Developmental Changes in Postural Sway in Children at High and Low Risk for Developing Alcohol-Related Disorders

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Background: *To utilize the power of latent growth analysis to evaluate changes in postural sway during development in children who are either at high or low risk for developing alcoholism.*

Methods: *A total of 629 assessments of postural sway have been performed in children and adolescents (n = 126) who were evaluated annually over a 7-year period.*

Results: *Latent curve models indicated that these children/adolescents show a linear decrease in sway with age. Moreover, significantly different rates of change in the amount of sway between high- and low-risk offspring were seen. With the exception of one of the four stances tested, high-risk boys consistently showed a slower rate of improvement with respect to the amount of sway exhibited compared to low-risk boys. In girls, similar rates of improvement with age were seen in high- and low-risk individuals, though in one stance the high-risk girls showed a deterioration (greater sway with increasing age).*

Conclusions: *Previous reports of increased postural sway in high-risk offspring most likely reflect a developmental delay (high-risk children have greater sway than is appropriate for their age based on normative values by age).* Biol Psychiatry 2000;47:501–511 © *2000 Society of Biological Psychiatry*

Key Words: Alcoholism, postural sway, risk, development, neurobehavioral markers

Introduction

Several studies have investigated differences in postural sway between individuals at high and low risk for alcoholism, either in a baseline condition (Hegedus et al 1984; Hill and Steinhauer 1993b; Hill et al 1987), or both at baseline and following administration of varying doses of alcohol (Behar et al 1983; Lex et al 1988; Lipscomb et al 1979; McCaul et al 1991; Nagoshi and Wilson 1987; O'Malley and Maisto 1985; Schuckit 1985). Five studies have found differences in the amount of sway produced by high-risk in contrast to low-risk subjects (Hegedus et al 1984; Hill and Steinhauer 1993b; Hill et al 1987; Lester and Carpenter 1985; Lipscomb et al 1979). Results of studies assessing postural sway following alcohol consumption in persons at high or low risk for developing alcoholism have varied in outcome, with some showing greater sway in high-risk persons (McCaul et al 1991), while others have found lesser sway (Lex et al 1988; Schuckit 1985). None of these studies found differences between the family history positive and negative groups at baseline, however. It is of interest that those studies finding baseline differences all involved minor children except for one report (Lipscomb et al 1979). Therefore, the age of the subjects tested appears to be an important factor in detecting baseline differences in sway.

The human postural control system is highly complex, involving the integration of information from three sensory systems: proprioceptive, visual, and vestibular, with adjustment of postural muscles maintaining body posture in response to these sensory inputs (Ghez 1991; Nashner and McCollum 1985). All of the sensory afferents converge toward the vestibular nuclei of the brainstem, where they are integrated and result in induction of the motor reflex responses. Motor control similarly involves multiple influences, including stretch receptors and long loop reflexes, which are influenced by supraspinal input from higher motor control programs. Thus, stability during upright stance depends on vestibular function and to a large extent, vestibulospinal function. However, stability also depends on sensory input including vision, somatosensation, and motor control, especially that concerned with the lower extremities and the trunk (Furman 1995). Due to the importance of vision and the oculomotor control involved in maintaining balance, closing the eyes during performance of balance tests increases sway both in a no alcohol condition (Hill and Steinhauer 1993b; Hill et

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al 1987) and when the tests are performed following alcohol administration (Ledin and Odkvist 1991). Results of these studies suggest the importance of vestibular and oculomotor integration.

As is the case with other types of motor performance, balance appears to improve with age in children (Odenrick and Sandstedt 1984; Usui et al 1995) and decline with advancing age in older adults (Perrin et al 1997; Schultz et al 1997). In children, postural sway has been shown to decrease markedly between the ages of 3 and 5 years and then slowly after age 6, with boys showing more sway under the age of 10 than girls (Usui et al 1995).

Because previous studies have demonstrated greater sway in high-risk than low-risk children (Hegedus et al 1984; Hill and Steinhauer 1993b; Hill et al 1987; Lipscomb et al 1979) and age-related changes in sway during childhood have been noted (Usui et al 1995), we hypothesized that the familial risk differences previously observed might be due to a developmental delay in acquiring age-appropriate levels of balance among high-risk children.

