Genetic effects on alcohol dependence risk: Re-evaluating the importance of psychiatric and other heritable risk factors

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Genetic effects on alcohol dependence risk: re-evaluating the importance of psychiatric and other heritable risk factors

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ABSTRACT

Background. Genetic influences have been shown to play a major role in determining the risk of alcohol dependence (AD) in both women and men; however, little attention has been directed to identifying the major sources of genetic variation in AD risk.

Method. Diagnostic telephone interview data from young adult Australian twin pairs born between 1964 and 1971 were analyzed. Cox regression models were fitted to interview data from a total of 2708 complete twin pairs (690 MZ female, 485 MZ male, 500 DZ female, 384 DZ male, and 649 DZ female/male pairs). Structural equation models were fitted to determine the extent of residual genetic and environmental influences on AD risk while controlling for effects of sociodemographic and psychiatric predictors on risk.

Results. Risk of AD was increased in males, in Roman Catholics, in those reporting a history of major depression, social anxiety problems, and conduct disorder, or (in females only) a history of suicide attempt and childhood sexual abuse; but was decreased in those reporting Baptist, Methodist, or Orthodox religion, in those who reported weekly church attendance, and in university-educated males. After allowing for the effects of sociodemographic and psychiatric predictors, 47% (95% CI 28–55) of the residual variance in alcoholism risk was attributable to additive genetic effects, 0% (95% CI 0–14) to shared environmental factors, and 53% (95% CI 45–63) to non-shared environmental influences.

Conclusions. Controlling for other risk factors, substantial residual heritability of AD was observed, suggesting that psychiatric and other risk factors play a minor role in the inheritance of AD.

INTRODUCTION

The strong familial aggregation of alcoholism is well-established (Reich et al. 1988; Merikangas, 1990; McGue, 1994; Merikangas et al. 1998), with controlled studies of the families of alcoholic probands revealing a three-fold increased risk of alcoholism among the relatives of affected probands when compared to controls (Merikangas & Avenevoli, 2000). A family history of alcoholism has been shown to be the most consistent risk factor for developing alcohol dependence (AD), after personal alcohol use variables and pre-existing emotional
and behavioral disorders (Sher et al. 1991; Merikangas et al. 1998). Studies have also indicated that family history and individual history of psychopathology play a more significant role in the transition to problematic alcohol use and dependence than other individual characteristics and peer influences (Buchoz et al. 2000; Merikangas & Avenevoli, 2000); whereas the latter have been suggested to strongly affect exposure and initial patterns of alcohol and drug use (Pickens et al. 1991; Merikangas et al. 1998).

Twin and adoption studies indicate that genetic factors play a major role in the familial aggregation of AD. In the interview-based Danish adoption study, alcoholism in men was associated with alcoholism in biological but not adoptive parents (Goodwin et al. 1972, 1977). A similar association between record-based determination of alcoholism in adopted-away sons and their biological fathers was reported in Sweden (Cloninger et al. 1981; Sigvardsson et al. 1996). Likewise, the Iowa adoption studies (Cadoret et al. 1985a, 1987; Cadoret, 1994) showed a significantly elevated risk for AD in adopted-away sons and daughters from an alcoholic biological background, compared to control adoptees, consistent with a genetic influence on alcoholism. National and regional twin studies, both in the USA and abroad, of the risk of developing alcoholism in identical [monozygotic (MZ)] and fraternal [dizygotic (DZ)] co-twins of alcoholic twins have confirmed a higher risk to MZ compared to DZ co-twins of alcoholics, regardless of whether alcoholism was assessed by treatment or other official records (e.g. Hrubec & Ommenn, 1981; Koskenvuo et al. 1984; Romanov et al. 1991; Kendler et al. 1997b) or by diagnostic interview (Kendler et al. 1992a; Heath et al. 1997b; Prescott et al. 1999; True et al. 1999). Across studies, genetic effects have been found to account for approximately 60% of the variance in alcoholism risk in both men and women of European ancestry (Heath, 1995; Heath et al. 1997a, b). These data also suggest no significant effect of family environment on the liability to develop AD.

