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Genetic Differences in Psychomotor Performance Decrement after Alcohol: A Multivariate Analysis*

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ABSTRACT. We reanalyzed data on the decline in performance on a battery of psychomotor tests, after a standard dose of ethanol (0.75 g/kg body weight), of 206 same-sex twin pairs. Principal components analysis identified two orthogonal factors. The first factor was strongly associated with increased body sway, self-rated intoxication and unwillingness to drive, and reported low average weekly alcohol consumption, but showed a very weak association with blood alcohol concentration. The second factor had high loadings on tests assessing psychomotor coordination, was strongly associated with blood alcohol concentration, but was unrelated to willingness to drive or self-rated intoxication. Multivariate genetic analysis indicated independent genetic and environmental determination of differences in sensitivity to the effects of alcohol on these two factors. (*J. Stud. Alcohol* **53:** 262-271, 1992)

EVIDENCE for a genetic effect on male vulnerability to alcoholism is provided by studies of adoptees (Cadoret et al., 1980; Cloninger et al., 1981; Goodwin et al., 1974) and of half-siblings (Schuckit et al., 1972), and by some (Hrubec and Omenn, 1981; Kaij, 1960; Kaprio et al., 1987; McGue et al., 1989) but not all (Gurling et al., 1981; Murray et al., 1983) twin studies. Such findings have generated interest in identifying the specific vulnerability or vulnerabilities that may be inherited (Schuckit, 1984a). High-risk studies comparing the sons of alcoholics and controls have found a decreased reactivity to a standard dose of alcohol in the former group: sons of alcoholics report less intoxication (Moss et al., 1989; O'Malley and Maisto, 1985; Pollock et al., 1986; Schuckit, 1984a), and exhibit a smaller increase in body sway (Schuckit, 1985), diminished cortisol response (Schuckit, 1984b; Schuckit et al., 1987) and more rapid recovery of normal prolactin levels (Schuckit et al., 1983, 1987). Given these multiple differences in response to alcohol, it is natural to question whether these reflect a single underlying inherited vulnerability or independent dimensions of genetic vulnerability (Schuckit and Gold, 1988). The discriminant function and principal component analyses of Schuckit and Gold (1988) suggest that there may be relatively independent genetic dimensions influencing subjective feelings, hormonal changes plus body sway, and low-dose prolactin changes. These findings are thus consistent with a multifactorial model for the etiology of reactivity to alcohol.

Heritable differences in response to alcohol have been demonstrated in general population samples of twins not selected for risk of alcoholism (Kopun and Propping, 1977; Martin et al., 1985a,b; Propping, 1977a,b; Vesell, 1972; Wilson and Plomin, 1985). Genetic effects on rate of elimination of alcohol have been reported consistently (Kopun and Propping, 1977; Martin et al., 1985b; Vesell, 1972; Wilson and Plomin, 1985). The largest study (but not the small study of Propping, 1977a,b) also found evidence for genetic effects on several measures of psychomotor performance after a standard, body-weight-adjusted dose of alcohol (Martin et al., 1985a), as well as genetic influences on self-ratings of intoxication (Heath and Martin, 1991b; Neale and Martin, 1989). Very little of this genetic influence could be explained by genetically determined differences in blood alcohol concentration after the standard dose of alcohol (Martin et al., 1985a).

In this article, we apply methods of multivariate genetic analysis (Heath and Martin, 1990; Kendler et al., 1987; Martin and Eaves, 1977) to the psychomotor performance data of Martin and colleagues (1985a). These methods allow us to address the question of whether, in a general population sample, there are independent genetic (or environmental) dimensions influencing intoxication self-ratings, body sway and other psychomotor performance measures, or only a single dimension of inherited sensitivity to the effects of alcohol.

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Method

Sample and protocol

Subjects were 206 twin pairs (43 MZ female, 42 MZ male, 44 DZ female, 38 DZ male and 39 opposite-sex DZ pairs) aged 18-34 years, recruited through the Australian NH&MRC Twin Registry from the Sydney and Canberra metropolitan areas. Analyses in this article are based on that subset of the total sample for whom the assessment battery also included a question about their willingness to drive (Martin and Boomsma, 1989). Allowing for listwise deletion of missing data, effective sample sizes were 29 MZ female, 30 MZ male, 30 DZ female, 28 DZ male and 31 opposite-sex DZ pairs. Zygosity was determined by blood-typing.