Methods and Materials

Subjects

RECRUITMENT OF PEDIGREES. A total of 126 high and low-risk children between the ages of 8 and 18 years participated in the study. The children were drawn from families that were part of a larger family study of alcoholism (Cognitive and Personality Factors in Relatives of Male Alcoholics), which included families chosen either for a high density of alcoholism (high-risk families) or families chosen for an absence of alcoholism and most major psychopathology (low-risk families).

HIGH-RISK CHILDREN. High density for alcoholism families had been enrolled in the study through selection procedures that required the presence of at least two alcoholic brothers. Inclusion criteria required that all first-degree relatives of the proband be free of DSM-III (Axis I) disorders other than alcoholism. (DSM-III was the diagnostic system used at the time the study was initated). Thus, the children were from families where both first- and second-degree relatives were free of Axis I psychopathology other than alcoholism.

LOW-RISK CHILDREN. Individuals who responded to advertisements for participants in a “study of hereditary aspects of personality” were interviewed to determine if they had available adult family members for inclusion in the study. Those families meeting the first screen were asked to participate. All available first-degree relatives of the respondent to the advertisement were interviewed to determine if any Axis I diagnosis, including alcoholism, was present. Those families with any member having these diagnoses were excluded. Children who comprised the low-risk group were from pedigrees involved in the family study that had been selected in this way.

PSYCHIATRIC ASSESSMENT OF THE CHILD’S FIRST AND SECOND-DEGREE RELATIVES. An in-person diagnostic assessment was performed for all living and available parents, grandparents, aunts, and uncles of these children (more than 80% of relatives) by two trained clinicians who were required to meet a consensus diagnosis. A structured interview, Diagnostic Interview Schedule (DIS) was performed by a trained MA level interviewer. A second, unstructured interview was performed by an MA or PhD level psychologist to arrive at a best-estimate consensus diagnosis. The DIS allowed for determination of whether or not the adult relative met DSM-III and Feighner Criteria (Feighner et al 1972) for Axis I psychopathology. For those relatives not assessed by a face-to-face interview, a minimum of two family history reports was used to arrive at an appropriate family history diagnosis. Further details concerning the psychiatric status of the individuals comprising the extended pedigrees from which the children came are provided in Hill (1992).

ASSESSMENT OF PRENATAL ETHANOL EXPOSURE. Because the children’s body sway could potentially be influenced by their mothers’ use of alcohol and drugs, careful drinking histories were obtained for all mothers in both the high- and low-risk groups. All mothers were interviewed about the quantity of alcohol consumed during pregnancy (even those who were social drinkers). Among the mothers were 15 alcoholic women. Four of these mothers did not drink during pregnancy. Thus, of the thirty-six (30%) mothers who drank at least one drink during pregnancy, eleven met lifetime criteria for alcoholism. Most mothers, including the alcoholic women, decreased their intake by the second and third trimester. For the 11 alcoholic mothers who drank during pregnancy, an average of 205 drinks were consumed throughout the entire pregnancy; however, the nonalcoholic mothers (high- and low-risk) only drank an average of 42 drinks, with the largest quantity consumed during the first trimester. The remainder (70%) reported no drinking during pregnancy. Additionally, information on cigarette and drug use during pregnancy was obtained. Fifteen (12%) of the mothers reported smoking during pregnancy, whereas drugs were used by the mother of two children (2%); however, because there were too few cases of cigarette and drug use, only prenatal alcohol quantities could be entered into an analysis of covariance.

DEMOGRAPHIC CHARACTERISTICS. All children included in the present analysis were Caucasian, with the exception of one child (Japanese mother with Caucasian father). An attempt was made to match the high- and low-risk children for age and socioeconomic status of their parents. In addition, all children were weighed and measured, and their grade levels were noted at each follow-up (Table 1). Also, the socioeconomic status (SES; Hollingshead 1975) of the children’s families (based on an average score from both parents) was not significantly different ($\chi^2 = 3.21$, df = 1, $p = .073$), though the SES was somewhat higher for the low-risk than the high-risk children (approximately 63% of the low-risk children were from professional/technical families, whereas approximately 47% of the parents in the high-risk group were from these levels).

