Behavior Genetics, Vol. 30, No. 5, 2000

A Study of the Genetic and Environmental Etiology of Stuttering in a Selected Twin Sample

S. Felsenfeld,[1,4] K. M. Kirk,[2] G. Zhu,[2] D. J. Statham,[2] M. C. Neale,[3] and N. G. Martin[2]

Received 25 Feb. 2000—Final 12 Oct. 2000

Stuttering is a developmental disorder of speech production that usually emerges in childhood. In this study, a large population-based twin sample from the Australian Twin Registry (1567 pairs and 634 singles aged 17–29 years) was screened to identify twin pairs in which one or both members reported themselves to be affected by stuttering. Telephone interview-based diagnoses were obtained for 457 of these individuals (self-reported affected cases, cotwins, and controls) to determine whether the self-report was correct. To correct for ascertainment bias we carried out a bivariate analysis of the final diagnosis in the selected sample with the screening item in the full sample, using the categorical raw data option of Mx 1.47c. After correcting for ascertainment bias, approximately 70% (95% confidence interval: 39–86%) of the variance in liability to stuttering was found to be attributable to additive genetic effects, with the remainder due to nonshared environmental effects.

KEY WORDS: Twins; stuttering; speech disorders; bivariate analysis; ascertainment bias.

INTRODUCTION

Stuttering is a puzzling and debilitating disorder that prevents those affected from engaging in effortless and spontaneous conversational interactions. The disorder is characterized by chronic disturbances in a speaker's ability to produce (but not conceive) smooth, forward-moving speech. To some, the essence of stuttering is the fracturing and disruption of the motor sequence of the word, almost as though a temporary loss of control over the movements of the speech musculature had occurred (Perkins, 1990; Van Riper, 1982). In addition to the primary difficulties in the production of fluent speech, several associated affective features of the stuttering disorder have been identified. While not essential to the diagnosis, these reactive responses (e.g., avoidance of speaking, speech-associated anxiety, social withdrawal) occur commonly among persistent cases and can constitute a major part of the clinical syndrome (Manning, 1996).

Stuttering incidence rates reported in the literature since 1950 yield quite variable values, ranging from a low of 0.7% (Culton, 1986) to a high of 15.4% (Glasner and Rosenthal, 1957). The morbid risk for stuttering is usually cited as 5.0%, which reflects the average across studies. Presently, it is not known why reported morbid risk is so variable for this condition, but it may reflect differences across studies in the sample characteristics (e.g., subject age), sampling methods (interview versus questionnaire), and disorder definition. Stuttering symptoms almost always emerge in childhood, usually prior to age 10. Phenotypic severity and symptom expression are variable. As with many complex behavioral disorders, most stuttering cases in the population are probably mild in severity, although there is limited empirical evidence from population-based studies to document this. Among young children, partial or complete recovery from stuttering is common for reasons that are still unknown, with recovery

[1] Department of Speech–Language Pathology, Duquesne University, Pittsburgh, Pennsylvania 15260.
[2] Queensland Institute of Medical Research and Joint Genetics Program, The University of Queensland, Brisbane, Australia.
[3] Virginia Institute for Psychiatric and Behavior Genetics, Virginia Commonwealth University, Richmond, Virginia 23284.
[4] To whom correspondence should be addressed.

0001-8244/00/0900-0359$18.00/0

estimates ranging from 36 to 89% (Cooper, 1972; Peters and Guitar, 1991; Yairi *et al.,* 1996). Males are more likely than females ever to have stuttered. Among young children, the gender ratio is approximately 2:1, whereas, among adults who persist in stuttering, the ratio is typically cited as 4 or 5:1. The latter phenomenon suggests that females may be more likely than males to recover (Ambrose *et al.,* 1993).

Despite nearly a century of research activity, the etiology of stuttering remains uncertain. Within the last two decades, however, promising findings from behavioral genetic studies have provided evidence that genetic factors may be important in the expression of this condition (Ambrose *et al.,* 1993; Andrews and Harris, 1964; Andrews *et al.,* 1991; Howie, 1981; Kidd, 1984). Evidence from three family studies of the disorder have found that about 15% of the first-degree relatives of a stuttering proband will report a history of stuttering, in comparison to 1–3% of the relatives of control cases and a morbid population risk of about 5% (Ambrose *et al.,* 1993; Andrews and Harris, 1964; Kidd, 1984). Both a single major locus model with sex-modified transmission and a multifactorial/polygenic threshold model have been shown to provide a reasonable fit to the existing family data (Ambrose *et al.,* 1993; Kidd, 1980, 1984).