Since the NH&MRC Twin Registry was a volunteer twin panel, and since many twins from the Twin Registry would not be willing to participate in an alcohol challenge study, sampling bias is an important consideration. Twin pairs were included in the study if neither twin was an abstainer, both were alcohol free at the beginning of testing and both successfully completed the experimental protocol (Martin et al., 1985a,b). No screening for presence or absence of a history or family history of alcoholism was performed. Average weekly consumption of alcohol reported by the female subjects (10.01 gm absolute alcohol per day; Heath and Martin, 1991b) was comparable to that reported for female drinkers (9.36 gm for female drinkers aged 18-24, 10.04 gm for female drinkers aged 25-44) in a 1977 survey conducted by the Australian Bureau of Statistics (ABS) (1978). Reported weekly consumption by male subjects (19.28 gm absolute alcohol per day; Heath and Martin, 1991b) was lower than the ABS consumption figures for men (28.5 gm for male drinkers aged 18-24; 28.95 gm for male drinkers aged 25-44) but comparable to results obtained in a mailed questionnaire survey of the twin panel (21.23 gm for male drinkers aged 18-24; 23.81 gm for male drinkers aged 25-44; Heath and Martin, 1991b; Jardine and Martin, 1984). Thus, the female subjects appear to be representative of the general population of drinkers. The male subjects appear to be representative of cooperative twins on the Twin Registry, but report lower consumption levels than the general population of male drinkers. It is not certain to what degree this reflects undersampling of heavy male drinkers and to what degree it is caused by changes in male consumption patterns between 1977 and 1979-81.

Members of a twin pair were tested on the same day, beginning at about 9:00 AM, having been instructed to eat a light, nonfatty breakfast approximately 1 hour earlier. Twins completed a questionnaire about their age-of-onset of alcohol use and their habitual alcohol consumption patterns, including average weekly consumption of beer, wine, spirits, sherry and other alcohol beverages. From this, each subject's years of drinking and average weekly consumption in standard drinks of alcohol (x) were computed and both measures were log (x + 1) transformed. A baseline breath alcohol reading was taken (see Martin et al., 1985b, for further details of measurement procedures) and any twins who were not alcohol-free at baseline were excluded from the study.

The experimental protocol included the following tasks, taken from the test battery of Belgrave et al. (1979) (see also Franks et al., 1976):

1. Vienna Determination Apparatus (VDA), a test of psychomotor coordination. Subjects were presented with a random sequence of visual and auditory stimuli, presented at 1.22-second intervals, and had to respond with specific button or foot-pedal responses. Variables used for analysis were the number of correct responses (VDA correct) and the number of delayed correct responses (VDA delayed correct).
2. Body sway. Assessed by having the subject stand relaxed and as steady as possible on a platform, beneath which a displacement transducer had been mounted, which created an electric impulse if there was any forwards-backwards sway. Oscillations were integrated and the time taken in seconds to accumulate a given amount of sway was recorded on a polygraph: the longer the time, the steadier the subject. Duplicate measurements were made under two conditions, first with the subject's eyes open and then with eyes closed, and the average of the measurements under each condition was taken. Subjects in high heels removed their shoes for this test.
3. Pursuit-rotor, a measure of eye-hand coordination. Subjects attempted to track a light target moving in a clockwise circular motion with a photocell stylus. The number of times off the target and the accumulated total time off the target were recorded.
4. Arithmetic computation. Assessed using the Arbeit und Konzentration Testgrate (AKTG), a speeded task in which the subject is presented with simple addition and subtraction computations and asked to answer as many as possible in 2 minutes. The number of correct responses and the number of incorrect responses were recorded.
5. Blood alcohol concentration (see Martin et al., 1985b, for full details of the measurement and interpolation procedures). Finger pricks were made with a lancet, and blood taken into a 0.25-ml heparinized capillary tube. An 0.1-ml aliquot was pipetted from each tube into a 1-ml reaction vial which contained 0.9 ml 0.01% (v/v) n-propanol. Most samples were assayed for ethanol concentration (by gas-liquid chromatography) within 24 hours, but otherwise were frozen at −20°C until subsequent analysis. On each day of testing a standard curve was calculated using duplicate samples of known ethanol concentrations (0,25,50,75 and 100 mg ethanol/100 ml), prepared in exactly the same way as blood samples; and additional standard samples (50 mg/100 ml) were interspersed with blood samples to check for instrument drift.
6. Intoxication self-rating. Subjects were asked, "How drunk do you feel now, on a scale of 1 = completely sober to 10 = the most drunk I have ever been."

7. Willingness to drive. Subjects were asked, "Would you drive a car now?" and responses were coded as 0 (No) or 1 (Yes).

After baseline assessments, each twin was given a single alcohol dose of 0.75g ethanol/kg body weight, diluted to 10% (v/v) in sugarless squash, which was consumed under supervision over a 20-minute period, at a constant rate. No attempt was made to assess performance at other alcohol doses, or after placebo. After a further 20 minutes, the first of three hourly cycles of testing began, with measurements of blood alcohol, psychomotor performance, body sway, and self-ratings of intoxication and willingness to drive being obtained. We consider only the results from the first testing cycle. Two to six twin pairs were tested on each day, and co-twins were never tested consecutively, to minimize the possibility of observer bias.

