Multivariate genetic analysis of the causes of temperance board registrations

In all Swedish male–male twin pairs born 1926–1949

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Background The Temperance Boards in Sweden registered individuals for three reasons: public drunkenness, driving under the influence of alcohol and committing a crime in connection with alcohol. We wanted to ascertain whether these three forms of alcohol-related problems result from similar or different genetic and environmental risk factors.

Method We conducted a trivariate twin analysis of these three causes of registration in all male–male twin pairs of known zygosity born in Sweden, 1926–1949 (n=5177 twin pairs).

Results Prevalences of registration for public drunkenness, drink-driving and alcohol-related crime were, respectively, 9.0, 3.6 and 4.0%. The best-fitting model had one general genetic and one general familial–environmental factor with specific genetic risk factors for drink-driving and specific familial–environmental risk factors for alcohol-related crime.

Conclusions The three causes of alcohol registration in Sweden largely reflect the same genetic and environmental risk factors. Estimated heritabilities were similar for the three forms of registration. However, specific genetic risk factors exist for drink-driving and specific familial–environmental risk factors for alcohol-related crime. Genetic factors are somewhat less important and familial–environmental factors more important for public drunkenness than for drink-driving and alcohol related crime.

We have previously examined temperance board registration in all male–male twin pairs born in Sweden from 1902 to 1949 and found that the risk for any temperance board registration was substantially influenced by both genetic and environmental factors (Kendler et al., 1997). Three main causes of registration were established by Swedish authorities: drunkenness, driving under the influence of alcohol and committing an alcohol-related crime. In treating temperance board registration as a single variable, our previous analyses produced results 'averaged' over these potentially heterogeneous causes for registration. We investigate three issues in this study. Whether the aetiological importance of genetic and familial–environmental factors differs for the three causes of registration; whether the same genetic and environmental factors lead to an increased risk for these three causes of registration, or whether there are specific genetic and/or environmental factors that independently influence the liability to each separate form of alcohol-related problems; to what extent genetic and environmental factors are responsible for the observed correlation in this population for the three causes of registration.

METHOD

Sample

Temperance boards were officially established in Sweden in 1916 (Dahllberg, 1942) but registrations were not reliably recorded until 1929 (Amark, 1951). National records after 1974 are unavailable. While any individual could report someone to the temperance board, most registrations occurred through physicians, police and public prosecutors (Hjortzberg-Nordlund, 1968). All individuals charged with 'disorderliness and other offences under the influence of alcohol' and driving 'under the influence of alcohol' had to be reported to the temperance board (Hjortzberg-Nordlund, 1968). Except under special circumstances, physicians were obliged to report cases of known alcoholism to the temperance board. The board had to investigate each case, and an individual's record would follow him throughout life. Temperance boards did not have authority in cases of 'occasional use of alcohol without obvious injury to himself or others' (Hjortzberg-Nordlund, 1968). The probability of temperance board registration was related to "...degree of severity of the alcohol abuse and the social injury caused" (Amark, 1951). Temperance board records were available to us only for males and included age at first registration, number of total registrations, and the reason(s) for registration; that is, drunkenness, illegal manufacture or sale of alcohol, driving under the influence of alcohol or committing a crime 'in connection with alcohol' (most frequently petty theft or disorderly conduct). As the second reason for registration does not reflect alcoholism, we excluded from further analyses twins whose sole registrations were for illegal manufacture or sale. Each of the three remaining reasons for registration could be independently assigned and no hierarchy was seen in the data.

We examined twins from the 'new' Swedish twin registry (Medlund et al., 1977), which consists of over 99% of all twins born 1926–1958 where both members were alive in 1971. We found that rates of temperance board registration were quite stable for the birth years 1926–1949, but fell sharply for birth years 1950–1958, as individuals whose alcoholism began after 1975 were not registered (Kendler et al., 1997). Therefore, we restrict our analyses to twins born 1926–1949, where ascertainment of temperance board registration was likely to be more complete. We do not use results from the 'old' Swedish twin registry here because the coding of temperance board registrations in the data set did not include a separate enumeration of the number of registrations for public drunkenness, drink-driving and alcohol-related crime. Zygosity was determined by responses to self-report questionnaires (available from one or both members of 89% of the sample) using an algorithm of approximately 94% accuracy (Cederlof et al., 1961).

Statistical methods

While the goal of univariate genetic analysis is the decomposition of the variance of a trait...
into genetic and environmental components, in multivariate genetic analysis the focus shifts to identify sources of covariance between traits (Kendler et al., 1987; Neale & Cardon, 1992; Kendler, 1993). To illustrate the difference between univariate and multivariate twin analysis, the concept of latent or unobserved factors is introduced. In a traditional or 'phenotypic' factor analysis, latent factors are postulated to cause the resemblance or, more technically, covariation among items. The goal of factor analysis is to identify a small number of latent factors which account for the correlations among a large number of variables. Multivariate genetic analysis is also a method of explaining correlations among multiple items. However, it goes beyond traditional factor analysis in providing insight into the causes of covariation among variables.