Sociodemographic and family variables such as religious affiliation, religious involvement, educational level and childhood sexual abuse (CSA), and psychiatric risk factors such as childhood conduct disorder, antisocial personality disorder (ASPD), and major depression may play an important role in the familial transmission of AD, and (with the exception of purely cultural variables such as religious affiliation) in contributing to genetic influences on AD risk. Religiosity as measured by strong familial variables such as personal devotion and institutional conservatism, has been shown to be significantly and inversely associated with lifetime risk for AD (Kendler et al. 1997a). Similarly, Heath et al. (1997b) reported that weekly church attendance was associated with decreased alcoholism risk in both men and women. Educational level, which has been found to be associated with AD risk in some samples (e.g. Heath et al. 1997b), also shows strong familial transmission, which in recent birth cohorts, is largely genetically determined (Heath et al. 1985). CSA has also been shown, in general population studies, to increase risk for alcohol abuse and/or dependence (e.g. Fergusson et al. 1996; Spak et al. 1998; Kendler et al. 2000; Nelson et al. 2002) even after controlling for confounding effects of family background (Nelson et al. 2002). Important genetic influences have been reported for major depression (Cadoret et al. 1985b; Kendler et al. 1992b; Lyons et al. 1998; Bierut et al. 1999; Kendler & Prescott, 1999), childhood conduct disorder (Slutske et al. 1997; Jacobson et al. 2000) and adult ASPD or antisocial traits (Cloninger & Gottesman, 1987; Grove et al. 1990; Lyons et al. 1995). Both depression and ASPD have been shown to co-occur at higher than expected rates with AD (Kessler et al. 1997; Regier et al. 1990), and high genetic correlations have been reported between AD and history of childhood conduct disorder (Slutske et al. 1998) or ASPD (Fu et al. 2002), as well as significant genetic correlations between AD and history of major depression (Kendler et al. 1993; Prescott et al. 2000), although the role of ASPD as a confounding factor in the latter association cannot yet be discounted (Fu et al. 2002).

While it is clearly possible that psychiatric and sociodemographic risk factors may account for much of the familial variance in AD risk, existing studies have addressed this question in a limited fashion. One approach has been to fit multivariate genetic factor models to psychiatric outcomes including AD (e.g. Kendler...
et al. 1995). However, finding a significant genetic correlation between risks of two disorders carries no necessary implication that one disorder is mediating some of the genetic influences on the second disorder. It could equally be the case that some intervening variables (e.g. genetically determined differences at the level of neurotransmitter systems) are contributing to risk of each disorder, with no direct effect of either disorder on the risk of the other. A second approach has been to use regression models, testing for zygosity differences in the association between respondent’s and co-twin’s AD history, after controlling for risk factors such as personality, religion, education, and psychiatric history (Heath et al. 1997b). However, with this method, no direct test of residual genetic influence on AD risk is conducted. Thus, the primary objectives of the present study focus on determining the role that sociodemographic and psychiatric variables play in mediating genetic influences on AD and are three-fold: (1) To identify risk factors for DSM-IV AD in both men and women; (2) to compare risk of AD in MZ and DZ twins as a function of co-twin history after controlling for the identified risk factors; and (3) to determine the extent of residual genetic and environmental influences on alcoholism liability, controlling for effects of sociodemographic and psychiatric predictors on risk.

METHOD
Participants and measures
The data for this analysis were collected from young adult twin pairs born between 1964 and 1971 who participated in a volunteer twin panel maintained by the Australian National Health and Medical Research Council. This sample is completely distinct from the older cohort of Australian twin pairs analyzed by Heath et al. (1997b). Twin pairs were ascertained as children in response to systematic appeals to parents through the Australian school systems and the mass media during the period 1980–1982; however, they were never assessed as children. Out of a total of 8020 twins (4010 pairs) ascertained as children, diagnostic interviews were conducted with 6207 twins (77.4% response rate), including both members of 2723 pairs. Non-participation was due to the following: partial interview (0.6%), deceased/incapable twins (2.1%), refusals (14%), unable to be contacted (5.1%), and no response (0.8%). After deleting observations with incomplete data, the present set of analyses includes data from a total of 2708 complete twin pairs (690 MZ female, 485 MZ male, 500 DZ female, 384 DZ male, and 649 DZ female/male twin pairs). All participants completed a telephone diagnostic interview conducted during 1996–2000. This interview was based upon a modified version of the SSAGA (Semi-Structured Assessment of the Genetics of Alcoholism; Bucholz et al. 1994; Hesselbrock et al. 1999), which was developed for the Collaborative Study of the Genetics of Alcoholism and is a comprehensive psychiatric interview used to assess physical, psychological, social, and psychiatric manifestations of alcohol abuse and dependence and related psychiatric disorders in adults (see Bucholz et al. 1994 and Hesselbrock et al. 1999 for reliability and validity data). Modifications were made to the SSAGA to incorporate DSM-IV (APA, 1994) criteria as well as to adapt it for telephone use. Verbal consent was obtained from all participants prior to their participation in the interview, using procedures approved by the Human Studies Committee at Washington University and the Ethics Committee at Queensland Institute of Medical Research.