The children who were assessed for postural sway were

Table 1. Demographic Characteristics (Mean ± SD)

	High-risk	Low-risk
Number of males	38	29
Number of females	36	23
Age at entry (years)	9.85 ± 2.1	9.90 ± 2.0
Age at last follow-up	15.26 ± 2.3	15.31 ± 2.5
Weight at entry (lb)	88.6 ± 30.9	88.9 ± 30.9
Weight at last follow-up	148.1 ± 37.3	140.8 ± 37.3
Height at entry (inches)	55.8 ± 5.2	55.8 ± 4.9
Height at last follow-up	65.6 ± 4.3	65.1 ± 4.6
Grade at entry	4.4	4.8
Grade at last follow-up	9.8	9.8

participants in a longitudinal study, which evaluated children at approximately yearly intervals. Because children entered the study at various ages, not all children completed the same number of assessments over the 7-year period (Table 2). The high-risk group contained 38 male and 36 female children. The low-risk group was comprised of 29 male and 23 female children. In some cases, multiple children from the same nuclear family were included. Ten low-risk nuclear families contributed one child, 15 families contributed two children, and four families contributed three children. For the high-risk families, 20 families contributed one child each, 19 families contributed two children, four families contributed three children, and one family contributed four children.

MEASUREMENT OF POSTURAL SWAY. All children were assessed for postural sway at approximately yearly intervals. Although the study has been on-going for 7 years, some children have not yet reached seven assessments. Therefore, statistical analyses were based on the maximum number of repeated assessments available for each child ($n = 629$; see Table 2). Overall, the dropout rate has been relatively low (approximately 10%), with equal percentages of children from the high- and low-risk groups.

The assessment of postural sway utilized four tasks administered to all subjects in the following order: a Lipscomb stance (the child stands with feet side by side after Lipscomb et al 1979 and Hill et al 1987); a Romberg stance, consisting of a heel to toe position with right foot forward (Hill et al 1987); and two monopedal stances (left monopedal—left foot raised with the right foot as the weight bearing foot; followed by right monopedal—right foot raised). In general, the children find the Romberg position more difficult than the Lipscomb stance and the monopedal stances the most difficult.

Table 2. Distribution of 629 Annual Assessments

	High-risk	Low-risk
Baseline	74	51
Retest 1	70	50
Retest 2	64	43
Retest 3	60	39
Retest 4	54	37
Retest 5	31	22
Retest 6	20	14

In 10 cases, data were incomplete.

Each stance consisted of six 30-sec trials with a 30-sec rest between trials. In order to accommodate children who had consented to five previous assessments and retain them in the follow-up, the protocol was shortened. On the sixth and subsequent visits, four trials were obtained for the Lipscomb, Romberg, and left monopedal procedures. Six trials of the right monopedal procedure were retained because greater risk group differences were found for this stance in an earlier report (Hill and Steinhauer 1993b). Comparison of the abbreviated protocol showed comparable results to the full-length battery.

The children were asked to stand without shoes in the middle of a stationary platform (Model 9281B11, Kistler, Winterthur, Switzerland). The output of a multichannel amplifier assembly (8 charge amplifiers) provided center of pressure data reflecting changes in pressure at varying points on the platform. The force plate was interfaced with a laboratory computer so that amplitude and speed of sway in the anterior–posterior and medial–lateral directions could be calculated. Data were digitized, sampled at 18 times per sec, and stored. An experimenter, blind to the risk status of the child, used menu-driven software to collect and analyze the data.

At the beginning of the procedure, a standard set of instructions was read to each child. The instructions included demonstrating each stance and asking the child to keep his or her arms folded across the chest. In the monopedal position, the child was asked to keep one leg freely dangling (no hooking of the elevated leg against the rigid one to improve balance). Each stance was evaluated first with the child's eyes open and again while closed and blindfolded. Distractions were kept to a minimum by asking the child to focus on a designated spot on the wall approximately 24 inches from the child in the eyes open condition. On those trials in which visual input was denied, the child was fitted with a mask that did not allow any visual cues. These conditions were alternated across trials. Additionally, the room was kept quiet by refraining from conversation during the sway trials. Unavoidable building noise occasionally occurred and was noted in the child's record. A 30-sec inter-trial interval and a 1 min interval between tasks were provided in which the child was allowed to get off the platform and move about. Because some of the trials became sufficiently difficult that the child went out of position briefly, an over-ride system was programmed so that by pressing a button, the experimenter could count a "time-out." The time the child remained in position was entered as a covariate into the statistical analyses.