In univariate twin analysis, information regarding the causes of variation is obtained by comparing the resemblance of monozygotic and dizygotic twins for a single variable. In the multivariate case, the correlations among two or more variables are the primary unit of analysis. By comparing the cross-twin, cross-variable correlations of monozygotic and dizygotic twins, and contrasting these to the cross-twin within-variable and within-twin cross-variable correlations, the covariation of two or more variables can be partitioned into genetic and environmental components.

Two alternative models are tested to describe how genetic and environmental factors may influence covariation. In the common pathway (Kendler et al., 1987) or psychometric model (McArdle & Goldsmith, 1990), genetic and environmental factors influence covariation through a single common pathway. That is, genetic and environmental variables act conjointly through a latent phenotype such as liability to alcoholism. By contrast, in the independent pathway model (Kendler et al., 1987), genes and the environment contribute to covariation through separate genetic and environmental latent factors.

The form of data for our multivariate genetic analysis is two 6x6 polygenic correlation matrices, calculated by PRELIS II (Joreskog & Sorbom, 1988), giving the polygenic correlations within and across twins for the three causes of registration, separately for monozygotic and dizygotic twins. For each cause of registration, we divided the sample into three classes of no registration, those with only one registration and those two or more registrations. We tested the goodness of fit of our multiple threshold model, which assumed that these three classes reflected differing levels of severity on a single continuum of liability. Including within-twin cross-traint, cross-twin within-traint and cross-twin cross-traint comparisons, we fitted a total of 15 multiple threshold models separately in monozygotic and dizygotic twins. The $\chi^2$ goodness of fit test (d.f. = 3) failed at the 5% level only three times in these 30 tests, a result not different from chance expectation (Feild & Arzenakis, 1974).

To best describe how genes and environment influence the resemblance among the forms of temperament board registration a series of multivariate models was fitted to these matrices, and the accompanying asymptotic weight matrix, using Mx (Reich & Earls, 1990) by the method of weighted least squares. We used a Cholesky or triangular decomposition in which the first latent factor loads on public drunkenness, drink-driving and alcohol related crime, the second latent factor on only drink-driving alcohol-related crime, and the third factor solely on alcohol-related crime (Neale & Cardon, 1992). The model which best combined the features of parsimony and goodness-of-fit was selected by Akaike's information criterion (AIC; Akaike, 1987; Williams & Hjalaman, 1994).

RESULTS

Sample

The study examined both members of 5177 twin pairs, of whom 1896 were monozygotic and 3281 dizygotic. Of the 10354 individual twins, the number (and percentage) registered with the temperance boards for public drunkenness, driving while intoxicated and committing a crime under the influence of alcohol were, respectively, 1148 (9.0%), 375 (3.6%) and 418 (4.0%). Proband-wise concordances and odds ratios for the three forms of registration were substantially greater in monozygotic than in dizygotic twins (see Table 1).

Correlation matrices

The within-twin correlations among the three forms of registration were high and stable across zygozity groups (see Table 2). For example, the correlation between registration for public drunkenness and driving while intoxicated was approximately $0.65$, while that for drink-driving and committing a crime while under the influence of alcohol was around $0.76$. The correlations within twin pairs for each cause of registration were consistently higher in monozygotic than in dizygotic twins. For example, the polychoric correlation for public drunkenness in monozygotic twins was $0.66$, and $0.47$ in dizygotic twins.

Further indication that genetic factors play a role in the covariation among the causes of registration is evidenced by the cross-twin cross-traint correlations being consistently greater in monozygotic than in dizygotic twins. For example, the cross-twin public drunkenness—drunken driving correlation is around $0.46$ in monozygotic twins and around $0.31$ in dizygotic twins.

Model fitting

The full independent pathway model, containing separate additive genetic, common environmental and individual-specific environmental factors for each of the three causes of registration fitted well ($\chi^2 = 7.41$, d.f. = 24, $P = 1.00$, AIC = $-40.59$) and substantially better than the common pathway model ($\chi^2 = 22.84$, d.f. = 22, $P = 0.41$, AIC = $-21.12$).

