09	0.45	0.13	0.22	0.67				
	(0.21–0.64)	(0.00–0.32)	(0.34–0.55)	(0.00–0.43)	(0.00–0.45)	(0.49–0.86)				
No. partners	0.56	0.00	0.44	0.21	0.18	0.64				
	(0.28–0.69)	(0.00–0.24)	(0.29–0.59)	(0.00–0.48)	(0.00–0.39)	(0.43–0.84)				
Reduced common pathway							75.360	62	0.119	−48.64
Feelings	0.60	—	0.40	0.35	—	0.65				
	(0.48–0.72)		(0.28–0.52)	(0.18–0.51)		(0.49–0.82)				
Attitude	0.57	—	0.43	0.32	—	0.68				
	(0.48–0.65)		(0.35–0.52)	(0.18–0.47)		(0.53–0.82)				
No. partners	0.55	—	0.45	0.34	—	0.66				
	(0.41–0.69)		(0.31–0.59)	(0.17–0.52)		(0.48–0.83)				

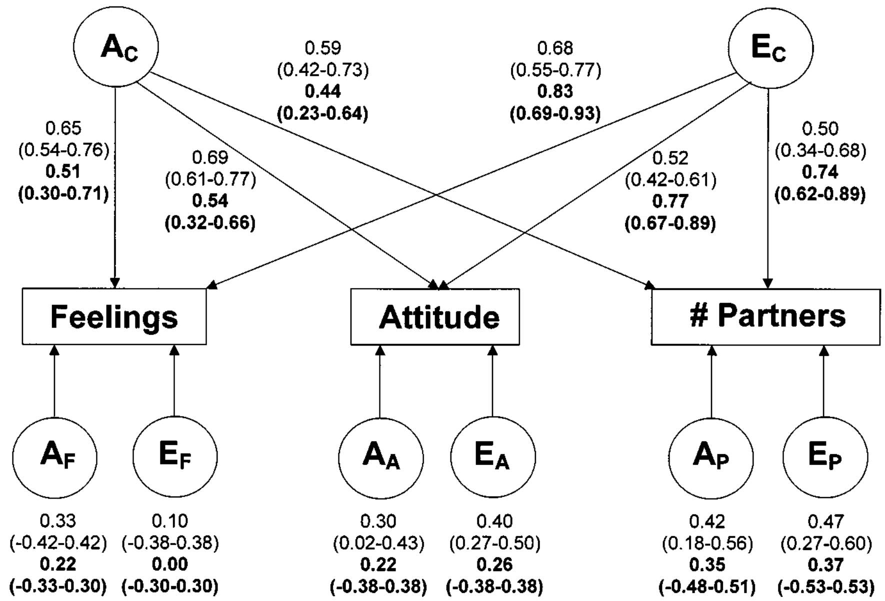

Fig. 1. Path diagram showing latent genetic and environmental influences on the measured phenotypes of orientation of present sexual feelings (Feelings), attitude to sex with a person of the same sex (Attitude), and lifetime number of sexual partners of the same sex (# Partners). A_C and E_C represent additive genetic and environmental factors common to all three observed variables, while A_F, A_A, and A_P and E_F, E_A, and E_P represent additive genetic and environmental factors specific to the individual variables. Path coefficients are shown for females (above; normal font) and males (below; boldface font), with 95% confidence intervals. These coefficients must be squared to obtain the proportions of variance of each measured variable accounted for by the latent variable.