Two notable twin studies of stuttering have been reported, both of which provided evidence for a substantial genetic effect. In the first of these, Howie (1981) evaluated 29 clinic-based twin pairs (ages 6 to 27 years) in which at least one member was reported to be a current or recovered stutterer. The age-corrected pairwise concordance rates for identical (MZ) twins was 63% (10/16 concordant affected pairs) in comparison to 19% for the fraternal (DZ) twins (3/13 concordant affected pairs). More recently, Andrews *et al.* (1991) obtained information about stuttering from several thousand Australian twins who were participating in a community-based twin study. From a sample of 3810 complete pairs born between 1893 and 1964 who responded to a questionnaire item about stuttering in a health inventory, 135 pairs were identified that contained at least one self-reported stuttering member (50 MZ and 85 DZ pairs). Of the 50 MZ pairs, 10 were concordant for stuttering (20%). In contrast, only 3% of the DZ pairs (3/85) were concordant for stuttering. When genetic models were fitted, the best-fitting model was one in which 71% of the variance in liability was attributed to additive genetic variance, with the remaining 29% attributed to the individual's unique environment.

The present study was designed to expand upon the findings of the earlier Andrews *et al.* (1991) investigation by obtaining interview and speech data from an independent cohort of twins born between 1964 and 1971 and enrolled in the Australian Twin Registry. Twins in the present study who responded positively to a questionnaire item about stuttering were interviewed by telephone to confirm the diagnosis. To obtain estimates of heritability, bivariate genetic models were fitted to the screening item from the full twin sample ($N = 3768$ cases) and the selected sample for whom an interview-based diagnosis was reached ($N = 457$ cases).

METHODS

Sample

Subjects in the present study were drawn from a Health and Lifestyle Questionnaire (HLQ) study of a cohort of twins born between 1964 and 1971 who were originally recruited through schools and enrolled in the Australian Twin Registry in about 1980. These twins (4269 pairs) were surveyed by mailed questionnaire in 1989–1990. Of the 3269 pairs who were still contactable, completed questionnaires were received from both members of 1567 pairs and from an additional 634 individuals. The mean age of respondents in this cohort was 23.2 (SD, 2.2) years, with a greater number of women participating than men (60.6% of cohort). Although the response rate was modest (48% pairwise, 58% individual), in view of the length of the HLQ and the wide range of topics covered, participation is likely to be random with respect to the target variable.

Zygosity

The zygosity of twins was determined on the basis of responses to standard questions about physical similarity and the degree to which others confused them. This method has been shown to give at least 95% agreement with diagnosis based on extensive blood typing (Martin and Martin, 1975; Eaves *et al.,* 1989). More recently, a subsample of 198 same-sex pairs was typed for 11 independent highly polymorphic markers in the course of an asthma study, with no errors in previous zygosity diagnosis detected (Duffy, 1994).

Screening Phase

Individuals with a history of stuttering were identified by self-report items in the disease checklist section of the HLQ. Any individual who responded

affirmatively to one or both items asking if they had "stuttering or stammering before [they] were 14 years old" or "when [they] were 14 and older" was considered to be positive for the screening phase of this study.

Interview Phase

Individuals identified to have a history of stuttering in the screening phase were selected for further study, of whom 218 were contactable and agreed to participate. Cotwins of these individuals were also contacted for possible inclusion in the interview phase regardless of screening response status and even if they did not respond to the original screening survey. In addition, 100 age- and gender-matched control pairs were selected for interview from the remaining pairs in the sample database. To be selected as a potential control case, an individual was required to have responded in the negative to both items about stuttering on the HLQ questionnaire. Once identified as a potential control, the HLQ responses from that individual's cotwin were also examined, if available. If cotwin responses to the stuttering items on the HLQ were not available for the control pair, that pair was not immediately eliminated. Rather, both twins were contacted and were asked to participate in the interview phase of the study; at that time, interview-based diagnoses were obtained and all positive cases were eliminated as controls.