DATA REDUCTION. Software was developed that enabled calculation of six main variables: distance (X, Y, and R) and speed (X, Y, and R). The distance variable Y summarized the total amount of excursion of the child in the anterior–posterior dimension from an arbitrary reference point (the last position), while the X variable measured the total lateral excursions. The reference point was determined by using the sum of the values in the anterior–posterior direction divided by the number of positions. This Y center of pressure could then be used to determine the total amount of excursion. The lateral sway was similarly determined. The distance R variable was the resultant vector (hypotenuse of X and Y), which circumscribed a roughly circular path that the child transversed when attempting to stand steadily on the platform. The R variables were calculated as root mean squares (RMS). The speed variables were calculated by taking the absolute values of X minus X-1 and dividing by the time in position for the lateral direction and the absolute values of Y minus Y-1 divided by the time in position for the anterior–posterior direction. The speed R variable was the resultant vector divided by the time in position. Results were analyzed for both distance (X, Y, and R) and speed (X, Y, and R). Analyses of variance of both distance and speed showed comparable results. Therefore, the distance R results are presented here for the analyses of variance. Only the distance R results were used for the latent growth-curve modeling.

Values obtained with this system had been cross validated with data obtained with an identical system utilized in the Raymond E. Jordan Center for Balance Disorders, Department of Otolaryngology, University of Pittsburgh. Persons with clinically relevant vestibular problems exhibit mean vector amplitude (distance) sway of 1.68 to 2.38 in the eyes closed condition and .93 to 1.32 in the open condition (Blatchly 1990).

POSSIBLE SOURCES OF EXPERIMENTAL ERROR. The complexity of postural control and its susceptibility to a variety of factors are well known (Ghez 1991; Nashner 1985). Although the main variables of interest were risk group status, age, gender, and whether the child was tested in an eyes open or closed condition, other potential sources of variation were also considered. These included characteristics of the subject (e.g., motivation, mother's drinking during pregnancy) as well as aspects of the test environment (random noise) that promote or detract from maximal performance.

CHILD/ADOLESCENT USE OF ALCOHOL OR DRUGS. All participants were asked to refrain from use of alcohol or drugs for 48 hours before testing. Scheduling letters asked that they call to reschedule their appointment if they should use either alcohol or drugs during the 48-hour window. Additionally, a preprotocol interview addressed the issue once again. Moreover, urine screens for all commonly used street drugs was performed on the day of testing. Children who were using significant amounts of drugs on the day of testing would not have had their data included in the analysis.

HEALTH AND MEDICATIONS SCREENING. Each child and his or her parent were interviewed using a structured questionnaire to determine current and past health problems and use of medications. Children judged to have medical problems (e.g., sprained ankle) that would possibly influence sway assessment were excluded from testing. Due to the possible effects of recurrent ear infections on vestibular function, data were analyzed using responses to a question concerning whether the child had three or more ear infections by lifetime history. No significant differences were seen between the number of children in the high- and low-risk groups who had recurrent ear infections. Rates of head trauma with associated loss of consciousness were tabulated with 28% of the high-risk and 15% of the low-risk children having lost consciousness. (None of the children experienced a head trauma with loss of consciousness of 30 min or more, however.) Therefore, the effects of medical problems were not considered in further analyses.

MOTIVATION TO PERFORM. A participant's level of arousal, attention, and motivation to perform a postural sway task has been shown to influence the amount of sway observed (Maki and McIlroy 1996; Nardone et al 1997; Sveistrup and Woollacott 1997; Tarantola et al 1997). Because the child's capacity to stand steady could have been affected by poor motivation, any spontaneous comment from the child that his or her "feet hurt," or that he or she was "tired" or "bored" was noted. Any instance where the experimenter determined that the verbalizations might indicate an extreme lack of motivation was documented in the laboratory log and used as a covariate in an ANCOVA analysis.

MENSTRUAL CYCLE EFFECTS. The phase of the menstrual cycle was hypothesized to provide variation in sway performance in the female subjects who had reached the age of menses. It is known that phase of the menstrual cycle influences not only mood (Evans et al 1998) but performance of motor tasks (Resnick et al 1998). Thus, the phase of the menstrual cycle [premenstrual, menstrual, or post-menstrual (week after end of menses plus any other nonpremenstrual week)] was measured in all female subjects who had reached menarche ($n = 134$ evaluations).