The adapted SSAGA (SSAGA-OZ) included diagnostic assessments (DSM-IV) of AD, history of major depression, panic disorder, and childhood conduct disorder. Non-diagnostic measures of social anxiety and suicidality were also included. In addition to standard psychiatric assessment, information about CSA was collected. A binary composite CSA variable was constructed from five component questions regarding (a) forced sexual intercourse/activity before age 18, (b) sexual contact, before age 16, with someone other than a family member who was 5 or more years older than the respondent, (c) sexual contact, before age 16, with family members, (d) rape before age 18, (e) sexual molestation before age 18 (see Nelson et al. 2002 for more detail). A diagnosis of DSM-IV AD was assigned by computer algorithm. In addition, DSM-IV major depression, conduct disorder, and panic disorder diagnoses, and non-diagnostic measures of social anxiety, CSA, and history of suicide attempt as well as age
of onset for these measures were also determined by computer algorithm.

Finally, standard measures of sociodemographic variables and rearing history were also obtained. Educational level was collapsed to a four-point scale: (1) those who left school early (before 10 years of schooling) without any further training; (2) those who had some high school education, a diploma, trade certificate, or apprenticeship; (3) those who attended a technical or teacher’s college; and (4) those who had a university education or higher. Religion was divided into six categories: Roman Catholic, Anglican/Presbyterian/Uniting Church, Baptist/Methodist, Greek or Russian Orthodox, Other, and None. Church attendance was collapsed into a two-point scale: at least weekly versus less often. Zygosity of same-sex twin pairs was determined by standard questions for zygosity assignment (Nichols & Bilbro, 1966).

In Australia, minority populations differ considerably from those in the United States (less than 5%). No member of any minority was excluded from participation in the sample being analyzed; however, research on Australian aboriginal populations requires special community consultation procedures and permissions, and thus, this group was not represented in this Australian Twin Panel.

Data analysis

Descriptive analyses

Kaplan–Meier estimates of the lifetime prevalence of DSM-IV AD were computed by gender, as well as by co-twin’s DSM-IV AD status, using six dummy variables (i.e. MZ co-twin AD, DZ male co-twin AD, DZ female co-twin AD, DZ female co-twin unaffected, DZ male co-twin unaffected, and MZ co-twin unaffected; cf. Heath et al. 1997b). The rationale behind this is that those with an MZ AD co-twin are at greater risk of becoming AD than those with a DZ AD co-twin and so on, with those at lowest risk being individuals who have an MZ unaffected co-twin.

Ages-of-onset of co-morbid diagnoses were elicited to determine how often the onset of AD occurred before, in the same year, or after the onset of a psychiatric disorder. The association between AD and sociodemographic and psychiatric predictors was then investigated using Cox regression models. The use of such models allowed us to correct for (i) censoring (the problem that some of the non-AD individuals in this young sample are not yet through the period of risk for AD), (ii) the fact that a disorder occurring after the onset of AD should not properly be included as a predictor, and (iii) the incorporation of time-dependent covariates, i.e. those that may change in value over the course of the observation period (e.g. because of onset of depression; Allison, 1995). Cox regression estimates a hazard ratio, which is the ratio of the estimated hazard (i.e. probability of onset of AD) for those with the covariate (e.g. DSM-IV depression) to those without the covariate. For these analyses, Anglican/Presbyterian/Uniting Church served as the reference group for the religion variables, and those who left school early with no further training were the reference group for the education measures. Where significant gender × predictor interactions were observed, separate measures were created for men and women. Both members of pairs were included in these regression analyses; therefore, confidence intervals were adjusted to allow for the non-independence of twin pairs using the Huber–White robust variance estimation option as implemented via the Stata statistical package (StataCorp, 1999). Models were re-estimated with inclusion of dummy variables for twin-pair zygosity (MZ versus DZ), having an AD MZ co-twin, and having an AD DZ co-twin, to determine whether increased risk was observed in the MZ compared to the DZ co-twins of AD twins after controlling for psychiatric and sociodemographic predictors. Inclusion of these dummy variables for twin-pair zygosity and AD history resulted in a violation of the assumption of proportional hazards, thus hazard ratios associated with these measures represent an average effect over the range of time (Allison, 1995). Alternative models explicitly allowing for the interaction of these zygosity measures with time (i.e. allowing for deviations from the assumption of proportional hazards; Allison, 1995) were also fitted to the data and yielded similar results to those obtained under the assumption of proportional hazards, hence we report findings under the model with no interactions. Differences in hazard ratios (MZ versus DZ) were tested by Wald $\chi^2$ tests (adjusted for
non-independence of observations in twin pairs).