Prior to interview, approach letters were mailed to prospective interviewees explaining the purpose of the study and the procedures involved in study participation. After 7 to 10 days, telephone contact was made to determine whether the individual wished to participate. To minimize observer bias, each twin in a pair was contacted by a different interviewer. Interviewers were blinded to zygosity and to screening status (affected, cotwin, or control case). Before each interview commenced, subjects were asked to give verbal permission to audiotape the interview, and this permission was included on the audio record when given. Permission to audiotape the interview was refused by nine individuals.

Interviews were conducted in 1997, 5 to 7 years after the screening questionnaire was completed. We succeeded in interviewing 457 individuals by telephone, of whom 64 (31 cotwins of affected individuals and 33 controls) had not previously completed the screening survey. Subjects were interviewed using a protocol developed for research use called the Ease of Speech Production Scale (ESPS). This 23-item equal-appearing interval scale asks respondents to evaluate their current ability to produce smooth and effortless speech in a variety of speaking contexts, using a 7-point equal-appearing interval scale (1 = behavior never occurs; 7 = the behavior occurs very frequently). These items are summed to obtain a total score. Highly acceptable retest reliability (0.97) and internal consistency (0.97) values for the ESPS have been reported in a separate validation study (Eldridge and Felsenfeld, 1998).

In addition to the 23 scored items, the ESPS includes a small number of unscored descriptive questions. Two of these questions ask twins to report about the stuttering status of their cotwin ("Did your twin ever have a stuttering problem?" and "Does your twin have a stuttering problem now?). Included also in the scale is one categorical self-report item (H9) that asks respondents to identify their own lifetime fluency status (1 = have always been a normally fluent speaker; 2 = stuttered in the past but no longer have problems with stuttering; 3 = still stutter very mildly or occasionally; 4 = still stutter, with severity described as mild to moderate; 5 = still stutter, with severity described as moderate to severe).

To receive a diagnosis of stuttering in the interview phase of the study, subjects were required to meet at least two of the following three criteria: selection of categories 2–5 on question H9 of the ESPS, a total score of 36 or higher on the ESPS, and a positive cotwin report. For the present study, it was not necessary for subjects to be heard stuttering on the audiotape to be diagnosed as stuttering-affected. Because a large proportion of individuals in the population who have ever stuttered is mild or recovered cases, studies that rely upon the presence of perceptually obvious stuttering moments in a brief exchange to diagnose the disorder may underestimate the number of ever-affected cases.

Statistical Methods

In both the screening and the interview phases of this study twins were scored as either affected or unaffected. We estimated tetrachoric correlations between twins for liability to stuttering on the assumption that underlying each variable is a continuum of liability which is normally distributed in the population and that, imposed on this liability distribution, is a threshold above which individuals are affected (Neale and Cardon, 1992). However, while significant twin correlations establish the fact that there is familial aggregation for the measures of interest, they do not distinguish between the possible mechanisms by which this arises. We use structural equation modeling to aid us in making this

distinction, by considering which combination of additive genetic (A), shared environment (C), and unique environment (E) effects provides the most parsimonious explanation for the observed pattern of MZ and DZ twin correlations. Other effects that may be modeled include nonadditive genetic effects (e.g., epistasis, dominance) and sex differences in gene expression or environmental effects ("sex limitation").

When subjects are obtained by selected sampling on a variable, the means, variances, and covariances of all corrected variables will be changed. When selection involves a threshold or cutoff point above which subjects will be used for further study, the general effects will be to increase the means of positively correlated variables. At the same time, the variance of correlated variables will be decreased, and the covariance of correlated variables will also be decreased. In the present context, the biases generated by failing to correct for ascertainment would decrease twin correlations and therefore reduce estimates of familial resemblance such as additive genes and common environment (Neale *et al.,* 1989; Martin and Wilson, 1977).

Two possible approaches to the correction for ascertainment may be used. First, one might obtain population estimates of the correlation between the screen and the interview, the correlation between twins for the screen, and the cross-correlation between one twin's screen and the cotwin's interview. The twin correlations would need to be estimated separately for MZ and DZ twins. From these correlations it would be possible to correct the analysis of the interview by using the Pearson Aitken selection formula. Clearly, this analysis requires estimates of correlations that are usually not available except in the data themselves. Therefore, a preliminary step for ascertainment correction would be a bivariate analysis to obtain the statistics required.