Data summary

For each measure in the test battery, except for the intoxication and willingness to drive ratings, the change in performance from baseline to the first occasion of testing after alcohol was computed. Use of regression residuals instead of change scores (Nagoshi et al., 1986, 1987) would also have been a feasible strategy, but one that raises statistical problems because of the nonindependence of observations on members of a twin pair (Neale and Martin, 1989). The analysis of change scores, or of regression residuals, is far from ideal when we wish to test multivariate genetic or other structural models (Neale and Martin, 1989). With larger sample sizes, the ideal approach would have been to include both baseline and postalcohol measures, estimating both "baseline-correction" factors, loading on both pre- and postalcohol measures, and "alcohol reactivity" factors, loading only on postalcohol measures (Martin et al., 1985a). However, this would have required the inclusion of 16 additional variables in the multivariate genetic analysis (eight baseline assessments on first and second members of each twin pair), which we considered to be computationally infeasible, given the relatively small sample sizes.

Because we were analyzing change scores, greater deterioration in performance after alcohol was indicated by higher positive change scores for VDA correct, duration of body sway and AKTG correct; and by more strongly negative change scores for VDA delayed correct, pursuit-rotor times off target and total time off target, and AKTG incorrect. This should be borne in mind when interpreting the results of the multivariate analyses.

Partial correlation matrices, controlling for age, were computed, separately for male and for female twins, ignoring the twin structure of the data, and were used as input for a principal components analysis. Although observations on members of a twin pair are not independent, this will not cause a bias in the point estimates of correlations, provided that sampling is random, but will cause the standard errors of those correlations to be underestimated. Principal components analysis was used, rather than factor analysis, since when factor analyses were attempted negative estimates of the specific environmental variances were obtained for one or more psychomotor measure(s). This raises the possibility of correlated measurement errors for some variables and probably reflects the fact that such variables as the arithmetic computation (AKTG) correct and incorrect scores, though not strictly linearly dependent (since the total number of items completed varied between subjects), would have been very highly negatively correlated. Component loadings were rotated according to Varimax criteria (Harman, 1976).

Genetic analysis

Correlation matrices (27 × 27) were computed for each same-sex zygosity group, giving all possible correlations of the age of the twin pair, first twin's scores and second twin's scores on each of the 13 variables. For willingness to drive, a dichotomous variable, tetrachoric and biserial correlations were computed (Joreskog and Sorbom, 1983; Olsson, 1979; Olsson et al., 1982). All other variables were treated as continuous. Twins from a pair were assigned as first or second twins at random. Multivariate genetic models (Kendler et al., 1987; Martin and Eaves, 1977) were fitted separately to the data from male same-sex pairs and from female same-sex pairs by the method of diagonal least squares (Heath et al., 1985; Joreskog and Sorbom, 1983; Kendler et al., 1987). This provided an approximate chi-square test of the model. Since we were doubtful about how well our goodness-of-fit statistic would follow a chi-square distribution, given the very small sample sizes, the data for men and women were analyzed separately, and the replication or nonreplication of results across sexes was used as an indication of the robustness of our findings.

Multivariate genetic analysis is a generalization of factor analysis (Harman, 1976) and of behavioral genetic analysis (Eaves et al., 1989; Jinks and Fulker, 1970) that permits simultaneous estimation of genetic and environmental factor loadings. We give here only an informal introduction to the basic concepts of multivariate genetic analysis, which are discussed more formally elsewhere (Martin and Eaves, 1977). Conventional factor analysis analyzes only within-person correlations and is used to estimate the number of factors that are needed to explain the observed pattern of phenotypic correlations and to estimate loadings of individual variables on each factor (Harman, 1976). Behavioral genetic analysis, when applied to a single variable (e.g., blood alcohol concentration), uses differences in family resemblance as a function of degree

of genetic relatedness to estimate the contributions of genes, family environment and nonshared environment to variation in that variable (Eaves et al., 1989). If variation is caused by the additive effects of genes plus environmental influences that are not shared even by sibs reared in the same family, for example, the monozygotic twin correlation is predicted to be twice the dizygotic twin correlation for that trait. Multivariate genetic analysis (Heath et al., 1989; Martin and Eaves, 1977) exploits the additional information contained in the cross-correlations between performances of first and second twins on different measures (e.g., between first twin's blood alcohol concentration and co-twin's body sway, and vice versa). If, for example, genetic effects are contributing to the correlations between blood alcohol concentrations and changes in body sway, after a standard dose of alcohol, then these cross-correlations would be predicted to be higher in MZ than in DZ twin pairs. This makes it possible to estimate the number of genetic and environmental factors that are needed to account for the phenotypic (within-person) and the within-variable and cross-variable twin correlations, and to obtain estimates of genetic and environmental factor loadings.