**Genetic model-fitting**

In order to determine the extent of genetic and environmental influences on risk of AD, genetic structural equation models were fitted to the twin data by the maximum-likelihood method using the Mx statistical modeling package (Neale et al. 1999). Normal liability threshold models were initially fitted to the data by the maximum-likelihood method. This model yielded estimates of the proportion of the total variance that could be explained by additive genetic ($a^2$), shared environmental ($c^2$), and non-shared environmental factors ($e^2$) without covariate adjustment. The full model allowed for genotype $\times$ gender interaction as well as different prevalence estimates (i.e. threshold values) for males and females in each of the zygosity groups. After confirming that there were no gender differences in genetic and environmental estimates ($\chi^2=0.671\, df=2\, p>0.50$), several submodels were fitted to the data to determine which prevalence estimates could be equated. From these submodels, it was determined that the best-fitting model was one in which all female prevalence estimates could be equated, MZ males had their own prevalence, and prevalence estimates for DZ males from both same-sex and opposite-sex pairs could be equated. Prescott et al. (1999) report a consistent finding of prevalence differences between MZ and DZ males in the Virginia Twin Study. Estimated additive genetic, shared environmental, and non-shared environmental variance components and their 95% likelihood-based confidence intervals (Neale & Miller, 1997) were recomputed under this model.

Based on the results of fitting Cox regression models, we subsequently modified this basic normal liability threshold model to control for significant ($p<0.05$) sociodemographic and psychiatric predictors. This was done by jointly modeling the probit regression of AD liability on significant sociodemographic and psychiatric predictors ($x_1, ..., x_n$). By doing this, we tested for residual genetic and environmental contributions to variation in risk of AD, controlling for the regression of AD risk on the covariates. For this analysis, covariates with an onset before or in the same year as the onset of AD were coded as 1 and those with onsets after the onset of AD were coded as 0. This coding scheme is conservative in that it will count as a predictor some cases where onset of AD occurred before, but during the same year as, onset of the second disorder. This over-correction should cause the magnitude of residual genetic influences on AD risk to be underestimated.

It has been hypothesized that measures of personality may be important mediators of genetic influences on alcoholism risk (Cloninger, 1987). Thus, the same set of analyses were repeated on a subsample of respondents (1238 twin pairs; Heath et al. 2001) who had completed a follow-up mailed questionnaire that included the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1976; Eaves et al. 1989) as well as additional personality data based on a short-form version of Cloninger’s Tridimensional Personality Questionnaire (TPQ; Cloninger et al. 1991; Heath et al. 1994). Measures of Extraversion, Neuroticism, Social-Nonconformity (‘Lie Scale’), Tough-Mindedness (‘Psychoticism’), Novelty-Seeking, Harm Avoidance, and Reward Dependence were included as additional control variables in these analyses.

**RESULTS**

Participants in the present study ranged in age from 23 to 36 years, with an average age of 30 years. With regard to religion, 44.4% reported being raised in the Anglican/Presbyterian/Uniting churches, 30.3% reported Roman Catholic as their religion, 5.2% were Baptist/Methodist, 1.5% Orthodox, 7.2% Other, and 11.4% reported no religion. However, only 10% of the sample noted attending church at least once a week. The sample was relatively well educated, with 27.2% having a university education or...
greater, 29% with a technical or teacher’s college certification, 34.7% with some high school with additional qualifications. Only 9.1% left school before 10 years and had no further training.