The second approach, which we use here, is to conduct bivariate analyses throughout the model-fitting process. In this case, the interview data were analyzed jointly with the entire screened sample in a bivariate analysis (Little and Rubin, 1987; Wade *et al.,* 1999). Of course, the interview diagnosis is missing for all the noninterviewed subjects, but joint analysis with the diagnosis from the screening instrument ensures that the interview data are corrected for the effects of ascertainment, provided that selection for interview is based entirely upon the results of the screening phase. As discussed by Little and Rubin (1987), this is a case in which data are effectively "missing" in the interview phase because both twins performed below threshold on the screen and were therefore not selected for further study. Any additional "missingness" is assumed to be caused by random processes not related to the interview scale.[5] To ensure valid ascertainment correction, the same effort to contact and interview was applied to all individuals in the sample, regardless of their zygosity or their cotwins' cooperation status. These analyses were conducted using maximum-likelihood methods for raw ordinal data recently implemented in Mx 1.47c (Neale, 1999).

RESULTS

Stuttering Prevalence in the Screening and Interview Phases

Table I summarizes participation and caseness in the two waves of the study. Self-report data on stuttering from the screening surveys were available from 3768 individuals, of whom 331 individuals (8.8% of the total sample; 7.0% of females and 11.5% of males) reported themselves as having a history of stuttering. The male-to-female ratio of self-reported stuttering was therefore 1.6:1.

Of the 457 subjects (232 women and 225 men) contacted for interview, 46 women and 93 men met the diagnostic criteria for being stuttering-affected. Comparative analysis of the screening and telephone interview responses indicated that the tetrachoric correlation between liability to self-reported stuttering and the diagnosis criteria was 0.60. No significant difference between males and females was observed for the overall accuracy of the screening instrument in predicting the interview-based diagnosis: the positive predictive value was 80%, while the false-positive and false-negative rates were 44 and 20%, respectively.

Concordances

Concordance rates (both pairwise and probandwise) for the screening and interview phases of the current study are shown in Table II, along with the equivalent statistics from previous twin studies of stuttering. Concordance rates for monozygotic (MZ) and dizygotic (DZ) twins obtained from the screening sample in the present study are comparable to those obtained from a similarly unselected (screening) sample re-

[5] It is of course possible that the nature of the task—a telephone interview—would selectively deter individuals with a stuttering problem from participating in the interview phase of the study. However, the low overall refusal rate (3%) for the interview phase suggests that such refusal was not a pervasive phenomenon.

Table I. Composition of Sample: Self-Report and Interview Diagnoses for Stuttering

	Screening		
Interview	Not Screened	Affected (self-report)	Unaffected (self-report)
Females			
Not interviewed		59	2018
Affected (interview-based)	5	34	7
Unaffected (interview-based)	21	67	98
Males			
Not interviewed		54	1244
Affected (interview-based)	11	65	17
Unaffected (interview-based)	27	52	53
Total	**64**	**331**	**3437**

Table II. Comparison of Twin Concordance Rates for the Current Study and Previous Twin Studies of Stuttering

					Current study			
	Howie (1981) (30 pairs)		Andrews *et al.* (1991) (3810 pairs)		Screening sample (1567 pairs)		Interviewed subsample (197 pairs)	
	MZ	DZ	MZ	DZ	MZ	DZ	MZ	DZ
Concordant affected pairs	10	3	10	3	20	8	17	8
Discordant pairs	6	10	40	82	98	121	21	45
Pairwise concordance	0.63	0.19	0.20	0.04	0.17	0.06	0.45	0.15
Probandwise concordance	0.77	0.38	0.33	0.07	0.29	0.12	0.62	0.26

ported by Andrews *et al.* (1991). In contrast, the concordance rates reported by Howie (1981) in her interviewed, clinic-based sample are higher for both the MZ and the DZ pairs and are more comparable to the concordance rates obtained for the interviewed cases in the present study.