Figure 1 illustrates a simple "one-factor" multivariate genetic model. As in a factor analysis, the model distinguishes between common factors, which contribute to the correlations between scores on different tests, and item-specific factors, which contribute to variation in scores on a single test but not to the covariance of that test with other tests. As in a conventional genetic analysis, the model distinguishes between genetic effects, environmental effects shared by twins reared in the same family (which, since both members of a twin pair were tested on the same day, will include day-of-testing effects) and

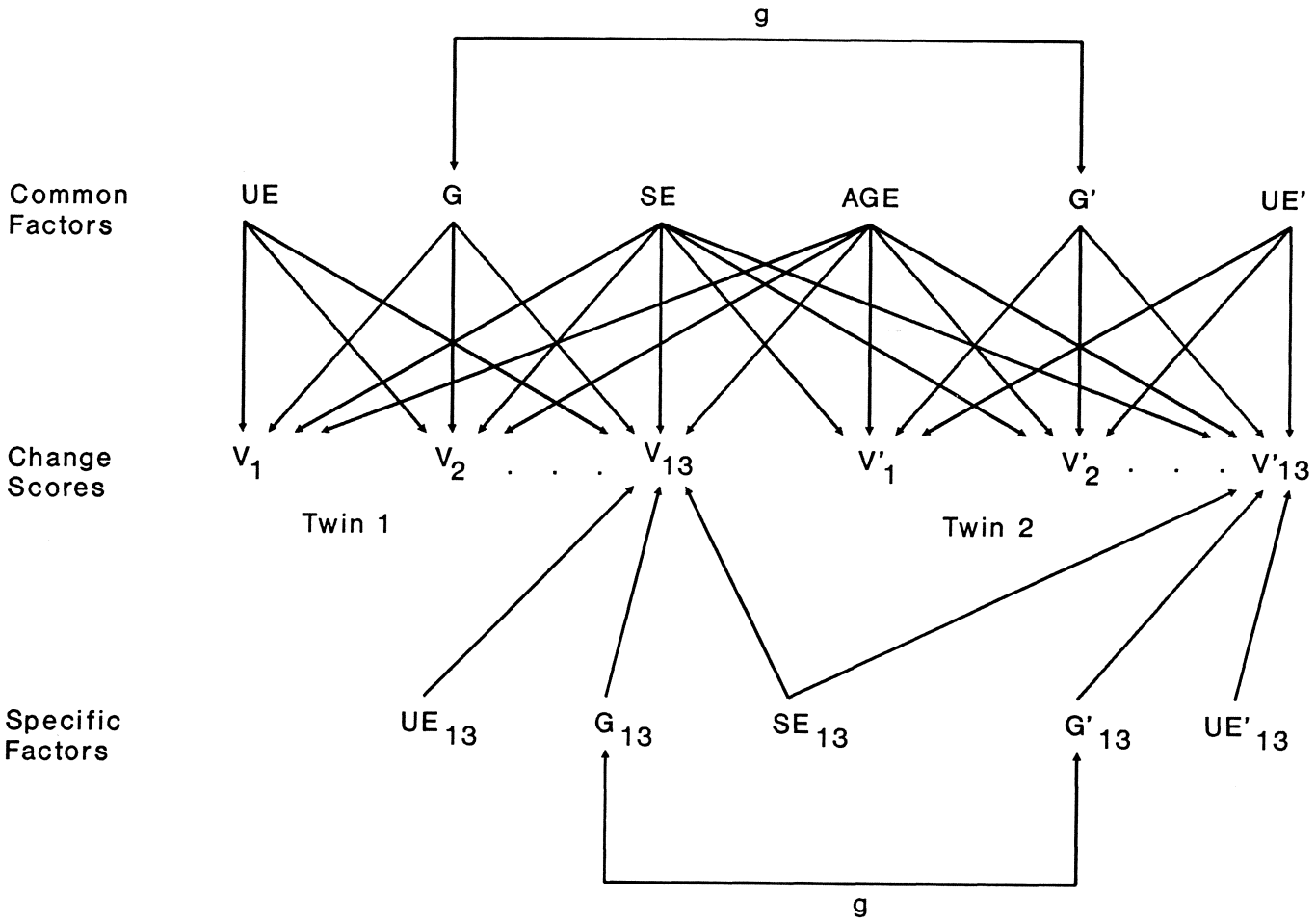

FIGURE 1. One-factor multivariate genetic model for twin data. (V = test score of first twin of each pair, V' = score of co-twin. Subscript numerals identify tests within the battery [see Method section]. UE = unique environmental common factor; G = genetic common factor, of first twin; SE = shared environmental common factor; UE' = unique environmental common factor; G' = genetic common factor; SE' = shared environmental common factor, of second twin. AGE = age common factor. g = correlation between genotypes [= 1 for monozygotic pairs, = 0.5 for dizygotic pairs]. UE_{13} and G_{13} denote unique environmental and genetic specific factors for variable 13 of the first twin, SE_{13} denotes shared environmental specific factor and UE'_{13} and G'_{13} denote unique environmental and genetic specific factors for variable 13 of the second twin. Specific factors are reproduced for variable 13 only, in order to simplify the diagram.)

unique environmental effects (i.e., those effects not even shared by twins reared in the same family, which therefore make one twin differ from his or her co-twin). The model is identified by constraining genetic and environmental common and specific factor loadings to be the same in first and second twins from each pair, and in twins from MZ versus DZ twin groups. However, the correlation between corresponding latent genetic factors in first and second twins will be unity in MZ twin pairs who are genetically identical and 0.5 in DZ twin pairs who, on average, share one-half of their genes in common. The model includes an age-correction factor (Heath and Martin, 1990; Neale and Martin, 1989), on which the loading of age is fixed to unity, to adjust for the effects of age on the variables under study. Loadings on this factor give the average correlation of each variable with age. Since twin pairs are perfectly correlated for their age, failure to include an age-correction factor would exaggerate the importance of common shared environmental effects in multivariate twin data.

Since our primary interest was in the common factor effects, rather than in the test-specific effects, we treated the latter as nuisance parameters and estimated test-specific genetic and shared and nonshared environmental variances rather than loadings, allowing these specific variances to take negative as well as positive values. A negative estimate of a shared environmental specific variance for a test would imply that, after controlling for the common factor effects, the residual MZ correlation was greater than one-half the residual DZ correlation for that test, implying genetic nonadditivity (Martin et al., 1978). A negative estimate of the additive genetic specific variance would imply a