The onset of DSM-IV depression occurred with about equal frequency both before and after the onset of AD regardless of gender (Table 1). The onset of DSM-IV conduct disorder, CSA, and, to a lesser extent, the onset of social anxiety tended to occur before the onset of DSM-IV AD, with approximately 98% of both men and women reporting the onset of AD after the onset of conduct disorder, over 94% of men and women reporting the onset of AD after the onset of CSA, and about 88% of men and women reporting the onset of AD after the onset of social anxiety problems. Suicide attempt more often preceded the onset of AD in women, but followed the onset of AD in men.

**Prevalence of AD**

Consistent with previous reports (e.g. Teesson et al. 2000) showing higher 12-month prevalence of alcohol-use disorders in Australia than in the USA, this young adult Australian sample was a heavy-drinking cohort, with prevalence of lifetime abstinence less than 1% in both genders. A total of 89% of men reported drinking at least nine standard drinks, and 69% of women at least seven drinks in a single day on at least one occasion. The lifetime prevalence of AD by age 35 years was 34.3% in men and 17.0% for women (Fig. 1). Cumulative incidence of AD was subsequently examined as a function of co-twin’s AD status. Lifetime prevalence by age 35 was highest in men with an AD MZ co-twin (53.9%), lower in men with an AD female DZ co-twin (48.0%) and men with an AD DZ male co-twin (42.7%), lower in men who had an unaffected male or female DZ co-twin (32%) and lowest in men with an unaffected MZ co-twin (19.3%).

The risk for AD was increased in men and in Roman Catholics; however, there was a decreased risk in males who reported having a university education and in men and women with at least some high-school education with

<table>
<thead>
<tr>
<th>DSM-IV</th>
<th>% AD before Males</th>
<th>% AD before Females</th>
<th>% AD same year Males</th>
<th>% AD same year Females</th>
<th>% AD after Males</th>
<th>% AD after Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major depression</td>
<td>49.8</td>
<td>44.3</td>
<td>9.4</td>
<td>14.6</td>
<td>40.8</td>
<td>41.1</td>
</tr>
<tr>
<td>Conduct disorder</td>
<td>0.5</td>
<td>0.0</td>
<td>1.8</td>
<td>2.4</td>
<td>97.7</td>
<td>97.6</td>
</tr>
<tr>
<td>Panic disorder</td>
<td>36.4</td>
<td>48.0</td>
<td>9.1</td>
<td>8.0</td>
<td>54.6</td>
<td>44.0</td>
</tr>
<tr>
<td>Social anxiety problems</td>
<td>8.2</td>
<td>10.3</td>
<td>2.6</td>
<td>2.7</td>
<td>89.3</td>
<td>86.9</td>
</tr>
<tr>
<td>Suicide attempt</td>
<td>51.5</td>
<td>34.5</td>
<td>12.1</td>
<td>6.9</td>
<td>36.4</td>
<td>58.6</td>
</tr>
<tr>
<td>Childhood sexual abuse</td>
<td>0.0</td>
<td>0.7</td>
<td>0.0</td>
<td>5.0</td>
<td>100.0</td>
<td>94.3</td>
</tr>
</tbody>
</table>
further qualifications (Table 2). In addition, there was a decreased risk for AD in Baptists/Methodists, in those with an Orthodox religious affiliation, and in those who report attending church at least once a week. For the psychiatric disorders, it can be seen that those with a history of problems with social anxiety and DSM-IV major depression were at increased risk for AD. The strongest association with AD was with history of DSM-IV conduct disorder, both in men and especially in women. Finally, histories of suicide attempt and CSA were significant risk factors for AD in women but not in men.

Having an AD co-twin, whether it be MZ or DZ, was a significant and substantial risk factor for AD (Table 3). This effect was only modestly reduced when psychiatric and sociodemographic predictors were controlled for. Further, the hazard ratio for AD in the case of having an alcoholic MZ co-twin (21-44 without covariate adjustment, 18-26 after covariate adjustment) was almost twice that associated with having a DZ affected co-twin (11-45 and 10-98 respectively). This difference between MZ and DZ hazard ratios was significant both before and after covariate adjustment (Wald $\chi^2 = 12.24$, df = 1, $p = 0.0005$ and Wald $\chi^2 = 7.97$, df = 1, $p = 0.0048$ respectively). In analyses that also controlled for personality risk factors, those that scored in the highest quartile on Extraversion, Neuroticism, and Psychoticism were at significantly greater risk of AD, as were those that scored in the highest quartile on Novelty Seeking. However, controlling for personality differences, there still remained a significantly elevated risk to MZ co-twins of alcoholics compared to