PRENATAL DRINKING. To control for possible effects of prenatal drinking by the participant's mother, information was obtained from each mother regarding her use of alcohol or drugs during pregnancy. A detailed account of the amount of alcohol consumed during each trimester was also determined. While these data are retrospective, there is reason to believe they were relatively accurate. All mothers reported a tendency to decrease drinking with each succeeding trimester, an observation often made in prospective studies of drinking during pregnancy. Also, mothers would report amounts that varied among siblings in accordance with changes in her lifetime history of drinking.

TIME IN POSITION. Data-collection software was programmed to allow the investigator to exclude data from a trial where the child was completely out of position. For example, data from a child who put his or her raised foot onto the platform during the monopedal stances or who fell entirely off the platform were not averaged. (To prevent injury, an investigator stood by the platform to catch any child who appeared to be falling.) Therefore, the total time a child balanced in position could be determined.

ENVIRONMENTAL VARIATION. Over the 7-year period of testing, random disruptions of the testing conditions have occurred due to uncontrolled building noise or equipment failure. Again, any instances of these occurrences were noted.

Results

Analysis of Variance

The effect of having the eyes closed versus open and the effects of gender on sway may be seen in Figure 1. These

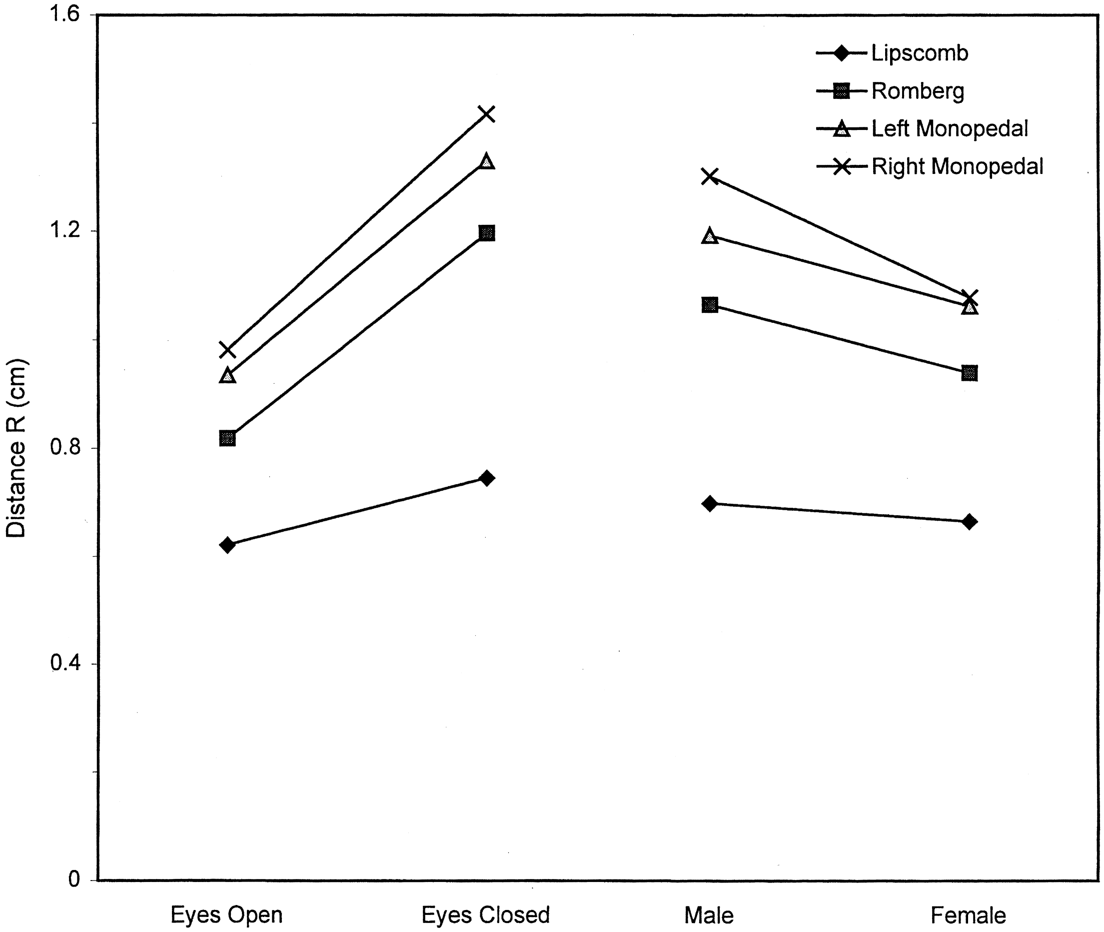

Figure 1. The effects of gender (male/female) and eyes (eyes open/eyes closed) on sway (distance R) for each of the four sway stances.