Model-Fitting Results

Tetrachoric correlations for liability to stuttering obtained for the various zygosity groups are shown in Table III for univariate and bivariate analyses of the self-report and interview measures of stuttering. All analyses estimated separate threshold estimates for males and females due to the different stuttering prevalence rates for men and women. Even with the large sample size, estimation of separate correlations for the five zygosity groups was not possible for the bivariate analysis due to insufficient data, so sexes were pooled within zygosity types.

For the population-based screening sample, threshold estimates do not differ between the two analyses, and the correlation estimates are also consistent (the bivariate correlation estimates for MZ and DZ twins are close to the average correlations for the individual groups in the univariate analysis). For the highly ascertained interview sample, however, there are substantial differences between the univariate threshold and correlation estimates and those obtained in the bivariate analysis. The effectiveness of the ascertainment correction on the interview data can be clearly seen by comparing the threshold and tetrachoric correlation estimates obtained in the two analyses, with the threshold estimates obtained in the bivariate analysis increased to values much more closely resembling those from the population-based screening sample. The tetrachoric correlation estimates for the monozygotic and dizygotic twin groups also increased.

After using bivariate analysis to correct the correlation and threshold values of the interview measure for ascertainment bias, the resulting twin correlations suggest a strong genetic influence on the liability to stuttering, since the correlation value for monozygotic

Table III. Thresholds and Tetrachoric Correlation Values for Univariate and Bivariate Analyses of Screening and Interview Measures of Stuttering: Numbers of Complete Pairs Included at Screening and Interview Phases

	Univariate analyses		Bivariate analysis		
	Screening (n = 3768)	Interview (n = 457)		Screening	Interview
Thresholds			*Thresholds*		
Female	1.48	0.87	Female	1.48 (1.41–1.56)	1.65 (1.45–1.84)
Male	1.20	0.21	Male	1.20 (1.11–1.23)	0.97 (0.74–1.17)
Correlations			*Correlations*		
MZF	0.36 (468 pairs)	0.68 (51 pairs)	MZ	0.44 (0.24–0.59)	0.75 (0.48–0.89)
MZM	0.56 (263 pairs)	0.639 (39 pairs)			
DZF	0.24 (318 pairs)	0.13 (26 pairs)	DZ	0.16 (–0.07–0.36)	0.149 (–0.23–0.48)
DZM	0.25 (167 pairs)	–0.06 (33 pairs)			
DZO	–0.05 (351 pairs)	–0.03 (48 pairs)			

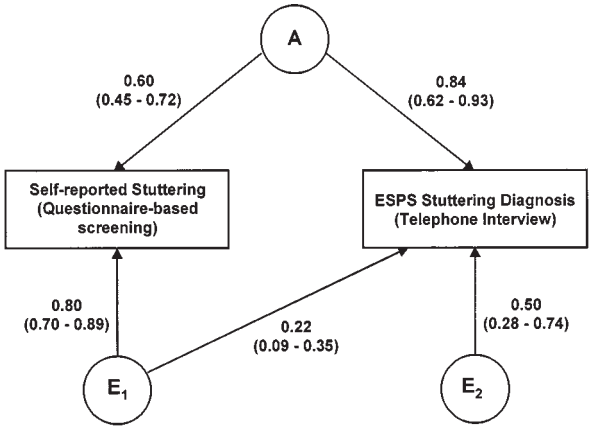

Fig. 1. Path diagram showing latent genetic and environmental influences (depicted by circles) on the self-report screening item and the interview-based diagnosis of stuttering. A represents an additive genetic factor influencing both the observed variables, and E_1 and E_2 are unique environmental factors. Numbers by paths are path coefficients and must be squared to obtain proportions of variance of the measured variable accounted for by the latent variable. All latent variables have unit variance.

twins substantially exceeds that for dizygotic twins (r_{MZ} = 0.75; r_{DZ} = 0.15). Multivariate structural equation modeling was undertaken to determine the proportions of variance for liability to stuttering attributable to genetic and environmental sources. A Cholesky decomposition model was fit to the data, and results are presented in Fig. 1. This figure displays the latent genetic and environmental influences on the screening (self-report) and interview-based diagnoses of stuttering, corrected for sex and cohort effects. The 95% confidence intervals for parameter estimates are also presented.[6] Note that these are path coefficients, and therefore all values must be squared to obtain the proportion of variance of the measured variable accounted for by the latent variable.