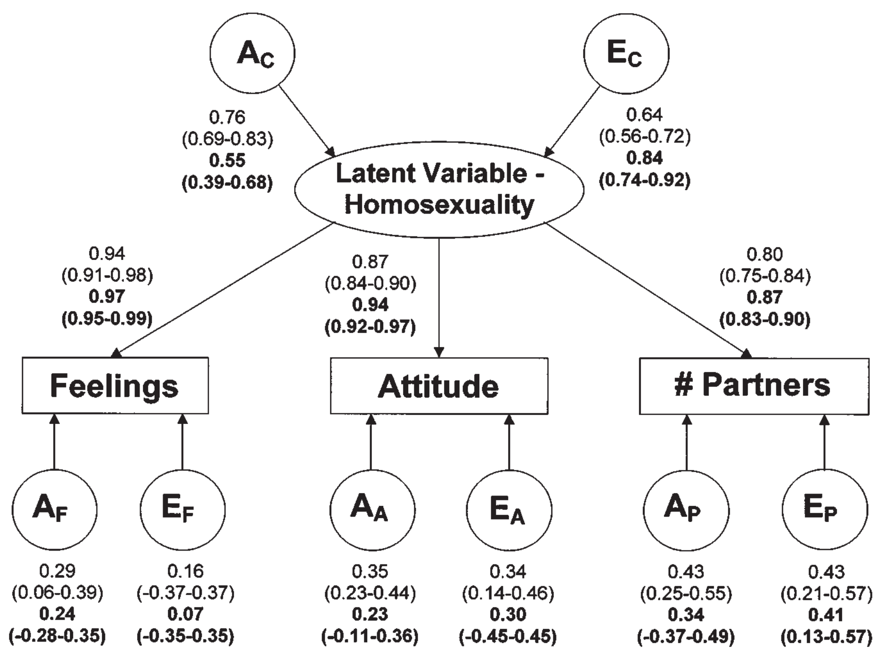

Fig. 2. Path diagram showing latent genetic and environmental influences on the measured phenotypes of orientation of present sexual feelings (Feelings), attitude to sex with a person of the same sex (Attitude), and lifetime number of sexual partners of the same sex (# Partners) via a common underlying latent variable, "homosexuality." A_C and E_C represent additive genetic and environmental factors acting on the latent variable, while A_F, A_A, and A_P and E_F, E_A, and E_P represent additive genetic and environmental factors specific to the individual observed variables. Path coefficients are shown for females (above; normal font) and males (below; boldface font), with 95% confidence intervals. These coefficients must be squared to obtain the proportions of variance of each measured variable accounted for by the latent variable.

DISCUSSION

Multivariate analysis of a number of distinct but related self-report measures of sexual orientation using independent and common pathway models has provided statistically significant support for the existence of significant genetic contributions to the trait of homosexuality. Both models fit the data quite well, and direct comparison of the common pathway model to the independent pathway model shows that they are not significantly different ($\chi^2_2 = 5.234$, $p = 0.073$). On the basis of these data, the hypothesis of a latent variable "homosexuality" underlying and accounting for most of the variation in the three observed variables cannot be rejected.

In each model, significant additive genetic influences were found for homosexuality in females and males, with heritability estimates of between 50 and 60% for females and approximately 30% for males. Although inspection of cross-twin cross-trait correlations suggested the possibility of additional shared environmental influences in females and nonadditive genetic influences in males, no significant effects of these kinds were detected. However, it is known that the power to detect nonadditive genetic effects is low, even with large samples. If these effects are real, they would act to increase the heritability in males. Independent pathway and common pathway models which included nonadditive genetic effects estimated the heritability in males to be 35–40%, with the heritability estimates for females essentially unchanged.

Overall, the results of this study are generally consistent with the analysis of the same data by Bailey *et al.* (2000). In that study, data pertaining to sexual orientation (average of Kinsey scales responses on sexual feelings and attraction), Childhood Gender Nonconformity, and Continuous Gender Identity were analyzed, with a view to investigating specifically psychological (as opposed to behavioral) sexual orientation. Significant familial effects on psychological sexual orientation were found for both men and women, although it was difficult to determine whether these were due to genetic or shared environmental effects, and the additive genetic effects on psychological sexual orientation in men were not statistically significant. The results of the present study are consistent with those obtained previously, with heritability estimates for measures of psychological sexual orientation falling within the (admittedly wide) confidence intervals of Bailey *et al.*

However, there are two major advantages in the present analysis. First, we consider both psychological aspects (nonheterosexual feelings and attitudes to homosexual sex) and behavioral aspects (number of same-sex partners) of sexual orientation and have, thus, been able to show that the additive genetic influences underlying measures of behavioral and psychological sexual orientation are primarily common to both. Second, the present multivariate analyses are of multiple measures of closely related indicator variables, all influenced by the latent variable "homosexuality." Capitalizing on the genetic covariance between these indicator variables has given us an increase in statistical power over the analysis by Bailey *et al.* (2000), which used a single aggregate sexual orientation measure with the Childhood Gender Nonconformity (CGN) and Continuous Gender Identity (CGI) scales. This increase in statistical power is demonstrated by much narrower confidence intervals for variance components and has allowed us to detect significant additive genetic effects affecting both psychological and behavioral sexual orientation in men and women.

It should be noted from Table I that the majority of the variation in sexual orientation in this sample is in the low range of Kinsey scores, a result which is consistent with prevalence estimates obtained by population-based studies in other countries such as the United Kingdom and France (Wellings *et al.*, 1994). This type of ordinal distribution (low prevalence of the trait of interest) has been shown to provide a low power to resolve whether familial aggregation is genetic or environmental in origin (Neale *et al.*, 1994), so it is not surprising that it was necessary to implement multivariate modeling techniques to detect significant additive genetic effects.

General survey participation biases from this study are described in detail elsewhere (Dunne *et al.*, 1997), with only small effect sizes on measures such as education, alcohol consumption, cigarette smoking, and personality observed between those who explicitly consented to participate in the study and those who explicitly refused. However, analysis of the anonymous item responses of twins whose cotwin also responded to the survey versus those whose cotwin did not respond can provide an estimate of the volunteer biases affecting those individual items, provided that the same encouragement to participate has been given to individuals regardless of the participation status of their relatives (Neale and Eaves, 1993). This analysis applied to the 10 items relating to sexual feelings and behavior in the questionnaire found a significant volunteer bias only for number of males' opposite-sex partners, with participants whose cotwins did not respond to the questionnaire recording more responses in the higher categories. This would tend to indicate that this type of volunteer bias has not significantly affected the results of this study, particularly as the affected questionnaire item was not incorporated in the multivariate analyses.

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