Table 2. Sociodemographic and psychiatric predictors of alcohol dependence. Hazard ratios estimated from Cox regression models

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Hazard ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender – Male</td>
<td>2.68**</td>
<td>2.27–3.16</td>
</tr>
<tr>
<td>Educational level†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University-educated males</td>
<td>0.57**</td>
<td>0.44–0.73</td>
</tr>
<tr>
<td>University-educated females</td>
<td>0.87</td>
<td>0.66–1.14</td>
</tr>
<tr>
<td>At least some high school with a diploma or apprenticeship</td>
<td>0.81*</td>
<td>0.66–0.99</td>
</tr>
<tr>
<td>Technical or teacher’s college</td>
<td>0.83</td>
<td>0.68–1.01</td>
</tr>
<tr>
<td>Religion‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roman Catholic</td>
<td>1.17*</td>
<td>1.01–1.35</td>
</tr>
<tr>
<td>Baptist/Methodist</td>
<td>0.73*</td>
<td>0.53–0.99</td>
</tr>
<tr>
<td>Orthodox</td>
<td>0.54*</td>
<td>0.30–0.97</td>
</tr>
<tr>
<td>Other</td>
<td>0.82</td>
<td>0.63–1.05</td>
</tr>
<tr>
<td>None</td>
<td>1.11</td>
<td>0.92–1.35</td>
</tr>
<tr>
<td>Church attendance</td>
<td>0.56**</td>
<td>0.43–0.73</td>
</tr>
<tr>
<td>Psychiatric history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSM-IV depression</td>
<td>1.52**</td>
<td>1.28–1.81</td>
</tr>
<tr>
<td>DSM-IV conduct disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>1.95**</td>
<td>1.65–2.32</td>
</tr>
<tr>
<td>Females</td>
<td>2.40**</td>
<td>1.85–3.12</td>
</tr>
<tr>
<td>DSM-IV panic disorder</td>
<td>1.40</td>
<td>0.86–2.27</td>
</tr>
<tr>
<td>Social anxiety problems</td>
<td>1.16*</td>
<td>1.02–1.32</td>
</tr>
<tr>
<td>Suicide attempt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>0.79</td>
<td>0.43–1.43</td>
</tr>
<tr>
<td>Females</td>
<td>1.58*</td>
<td>1.06–2.35</td>
</tr>
<tr>
<td>Childhood sexual abuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>1.23</td>
<td>0.91–1.65</td>
</tr>
<tr>
<td>Females</td>
<td>1.73**</td>
<td>1.38–2.17</td>
</tr>
</tbody>
</table>

* $p < 0.05$, ** $p < 0.01$.
† Reference group for education: those who left school early (before 10 years of schooling). Reference group for religion: Anglican/Presbyterian/Uniting Church.

Fig. 2. Lifetime prevalence of DSM-IV alcohol dependence as a function of age and co-twin’s alcohol dependence history in (a) women and (b) men. – ○ –, MZ co-twin alcohol dependent; – □ –, DZ male co-twin alcohol dependent; – ▽ –, DZ female co-twin alcohol dependent; – △ –, DZ female co-twin unaffected; – ■ –, DZ male co-twin unaffected; – ▲ –, MZ co-twin unaffected.

Genetics of alcohol dependence
The fact that this difference remained after controlling for other predictors suggests that much of the genetic influence on the risk for AD remains unexplained and is not associated with religion, church attendance, education, history of major depression, conduct disorder, panic disorder, suicide attempt, or CSA.

**DISCUSSION**

Results indicated that about half of the variance in DSM-IV AD risk was attributable to genetic factors. Additional analyses (not shown) indicated that this result was not conditional on the similarity of twins’ early experiences (e.g., being in the same classroom or having the same friends). Consistent with findings from an older cohort of Australian twins (Heath et al. 1997b), we also found no significant differences in heritability in males and females. These results, however, do not support those of Prescott et al. (1999), who found sex differences in estimates of heritability for multiple measures of alcohol abuse and dependence in a large

Table 4. Twin correlations (and 95% CI) and genetic and environmental variance component estimates (and 95% CI) for DSM-IV alcohol dependence before and after controlling for covariates