Parameter A represents an additive genetic factor influencing both the observed variables, and E_1 and E_2 are unique environmental factors. As can be seen, only one factor (A) was required to account for the additive genetic effects acting on both the self-report and the interview measures of stuttering, indicating that the additive genetic variance for the interview measure was due to the same influences as those acting on the self-report screening item. However, the nonshared environmental effects (E_1 and E_2) tended to differ between the two measures (the nonshared environmental effects on the self-report measure E_1) contributed less than 5% of the total variance in the interview measure). This would seem to indicate that a large percentage of the variance being attributed to "nonshared environmental effects" is actually measurement error, since true nonshared environmental influences on stuttering would be expected to influence both measures of stuttering in a consistent manner. Not surprisingly, we see a far greater measurement error, and consequently a lower heritability, for the self-report screening item (h^2 = 0.36) than for the interview-based diagnosis (h^2 = 0.70). The shared environmental parameter (not shown in Fig. 1) was nonsignificant for both the screening and the interview measures.

Threshold estimates of 1.65 and 0.97 were obtained for female and male subjects, respectively,

[6] The confidence intervals (CIs) depend on the effective sample size and on the observed correlations between relatives. The interview measure is based on a smaller sample and therefore has larger CIs.

corresponding to prevalence rates of 4.9% (95% confidence interval, 3.2–7.5%) and 16.7% (12.1–23.0%). giving a male-to-female ratio of stutterers for this sample of young adults of 3.3:1. This is generally consistent with literature suggesting that the male-to-female ratio of approximately 2:1 among young children increases to 4 or 5:1 in adulthood (Ambrose *et al.*, 1993). We also fitted models which allowed different genetic effects for men and women, but no sex-specific additive genetic effects were detected ($\Delta\chi^2_3 = 0.010$, $p = .999$), nor was there any significant difference in the proportions of variance attributable to genetic and environmental effects in males and females ($\Delta\chi^2_6 = 2.385$, $p = .881$). Additive genetic effects were found to account for approximately 70% of the variance for the interview-based diagnostic measure for stuttering in both men and women, with the remaining 30% attributable to the individual's unique environment. Since the correlation between MZ twins was substantially larger than twice the correlation for DZ twins, the possibility that some of the genetic influences acting on stuttering were nonadditive was also explored. However, no significant nonadditive genetic effects were detected ($\Delta\chi^2_3 = 3.776$, $p = .287$), although this is not surprising given the low power of our study to detect them (Martin *et al.*, 1978).

DISCUSSION

In this study, a large population-based twin sample from the Australian Twin Registry (1567 pairs and 634 singles aged 17–29 years) was screened to identify twin pairs in which one or both members reported themselves to be affected by stuttering at some point during their lifetime (both current and recovered cases). From this sample, 331 individuals (8.8%) identified themselves as stuttering-affected. Telephone interview-based diagnoses were subsequently obtained for 457 individuals from the screening cohort (all contactable self-reported affected cases, all contactable cotwins of these cases, and a subgroup of controls) to determine whether the self-report was correct. Ultimately, 91 complete twin pairs (38 monozygotic and 53 dizygotic pairs) containing at least one stuttering member were identified in the interview phase of the study.

Unlike earlier twin studies of stuttering, the present study controlled for the ascertainment bias inherent in the analysis of a highly selected subsample by using a bivariate analysis method based on the theory of missing data (Little and Rubin, 1987). Put simply, treatment of ascertainment bias in the present study served as a statistical tool to control for the fact that we did not have a random sample of twins once we advanced to the interview phase. Joint bivariate analysis of the final diagnosis in the selected sample with the screening item in the entire sample adjusted the estimates of thresholds, correlations, and variance components to the values expected in a random sample. Approximately 70% of the variance in liability to stuttering in men and women was found to be attributable to additive genetic effects, with the remainder due to nonshared environmental effects. These findings are quite consistent with those reported in two previous twin studies of stuttering (Andrews *et al.*, 1991; Howie, 1981). In fact, the estimate of heritability for the interview phase (70%) obtained by multivariate analysis in the present study is nearly identical to the results of the Andrews *et al.* (1991) investigation, which found that 71% of the variance could be attributed to additive genetic variance.