higher residual DZ than residual MZ correlation for a test. We compared the fit of nongenetic models allowing for only shared and nonshared environmental common factor loadings, additive genetic models allowing for only additive genetic and nonshared environmental common factor loadings and full models allowing for additive genetic and shared and nonshared environmental common factor loadings. In all cases, however, we estimated additive genetic, shared environmental and nonshared environmental specific variances.

As in the case of a conventional factor analysis, it is possible to estimate multiple genetic and environmental common factors. We therefore compared the fit of the one-factor solutions with solutions estimating two or more genetic, shared environmental or nonshared environmental common factors. When more than one set of genetic or environmental factors is estimated, the same problem of factor rotation that arises in conventional factor analysis (Harman, 1976) also occurs in multivariate genetic analysis. In such cases, the genetic, shared environmental and unique environmental common factor loadings were separately rotated according to varimax criteria.

TABLE 1. Factor loadings (× 100) of performance decrement scores and self-ratings under a two-factor solution

	MEN		WOMEN	
	I	II	I	II
BAC	−5	49	2	54
Weekly consumption	66	−4	62	23
Years drinking	13	−10	−8	7
Willingness to drive	62	−5	75	7
Intoxication	−62	20	−75	11
VDA correct	−3	84	−35	66
VDA delayed correct	4	−84	20	−55
Body sway (eyes open)	−67	27	−36	64
Body sway (eyes closed)	−65	30	−48	48
Pursuit rotor (times off target)	24	−53	−8	−44
Pursuit rotor (duration off target)	26	−42	2	−66
AKTG correct	−62	−10	0	48
AKTG incorrect	34	32	−13	−43

Results

Table 1 gives the varimax-rotated principal component loadings for the first two principal components. In both sexes, one component has high loadings on weekly alcohol consumption, self-ratings of willingness to drive and feelings of intoxication; and the other component has high loadings on blood alcohol concentration (BAC) and VDA and pursuit rotor measures of motor coordination. In women, the loadings of the two body-sway variables are higher on the second component than on the first, whereas in men these two variables have high loadings on the first component but only modest loadings on the second component. The arithmetic computation measures in women load on the second principal component, whereas in men, particularly in the case of the AKTG number correct score, the loading is higher on the first component. The pursuit rotor measures in men, and the VDA coordination measures in women, have moderate loadings on the first factor, in addition to higher loadings on the second factor. With these exceptions, the results show good consistency across sexes.

Table 2 gives the goodness-of-fit chi squares for multivariate genetic models estimating varying numbers of genetic, shared environmental and nonshared environmental factors. One-factor models that omit either genetic effects ("nongenetic models" in Table 2) or shared environmental effects ("additive genetic models") are rejected in both sexes by chi-square test of goodness-of-fit. Corresponding two-factor models give a good fit to the data, while the three-factor models do not give a significant improvement in fit over the two-factor models by likelihood-ratio chi-square test.