<table>
<thead>
<tr>
<th>Before controlling for covariates</th>
<th>After controlling for covariates</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MZF</strong> 0.53 (0.39–0.66)</td>
<td>0.47 (0.32–0.61)</td>
</tr>
<tr>
<td><strong>MZM</strong> 0.59 (0.52–0.66)</td>
<td>0.48 (0.36–0.59)</td>
</tr>
<tr>
<td><strong>DZF</strong> 0.28 (0.10–0.45)</td>
<td>0.22 (0.03–0.40)</td>
</tr>
<tr>
<td><strong>DZM</strong> 0.26 (0.10–0.41)</td>
<td>0.24 (0.07–0.40)</td>
</tr>
<tr>
<td><strong>DZOS</strong> 0.19 (0.04–0.33)</td>
<td>0.14 (–0.02–0.29)</td>
</tr>
<tr>
<td><strong>a^2</strong> 0.03 (0.00–0.15)</td>
<td>0.00 (0.00–0.14)</td>
</tr>
<tr>
<td><strong>e^2</strong> 0.47 (0.39–0.56)</td>
<td>0.53 (0.45–0.63)</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Results indicated that about half of the variance in DSM-IV AD risk was attributable to genetic factors. Additional analyses (not shown) indicated that this result was not conditional on the similarity of twins’ early experiences (e.g., being in the same classroom or having the same friends). Consistent with findings from an older cohort of Australian twins (Heath et al. 1997b), we also found no significant differences in heritability in males and females. These results, however, do not support those of Prescott et al. (1999), who found sex differences in estimates of heritability for multiple measures of alcohol abuse and dependence in a large

Table 4. Twin correlations (and 95% CI) and genetic and environmental variance component estimates (and 95% CI) for DSM-IV alcohol dependence before and after controlling for covariates

<table>
<thead>
<tr>
<th>Before controlling for covariates</th>
<th>After controlling for covariates</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MZF</strong> 0.53 (0.39–0.66)</td>
<td>0.47 (0.32–0.61)</td>
</tr>
<tr>
<td><strong>MZM</strong> 0.59 (0.52–0.66)</td>
<td>0.48 (0.36–0.59)</td>
</tr>
<tr>
<td><strong>DZF</strong> 0.28 (0.10–0.45)</td>
<td>0.22 (0.03–0.40)</td>
</tr>
<tr>
<td><strong>DZM</strong> 0.26 (0.10–0.41)</td>
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Table 3. Hazard ratios estimated from Cox regression models for MZ and DZ twins both before and after controlling for sociodemographic and psychiatric predictors

<table>
<thead>
<tr>
<th>Hazard ratio</th>
<th>95% CI</th>
<th>Hazard ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Having an MZ co-twin who is alcohol dependent 21.44** 16.26–28.27</td>
<td>18.26** 13.69–24.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Having a DZ co-twin who is alcohol dependent 11.45** 9.01–14.55</td>
<td>10.98** 8.72–13.82</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
population-based sample of southern USA (Virginia) twin pairs, indicating limitations in generalizing results between southern USA and Australian based samples. Also in agreement with findings from other samples, there were large differences in rates of AD in men and women, with men and women having lifetime prevalence rates of approximately 35% and 17%. Women with the same degree of genetic risk as men were less likely to become alcoholic, as can be seen by comparing the rate of women versus men with an AD DZ male co-twin or DZ female co-twin (Fig. 2a,b).

Results from the Cox regression models suggest that major depression, social anxiety problems, conduct disorder, and suicide attempt (in women only) may be significant mediators of genetic influences on alcoholism risk. Similar to previous reports (e.g. Prescott et al. 1997), we also found that high Extraversion, Neuroticism, Psychoticism, and Novelty Seeking scores were associated with increased risk of AD. However, controlling for these significant risk factors did not remove the significant association with having an alcoholic MZ co-twin, and the adjusted estimate of heritability of AD remained substantial suggesting that much of the genetic influence on the risk for AD is not accounted for by these psychiatric and personality measures. Thus, while history of conduct disorder and associated personality traits (Slutske et al. 1998, 2002; Fu et al. 2002), as well as major depression (Kendler et al. 1993; Prescott et al. 2000) may be important genetic correlates of AD risk, they appear not to be important mediators of genetic influences on risk (i.e. much of the association may be indirect).