One interesting finding to emerge from this investigation was the relatively modest correlation between the screening item responses and the interview-based diagnosis obtained 5 to 7 years later in this cohort of young adults ($r = .60$). This probably reflects the fact that stuttering, like many threshold-based conditions, is a behaviorally and pathogenically complex disorder that is deceptively difficult to diagnose when the phenotype is mild and when partial or complete recovery has occurred (Felsenfeld, 1997). In the present study, method of diagnosis (self-report versus interview) made a difference when the classification data were modeled; recall that our estimate of additive genetic influence was significantly higher for the interview phase ($h^2 = 0.70$) than for the screening phase ($h^2 = 0.36$). In the absence of a diagnostic "gold standard" for stuttering, this finding does not necessarily mean that the interview resulted in a superior (i.e., more valid) diagnosis. However, given that the stuttering diagnosis in the interview phase was based upon a subject's response to multiple items and required some triangulation of evidence (e.g., cotwin verification), it is reasonable to hypothesize that the interview method was more likely to yield a "true" diagnosis. If so, the interview diagnosis should agree favorably with a best-estimate diagnosis rendered by independent clinical experts who perform a chart review, a procedure that has been considered a "proxy" gold standard for diagnosing complex phenotypes (Kosten and Rounsaville, 1992; Leckman *et al.*, 1982). This hypothesis can be tested using the present data, and such an analysis is now under way.

Finally, the results of the present study suggest that, in addition to genetic effects, nonshared (but not shared)

environmental effects contribute a small but significant degree of influence on the expression of this condition. Because shared environmental variables such as excessive parental concern about imperfect speech, a competitive and perfectionistic parental style, and a family drive for upward mobility have been implicated in stuttering etiology for several decades (cf. Johnson, 1959; Guitar, 1998), the nonsignificant shared environmental parameter is of particular interest. Nonshared factors are etiologically relevant nongenetic events that affect individuals uniquely and, to some extent, idiosyncratically (e.g., birth events, traumas or illnesses, peer influences, etc.). For stuttering there is some preliminary evidence to suggest that two subgroups of affected cases may exist: stutterers whose etiology is primarily "genetic" in origin (those with a positive family history) and nonfamilial (sporadic) cases whose stuttering may have been precipitated by early brain damage (Poulos and Webster, 1991). Future research might profitably attempt to replicate this intriguing finding, preferably by examining prospectively this and other aspects of the nonshared environment of young stuttering-affected cases.

ACKNOWLEDGMENTS

The screening phase of this study was supported by NIH Grants AA07535 and AA07728, and the interview phase by NIH Grant DC 03776-01 to S.F. Dr. Neale's development of Mx is supported by NIH Grant MH 01458. The Australian Twin Registry is supported by the National Health and Medical Research Council. The authors would like to thank John Pearson, Olivia Zheng, Heather Way, Pam Barton, Marcia Knox, Carol Hourigan, Fran Husband, Shirley Entsch Sharon Clark, and Kevin Eldridge for their assistance. We also thank the twins who generously gave their time to participate in the screening and interview phases of this study.

REFERENCES

Ambrose, N., Yairi, E., and Cox, N. (1993). Early childhood stuttering: Genetic aspects. *J. Speech Hear. Res.* **36**:701–706.

Andrews, G., and Harris, M. (1964). *The Syndrome of Stuttering*, Heinemann Press, London.

Andrews, G., Morris-Yates, A., Howie, P., and Martin, N. (1991). Genetic factors in stuttering confirmed (Letter). *Arch. Gen. Psychiatry* **48**:1034–1035.

Cooper, E. B. (1972). Recovery from stuttering in a junior and senior high school population. *J. Speech Hear. Res.* **15**:632–638.

Culton, G. L. (1986). Speech disorders among college freshman: A 13-year survey. *J. Speech Hear. Disord.* **51**:3–7.

Duffy, D. L. (1994). *Asthma and Allergic Diseases in Australian Twins and Their Families*, Unpublished Ph.D. thesis, University of Queensland, Brisbane.

Eaves, L. J., Eysenck, H. J., and Martin, N. G. (1989). *Genes, Culture and Personality: An Empirical Approach*, Academic Press, Sydney.