Comparing the fit of full models estimating both genetic and shared environmental as well as unique environmental common factors, the one-factor model gave an excellent fit in men and an adequate fit in women. However, in each sex, the two-factor model gave a significant

TABLE 2. Comparison of goodness-of-fit of multivariate genetic models

NUMBER OF COMMON FACTORS				TEST OF GOODNESS-OF-FIT			
				Men		Women	
Genetic	Shared environment	Nonshared environment	df	χ^2	p	χ^2	p
Nongenetic models							
0	1	1	637	756.41	< .001	825.67	< .001
0	2	2	611	577.44	.83	624.12	.35
0	3	3	585	544.19	.89	601.38	.31
Additive genetic models							
1	0	1	637	727.64	.007	789.00	< .001
2	0	2	611	575.49	.85	601.41	.60
3	0	3	585	543.86	.89	578.66	.57
Full models							
1	1	1	624	625.63	.47	669.98	.10
2	2	2	585	524.59	.96	562.23	.74
1	2	2	598	537.12	.96	577.26	.72
2	1	2	598	538.65	.96	575.28	.74
2	2	1	598	575.86	.74	599.15	.48

improvement in fit over the one-factor model (men: $\chi^2 = 101.04, 39$ df, $p < .001$; women: $\chi^2 = 107.75, 39$ df, $p < .001$). Furthermore, both in men and in women, the two-factor full model gave a significant improvement in fit over the two-factor nongenetic model ($\chi^2 = 52.89$, 26 df, $p = .001$; $\chi^2 = 61.89$, 26 df, $p < .001$) and over the two-factor additive genetic model ($\chi^2 = 50.90$, 26 df, $p = .002$; $\chi^2 = 39.18$, 26 df, $p < .05$). Deleting from the full two-factor model either one shared environmental common factor ($\chi^2 = 14.06$, 13 df, $p = .37$; $\chi^2 = 13.05$, 13 df, $p = .44$) or one additive genetic common factor ($\chi^2 = 12.53$, 13 df, $p = .48$; $\chi^2 = 15.03$, 13 df, $p = .31$) did not significantly worsen the fit of the model, whereas deleting one nonshared environmental common factor did lead to a significant deterioration in fit ($\chi^2 = 51.27$, 13 df, $p < .001$; $\chi^2 = 36.92$, 13 df, $p < .001$). Thus, while two nonshared environmental factors were clearly needed to account for the observed data, we were unable to choose between models allowing for two genetic and one shared environmental versus one genetic and two shared environmental common factors on the basis of likelihood-ratio chi-square comparisons to the full two-factor model.

Table 3 gives the genetic and environmental common factor loadings under the general two-factor multivariate genetic model, allowing for two additive genetic, two shared environmental and two nonshared environmental common factors. We focus our attention on this solution because the two simpler models (2-1-2 and 1-2-2 in Table 2) could not be resolved. Erroneous omission of a factor would lead to biased parameter estimates. In men, the first genetic factor had a pattern of loadings similar to that of the first principal component (Table 1), with high loadings on weekly consumption, self-ratings of intoxication and willingness to drive, and body sway under both eyes open and eyes closed conditions. The first genetic factor in men also had a high loading on the AKTG (arithmetic computation) number of items correct (as did the first

TABLE 3. Genetic and environmental common factor loadings (× 100) under two-factor multivariate genetic model

	MEN							WOMEN						
	Genetic		Shared environment		Nonshared environment			Genetic		Shared environment		Nonshared environment		
	I	II	I	II	I	II	Age	I	II	I	II	I	II	Age
BAC	6	66	47	−2	−8	5	25	10	30	56	26	−3	11	22
Weekly consumption	72	6	−16	9	21	−9	−5	52	−13	34	8	−15	11	−3
Years drinking	13	13	0	0	−5	−15	93	−6	0	5	−2	−4	2	85
Willingness to drive	60	−8	−16	6	13	8	25	83	−21	−11	2	−6	13	4
Intoxication	−49	18	0	−6	−29	−4	−27	−57	36	2	4	−3	−26	−15
VDA correct	0	25	40	0	−10	90	−10	−2	32	54	23	−14	−61	4
VDA delayed correct	15	−37	−13	1	14	−80	20	−19	−6	−53	−10	21	92	7
Body sway (eyes open)	−49	−6	57	−7	−37	−15	−19	−9	75	−1	51	−12	−4	3
Body sway (eyes closed)	−52	−2	40	−6	−28	−11	−21	−25	63	13	38	4	−11	−5
Pursuit rotor (times off target)	−5	−3	−36	0	63	7	3	10	−14	−26	4	19	5	−20
Pursuit rotor (duration off target)	0	7	−55	0	77	0	−13	−30	−123	−12	85	42	−7	−1
AKTG correct	−48	6	6	−14	−22	0	−2	−2	21	−12	7	−57	0	1
AKTG incorrect	−30	27	6	392	3	6	−6	5	2	1	−1	84	−9	−9