In addition to investigating psychiatric risk factors for AD, we also assessed the potentially important contribution of sociodemographic variables, such as religiosity. In this sample, as in the older cohort analyzed by Heath et al. (1997b), Roman Catholicism was associated with increased alcoholism risk. We cannot exclude the possibility that this association is due to differences in ancestral origin (i.e. Australians of Irish ancestry), which may reflect underlying genetic differences. Those reporting Baptist/Methodist and Orthodox religious beliefs were at a decreased risk for alcoholism. In addition, regular church attendance was associated with decreased risk for AD. As with Heath et al. (1997b), we cannot exclude the possibility that drinking patterns affect church attendance. Educational level, which may in part be genetically influenced, was a significant protective factor in most cases. Despite these significant associations with AD, genetic model fitting failed to find significant shared environmental effects on the risk for alcoholism. Both before and after controlling for significant psychiatric and sociodemographic predictors, shared environmental effects were estimated at 0% with 95% confidence intervals of 0–15. This finding does not, however, preclude important genotype × shared environment interaction effects, whereby the environmental effects of family background risk factors are dependent upon offspring genetic vulnerabilities, since such G × E effects are confounded with additive genetic effects in twin data (Heath et al. 2002). It is also possible that genetic non-additivity (dominance or epistasis) is masking a modest effect of shared environment (Neale & Cardon, 1992).

Several important limitations need to be considered with interpreting these results. First, in controlling for psychiatric risk factors, we assumed that it was the occurrence of psychiatric disorder (e.g. onset of major depression) rather than subclinical manifestations (e.g. first depressive symptoms) that was associated with increased risk of AD. While this assumption is used routinely in epidemiological studies, it could cause underestimation of the importance of our control variables in accounting for genetic influences on AD risk. Second, we are also dependent upon the accuracy of retrospective reporting, so that errors in remembering whether a disorder had occurred, or when its onset had occurred, could have caused us to underestimate the importance of such risk factors. Since controlling for the lifetime occurrence of other psychiatric disorders only modestly diminished the residual heritability of AD, bias in recall of timing of onset of other disorders is unlikely to be an important factor. Some disorders that were not assessed in this study (e.g. post-traumatic stress disorder) but are associated with AD (Kessler et al. 1997) may play some role in the inheritance of AD risk. Since we did not assess ASPD, we cannot preclude the possibility that it is a major mediator of genetic influences on AD risk, although the low prevalence of the disorder, particularly in women,
and the fact that ASPD can only be diagnosed in those with a history of conduct disorder, makes it unlikely that it will account for much of the unexplained genetic variance in AD risk. Thirdly, these analyses included only co-morbid conditions (e.g. major depression) with onset prior to, or in the same year as, onset of AD. While there are instances where individuals report onset of AD before onset of other psychiatric outcomes, there are also undoubtedly cases where onset of co-morbid conditions has not yet occurred at the time of interview. It is possible that a genetic vulnerability for major depression (for example) increases risk for AD regardless of whether onset of depression occurs before or after onset of AD; thus, our analyses provide conservative estimates of the amount of variation of AD liability accounted for by these psychiatric measures.

With this Australian sample, results can only be generalized to individuals of European ancestry. Moreover, this twin panel, being a volunteer panel, was not systematically ascertained from birth records and well-educated individuals may be over-represented. We also cannot exclude the possibility that systematic sampling biases have occurred with respect to other, unmeasured variables that might be important determinants of alcoholism risk (Heath et al. 1997b). Finally, the Australian twin panel is a general population sample rather than clinically ascertained. Thus, the majority of cases of alcoholism are mild and typically untreated so results cannot be generalized to more severe alcoholics.

In general, results from the present set of analyses are consistent with an important genetic influence on risk of developing alcoholism in both men and women. However, the way these genetic influences arise remains unclear. Perhaps, as in Asian populations (cf. Higuchi et al. 1994, 1996a, b), genes that directly affect alcohol metabolism, or genes that affect other aspects of alcohol’s effects (e.g. subjective intoxication or ataxia; Schuckit & Smith, 1996; Heath et al. 1999) play a more important role in the etiology of AD than has previously been suspected. Further exploration into this topic, using additional information on alcohol use, subjective reactions, or levels of consumption, is needed to clarify the pathways through which genetic factors influence AD.

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DECLARATION OF INTEREST
None.

REFERENCES
Genetics of alcohol dependence