Eldridge, K., and Felsenfeld, S. (1998). Differentiating mild and recovered stutterers from nonstutterers. *J. Fluency Disord.* **23**:173–194.

Felsenfeld, S. (1997). Epidemiology and genetics of stuttering. In Curlee, R. F., and Siegel, G. M. (eds.), *Nature and Treatment of Stuttering: New Directions*, 2nd ed., Allyn and Bacon, Boston.

Glasner, P. J., and Rosenthal, D. (1957). Parental diagnosis of stuttering in young children. *J. Speech Hear. Disord.* **22**:288–295.

Guitar, B. (1998). *Stuttering: An Integrated Approach to Its Nature and Treatment*, 2nd ed., Williams and Wilkins, Baltimore.

Howie, P. (1981). Concordance for stuttering in monozygotic and dizygotic twin pairs containing stutterers. *J. Speech Hear. Disord.* **24**:317–321.

Johnson, W., and Associates. (1959). *The Onset of Stuttering*, University of Minnesota Press, Minneapolis.

Kosten, T. A., and Rounsaville, B. J. (1992). Sensitivity of psychiatric diagnosis based on the best estimate procedure. *Am J. Psychiatry* **149**:1225–1227.

Kidd, K. (1980). Genetic models of stuttering. *J. Fluency Disord.* **5**:187–201.

Kidd, K. (1984). Stuttering as a genetic disorder. In Curlee, R. F., and Perkins W. H. (eds.), *Nature and Treatment of Stuttering: New Directions*, Allyn and Bacon, Boston.

Leckman, J. F., Sholomskas, D., Thompson, W. D., Belanger, A., and Weissman, M. M. (1982). Best estimate of lifetime psychiatric diagnosis: A methodological study. *Arch. Gen. Psychiatry* **39**:879–883.

Little, R. J. A., and Rubin, D. B. (1987). *Statistical Analysis with Missing Data*, John Wiley and Sons, New York.

Manning, W. (1996). *Clinical Decision Making in the Diagnosis and Treatment of Fluency Disorders*, Delmar, Albany, NY.

Martin, N. G., and Martin, P. G. (1975). The inheritance of scholastic abilities in a sample of twins. I. Ascertainment of the sample and diagnosis of zygosity. *Ann. Hum. Genet.* **39**:213–218.

Martin, N. G., and Wilson, S. R. (1982). Bias in the estimation of heritability from truncated samples of twins. *Behav. Genet.* **12**:467–472.

Martin, N. G., Eaves, L. J., Kearsey, M. J., and Davies, P. (1978). The power of the classical twin study. *Heredity* **40**:97–116.

Neale, M. C. (1999). *Mx: Statistical Modeling*, 5th ed., Department of Psychiatry, Box 126 MCV, Richmond, VA 23298.

Neale, M. C., and Cardon, L. R. (1992). *Methodology for Genetic Studies of Twins and Families*, Kluwer Academic, Dortrecht.

Neale, M. C., Eaves, L. J., Kendler, K. S., and Hewitt, J. K. (1989). Bias in correlations from selected samples of ratives: The effects of soft selection. *Behav. Genet.* **19**:163–169.

Perkins, W. H. (1990). What is stuttering? *J. Speech Hear. Disord.* **55**:370–382.

Peters, T. J., and Guitar, B. (1991). *Stuttering: An Integrated Approach to Its Nature and Treatment*, Williams and Wilkins, Baltimore.

Poulos, M. G., and Webster, W. G. (1991). Family history as a basis for subgrouping people who stutter. *J. Speech Hear. Res.* **34**:5–10.

Van Riper, C. (1982). *The Nature of Stuttering*, 2nd ed., Prentice–Hall, Englewood Cliffs, NJ.

Wade, T., Neale, M. C., Lake, R. I., and Martin, N. G. (1999). A genetic analysis of the eating and attitudes associated with bulimia nervosa: Dealing with the problem of ascertainment in twin studies. *Behav. Genet.* **29**:1–10.

Yairi, E., Ambrose, N., Paden, E., and Throneburg, R. (1996). Predictive factors of persistence and recovery: Pathways of childhood stuttering. *J. Commun. Disord.* **29**:53–77.

Edited by Stacy Cherney