principal component) but, unexpectedly, the loading on the AKTG number of items incorrect was opposite in sign to what had been predicted. The second genetic factor in men had a high loading on blood alcohol concentration and moderate loadings on VDA correct and on delayed correct (the latter loading being negative); and the first shared environmental factor had high loadings on blood alcohol concentration, body sway and pursuit rotor measures. Thus, the association between blood alcohol concentration and deterioration in psychomotor performance apparent from the second principal component loadings appears to reflect both genetic and shared environmental influences. The second shared environmental factor in men had a high loading only on a single item (AKTG incorrect), and has taken a pathological value (3.92), giving rise to negative specific variances for this item. The first nonshared environmental common factor in men had high loadings on pursuit-rotor performance and more modest loadings on body sway and self-report intoxication. Loadings of this factor on average weekly consumption and blood alcohol concentrations were both slight, suggesting that the factor is assessing idiosyncratic features of the twin's recent experience that are influencing coordination. The second nonshared environmental common factor had high loadings only on VDA correct and delayed correct measures, and probably reflects only correlated measurement errors for these two variables.

Genetic factor loadings estimated for the female same-sex pairs were broadly consistent with those for men. The first genetic factor influenced weekly consumption, self-rated intoxication and willingness to drive, and eyes-closed body sway, but also loaded on pursuit rotor times off target. The second genetic factor had moderate loadings on blood alcohol concentration and VDA correct, but had more pronounced loadings on body-sway items and also pursuit rotor duration off target. (The latter loading exceeded unity, and for this item in women negative specific variances were observed.) This sex difference was also observed in the principal components analysis, where the body-sway items had more pronounced loadings on the second component in women, but on the first component in men. The first shared environmental factor in women also contributed to the association between blood alcohol concentrations and psychomotor performance (VDA number correct and delayed correct). In contrast to the finding in men, average weekly alcohol consumption did load moderately on this factor. The second shared environmental factor loaded on measures of body sway and pursuit-rotor duration off target, as well as blood alcohol concentrations. The two nonshared environmental factors were more minor and, as in men, probably reflect correlated measurement errors: the first loading on AKTG number correct and incorrect, and pursuit-rotor duration of time off target; and the second loading primarily on the VDA psychomotor coordination measures.

Predictably, the highest loading on the age factor, in both sexes, was years drinking. In women, there was a slight trend for older subjects to report higher blood alcohol concentrations, to give higher ratings of intoxication, but to do better on the pursuit-rotor task. For other tasks, age effects were slight. In men, older subjects again tended to have higher blood alcohol concentrations and to report feeling more intoxication, but there were also modest age effects on willingness to drive and body sway.

Discussion

Our analyses of psychomotor performance decrement after a standard dose of alcohol do not support the notion of a global, unidimensional factor of sensitivity to alcohol. A conventional principal components analysis, ignoring the twin structure of the data, yielded two orthogonal components that were broadly consistent across sexes. The first component was strongly associated with average weekly alcohol intake, body sway (especially in men) and ratings of intoxication and willingness to drive; and showed a weaker association with psychomotor coordination as assessed by the Vienna Determination Apparatus (in women only) or a pursuit-rotor test (in men only). Predictably, those with higher average weekly alcohol consumption levels reported reduced feelings of intoxication and greater willingness to drive, and exhibited a smaller increase in body sway and smaller deterioration in psychomotor performance.

The second component was more strongly associated with blood alcohol concentrations and VDA and pursuit-rotor coordination measures, as well as with body sway (particularly in women). Higher blood alcohol concentrations in this sample were associated with greater deterioration in coordination and a greater increase in body sway, but showed little association with drinking history. Subjective ratings of intoxication and willingness to drive, which had high loadings on the first component, had very low loadings on this second component, despite the fact that self-ratings were obtained at the end of each testing cycle (i.e., after the psychomotor coordination tests). Apparently, subjects must have been making assessments of their intoxication and capacity to drive on the basis of cues that were relatively insensitive to blood alcohol concentrations, but more strongly influenced by past drinking patterns. In men, at least, these cues may have included the amount of body sway, which had high loadings on the first principal component and only moderate loadings on the second component.