Table 1 Population prevalence, proband-wise concordance and odds ratio for three causes of temperament board registration in Swedish monozygotic (MZ) and dizygotic (DZ) male—male twin pairs

<table>
<thead>
<tr>
<th>Cause of registration</th>
<th>Population prevalence</th>
<th>Proband-wise concordance</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MZ</td>
<td>DZ</td>
<td>MZ</td>
</tr>
<tr>
<td>Public drunkenness</td>
<td>0.104</td>
<td>0.115</td>
<td>0.422</td>
</tr>
<tr>
<td>Drink-driving</td>
<td>0.037</td>
<td>0.037</td>
<td>0.227</td>
</tr>
<tr>
<td>Alcohol-related crime</td>
<td>0.042</td>
<td>0.039</td>
<td>0.360</td>
</tr>
</tbody>
</table>

1. Proband-wise concordance equals, for example, the prevalence of registration for public drunkenness in the co-twins of twins also registered for public drunkenness.
2. The odds ratio reflects the increased risk, over that observed in the relevant zygozity group, for registration for public drunkenness in the co-twin of a twin registered for public drunkenness, for example.
This suggests that genetic and environmental risk factors for the three causes of registration do not act through a general latent variable (e.g., risk of alcoholism) but rather produce differing patterns of covariation in the three causes of registration.

We next attempted to simplify the independent pathway model. Inspection of the estimates demonstrated that the loadings for the third genetic and third common environmental factors on alcohol-related crime were both zero. In addition, the loadings were low and smaller than their standard errors both for the second genetic factor on alcohol-related crime (0.10 (s. e. 0.13)) and the second common environmental factor on drink-driving (0.04 (s. e. 0.18)). So, we set these four parameters to zero with a resulting further improvement ($\chi^2=7.67$, d.f. = 28, $P=1.00$, AIC = 48.33). Each of the 14 remaining parameters in this model exceeded its standard error by at least 3.5-fold, suggesting that no further simplification was possible.

This best-fitting model by AIC is depicted in Fig. 1 and Table 3. This model had six major features:

(a) A single general genetic factor explained most of the genetic variance for all three reasons for registration. This factor loads most heavily on alcohol-related crime and least on drink-driving.

(b) The only form of temperament board registration for which specific common environmental factors exist was for committing a crime under the influence of alcohol, where it accounted for over one-third of the familial-environmental effects.

(c) The total heritability was relatively similar across the three forms of registration, ranging from 40% for public drunkenness to 52% for committing a crime under the influence of alcohol.

(d) A single general common environmental factor explained most of the familial-environmental effect on all three causes of registration. This factor loaded considerably more strongly on public drunkenness than on drink-driving or alcohol-related crime.

(e) The only form of temperament board registration for which specific common environmental factors exist was for committing a crime under the influence of alcohol, where it accounted for over one-third of the familial-environmental effects.

(f) A general unique environmental factor was found for all three forms of registration, indicating some commonality of non-familial environmental risk factors across public drunkenness, drink-driving and alcohol-related crime.

### Causes of correlation

On the basis of the best-fitting model, we decomposed the causes of correlations between the causes of temperament board registration into that due to genetic familial-environmental and unique environmental factors. General genetic factors were responsible for around half of the observed correlations between the causes of registration (see Table 3). For public drunkenness-drink-driving and public drunkenness-alcohol-related crime, familial and unique environment were each responsible for around 25% of the observed correlation. For drink-driving-alcohol-related crime, the pattern was somewhat different. Shared familial-environmental factors played a minor role in the observed correlation, over one-third of which was due to unique environmental factors.

### DISCUSSION

**Differing importance of genetic and environmental risk factors**

Analysis suggests that the magnitude of the aetiological role of genetic and environmental factors differed across the three forms of registration. The aetiological importance of genes differed only modestly, as heritability was highest for alcohol-related crime (51.5%), intermediate for drink-driving (43.1%) and lowest for public drunkenness (39.6%). Interestingly, larger proportional differences were seen in the role of family environment, which accounted for over three times as much variance in liability to public drunkenness (26.9%) as it did to drink-driving (8.2%).

Temperance board registrations were a key source of information in the analyses performed by Cloninger and colleagues, which resulted in their influential type I and type II alcoholism typology (Cloninger et al., 1981; Cloninger, 1987). Individuals with both types of alcoholism are likely to be registered for public drunkenness. However, individuals with type II or male-limited alcoholism, characterised by high levels of novelty-seeking and antisocial traits (Cloninger, 1987), would be more likely to be registered for drink-driving or alcohol-associated criminal activity. Type II alcoholism was found to be more heritable and less influenced by familial-environmental factors than type I alcoholism (Cloninger et al., 1981). Our results are consistent with these predictions. Compared with alcohol-related crime and drink-driving, registration for public drunkenness had both a lower heritability and was more influenced by familial-environmental risk factors.