In both male same-sex and female same-sex twin pairs, we were able to confirm by multivariate genetic analysis a significant genetic contribution to differences in performance decrement after alcohol, a finding consistent with the earlier report of Martin et al. (1985a) based on univariate analyses of these data. We also found a signif-

icant influence of environmental effects shared equally by MZ and by DZ twin pairs. However, since both members of a twin pair were tested on the same day, we cannot determine whether this reflects merely a short-term influence of conditions on the day of testing, or a more long-term influence of family background on differences in reaction to alcohol. When we compared the goodness-of-fit of multivariate genetic models estimating varying numbers of genetic, shared environmental and nonshared environmental factors we were unable to choose, on statistical grounds, between models allowing for two genetic and one shared environmental or one genetic and two shared environmental common factors. This finding is hardly surprising, given the relatively small sample sizes used in this study, compared to the large samples needed for resolving genetic and shared environmental effects when both are present (Martin et al., 1978).

The results of our multivariate genetic analysis, when two genetic, two shared environmental and two nonshared environmental common factors were estimated, were clearest in men, but were broadly replicated in women. One genetic factor was associated with differences in weekly consumption, self-ratings of intoxication and willingness to drive, and increase in body sway (men only). The second genetic factor influenced blood alcohol concentrations and the VDA measures of psychomotor performance (but also body sway in women). Unexpectedly, the association between blood alcohol concentrations and body sway and pursuit-rotor measures in both sexes appeared to reflect the influence of a shared environmental common factor, perhaps reflecting a day-of-testing effect. Equally surprising was our failure to find, in either sex, a general nonshared environmental common factor loading on all the performance measures. Apparently, whatever factors were making the performance of one twin differ from his or her identical co-twin were largely either test-specific, or restricted to a small number of tests.

Important sex differences in factor structure emerged both from the initial principal components analysis and from the multivariate genetic analysis. These were most marked for the body-sway variables for which important sex differences were already apparent from the univariate analyses of these variables (Martin et al., 1985a). In the principal components analysis, body sway in men loaded strongly on the first, "drinking history"-sensitive component, but had only modest loadings on the second, BAC-sensitive component. In women, loadings of the body-sway measures were as high or higher on the second component! In the multivariate genetic analysis, body-sway variables in men had high loadings only on the first component; whereas in women loadings on the first component were slight, and loadings on the second component were much more pronounced. We had not anticipated this sex difference, whereby female body sway appears to be most sensitive to blood alcohol concentrations and male body sway to average weekly alcohol consumption. It may reflect sex differences in the drinking experience of the subjects, relative to the magnitude of the challenge dose of alcohol. If a relatively small proportion of female subjects had previously consumed as high a dose of alcohol in as short a time period as in this study, then we might expect to find only a weak association between drinking history and body sway; whereas in men, we might expect a higher proportion of subjects to have had previous experience of a comparable dose and hence to find a stronger association. This explanation is certainly consistent with the lower correlation in women than in men between average weekly alcohol consumption and both body sway (Heath and Martin, in press) and self-ratings of intoxication (Heath and Martin, 1991a).

These multivariate results may have implications for high-risk research comparing sons of alcoholics and controls. In the paradigm for assessing body sway used in the Martin et al. (1985a,b) study, at least in men, differences in body sway, and differences in self-rated intoxication, appear to be influenced by a single underlying genetic common factor (the first genetic factor in Table 3), on which reported average weekly alcohol consumption also has a high loading. For both of these variables, in a study using somewhat different assessment procedures, sons of alcoholics have been reported to show a diminished response compared to controls (Schuckit and Gold, 1988). In a separate direction-of-causation analysis of intoxication rating and average weekly consumption in these twin data, we found that, in men at least, the major causal influence appeared to be that of regular consumption patterns on intoxication rating (Heath and Martin, 1991b). Similarly, in men, the association between drinking history and change in body sway after alcohol appeared to be largely determined by the causal influence of consumption patterns on body sway (Heath and Martin, 1991a). It is therefore possible that even after matching for gross drinking patterns, differences in drinking history between sons of alcoholics and controls are contributing to the differences in reactivity to alcohol.

The Vienna Determination Apparatus and pursuit-rotor psychomotor coordination tests, which we found to load most strongly on the second component in the principal component analysis, might be considered for inclusion in test batteries to be used in high-risk studies. The multivariate genetic analysis certainly suggests a genetic influence on deterioration in performance on the former measure that is independent of the genetic influence on self-rated intoxication and body sway, and is associated with genetic differences in ethanol metabolism (cf., Martin et al., 1985b). However, since ratings of intoxication and willingness to drive show such a lack of association with performance on these measures, it is possible that they are assessing effects of alcohol to which drinkers are relatively insensitive and which might therefore be

expected not to have a major influence on the natural history of patterns of alcohol use.

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