### Same or different genetic factors

The unity or diversity of genetic influences on alcoholism has been a subject of long debate (Babor, 1996). Although our different causes of alcohol registration certainly do not represent alcoholism subtypes, this is a powerful sample with which to address questions about the role of genes in the varied presentations of alcoholism.
Our results suggest substantial commonality among the genetic risk factors for the three forms of registration. Indeed, the best-fitting model indicates that public drunkenness and alcohol-related crime have a genetic correlation of unity. The genetic correlations between public drunkenness and drink-driving and between drink-driving and alcohol-related crime can be calculated and are both 0.79. Although these causes of temperance board registration probably bear only an oblique relationship with the type I/type II typology, our results are not consistent with the hypothesis that these forms of alcoholism are genetically independent (Sigvardsson et al., 1996).

It is intriguing that only drink-driving has specific genetic factors not shared with the other reasons for registration. It is tempting to speculate that these additional risk factors influence risk-taking, and/or sensation- or novelty-seeking (Zuckerman, 1972; Cloninger et al., 1994). Given that an individual is intoxicated, such personality traits might influence the probability of driving, particularly in a country with strict enforcement of drink-driving laws such as Sweden.

### Table 3

<table>
<thead>
<tr>
<th>% of variance in liability</th>
<th>Public drunkenness</th>
<th>Drink-driving</th>
<th>Alcohol-related crime</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Additive genetic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39.6</td>
<td>43.1</td>
<td>51.5</td>
</tr>
<tr>
<td>Common</td>
<td>39.6</td>
<td>26.7</td>
<td>51.5</td>
</tr>
<tr>
<td>Specific</td>
<td>–</td>
<td>16.4</td>
<td>–</td>
</tr>
<tr>
<td><strong>Common environment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26.9</td>
<td>8.2</td>
<td>19.7</td>
</tr>
<tr>
<td>Common</td>
<td>26.9</td>
<td>8.2</td>
<td>12.6</td>
</tr>
<tr>
<td>Specific</td>
<td>–</td>
<td>–</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>Individual-specific environment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>33.5</td>
<td>48.7</td>
<td>28.8</td>
</tr>
<tr>
<td>First (common) factor</td>
<td>33.5</td>
<td>10.3</td>
<td>10.0</td>
</tr>
<tr>
<td>Second factor</td>
<td>–</td>
<td>38.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Third factor</td>
<td>–</td>
<td>–</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Only criminal registrations were influenced by familial–environmental risk factors unrelated to the other forms of temperance board registrations. Substantial evidence suggests that the risks for childhood conduct disorder and subsequent antisocial and criminal behaviour are substantially influenced by a range of familial characteristics, including low socio-economic status and family disruption (Robins, 1966; Rutter, 1978). Bohman et al. (1982), in the Stockholm adoption project, found that low socio-economic status in the adoptive home was specifically associated with alcohol-related criminality. These results illustrate how genetically informative designs may clarify the action of environmental risk factors.

### SOURCES OF CORRELATION BETWEEN CAUSES OF REGISTRATION

Genetic multivariate methods provide a powerful method for addressing the question of why these different forms of registration are related in the way they are.
temperance board registration are so highly correlated in the Swedish male population. The strongest single set of shared risk factors are genes. That is, around 50% of the reason why registration for public drunkenness, driving while intoxicated and alcohol-related crime coveny in the Swedish population is because they are all influenced by a common set of genes. The remaining 50% of the covariation is split between shared familial and shared individual-specific environmental risk factors.

**Risk factors for temperance board registration**

Our analyses suggest that the three forms of temperance board registration in Sweden share most but not all of their genetic and familial-environmental risk factors. However, a specific set of genetic risk factors, perhaps reflecting levels of novelty-seeking, influence the risk for drunk-driving, and a specific family background, perhaps indexing socio-economic status or levels of familial disorganization, impacts on the risk for criminal alcohol registration. Genetic factors are somewhat less important and familial-environmental factors somewhat more important in the etiology of registration for public drunkenness than registration for driving under the influence or committing a crime associated with alcohol.

**CLINICAL IMPLICATIONS**

- The genetic and environmental risk factors for various forms of alcoholism— as exemplified by public drunkenness, drink-driving and drinking-related criminal activity—are substantially interrelated.

- Drink-driving is influenced by some genetic risk factors that are largely unrelated to those which impact on public drunkenness and drinking-related criminal activity.

- Drinking-related criminal activity is influenced by some familial—environmental risk factors that are largely unrelated to those of aetiological importance for public drunkenness and drink-driving.

**LIMITATIONS**

- Information about alcoholism was derived entirely from Swedish temperance board authorities and may not reflect current methods of clinical assessment.

- The relative importance of genetic and environmental risk factors for the various forms of alcoholism in Sweden may not extrapolate to other countries or ethnic groups.

- Information on alcoholism in this sample is available only for males.

**REFERENCES**