variables, along with risk group and age, were evaluated using a four-factor analysis of variance with three grouping and one within factor (BMDP 2V). The analyses were performed for the distance R variable for each of the four sway stances (Lipscomb, Romberg, left monopedal, right monopedal) to test the effects of risk group (high-risk vs. low-risk), gender (male and female), age (7 to 18 years old), and the within factor of eyes (open vs. closed). As may be seen in Table 3, analyses of variance conducted separately for each stance revealed significant effects in all four stances for age and for the eyes open/closed condition. As expected, the amount of sway decreased with increasing age and was greater in the eyes closed condition compared to the eyes open condition (approximately 0.7 to 1.4 cm). This finding is consistent with previous results from this laboratory (Hill and Steinhauer 1993b; Hill et al 1987) and others (Ledin and Odkvist 1991). Furthermore, gender was found to be significantly different in all the

Table 3. Summary of Analysis of Variance Findings for All Children

	Lipscomb[a]		Romberg		Left monopedal		Right monopedal	
Factor (df)	*F*	*p* value	*F*	*p* value	*F*	*p* value	*F*	*p* value
Group (1,583)	—	NS	—	NS	—	NS	—	NS
Age (10,583)	3.93	< .0001	10.20	< .0001	2.76	.003	2.29	.012
Gender (1,583)	—	NS	32.51	< .0001	10.30	.001	18.32	< .0001
Eyes (1,583)	325.38	< .0001	682.46	< .0001	473.19	< .0001	94.68	< .0001
Group × Age (10,583)	—	NS	—	NS	2.28	.013	2.49	.006

[a] For Lipscomb stance, degrees of freedom are 581.

Table 4. Summary of Analysis of Variance Findings for Male Children

	Lipscomb[a]		Romberg		Left monopedal		Right monopedal	
Factor (df)	*F*	*p* value	*F*	*p* value	*F*	*p* value	*F*	*p* value
Group (1,318)	7.24	.008	—	NS	—	NS	—	NS
Age (10,318)	—	NS	7.19	< .0001	2.87	.002	—	NS
Eyes (1,318)	168.60	< .0001	378.66	< .0001	271.94	< .0001	56.52	< .0001
Group × Eyes (1,318)	—	NS	12.39	.001	—	NS	4.39	.04
Group × Age (10,318)	—	NS	—	NS	2.67	.004	2.36	.002

[a] For Lipscomb stance, degrees of freedom are 317.

stances (girls had significantly less sway than boys), with the exception of the Lipscomb stance (Table 3). It should be noted that while the average deviations of 1 to 2 cm observed appear small, they are within the range obtained for adult clinical samples for this instrument (Blatchly 1990). While there were no significant main effects found for risk group, group by age interactions were found for both monopedal stances. This suggested that the high-risk group may have had a developmental delay in attaining age-appropriate postural control. This hypothesis was further evaluated using latent growth modeling.

The overall analysis seen in Table 3 included families in which only one child was available for study as well as those families with multiple siblings. As a result, there was concern that including multiple siblings might contribute to a biased estimate of the variance due to possible correlations in sway between the siblings. Therefore, analyses were repeated using one randomly selected child per family ($n = 69$ children). Overall, no alteration in the results was seen when the analyses were performed using one randomly selected child per family. The main effects of age, gender, and the eyes open/closed condition remained significant using the smaller unbiased sample, justifying the use of the whole sample in further analyses.

GENDER EFFECTS. Because gender was clearly a significant variable, the data were analyzed separately by gender. As may be seen in Table 4, for boys, a statistically significant risk-group difference was seen for the Lipscomb stance ($p = .008$), with the high-risk group swaying more than the low-risk group. Significant interactions between risk group and the eyes condition (open/closed) were seen in the Romberg stance ($p = .001$) and in the right monopedal stance ($p = .037$), when tested in boys. As predicted, high-risk boys had a greater decrement in postural stability going from the eyes open to eyes closed condition. Also, in both monopedal stances, high-risk boys showed less improvement with age compared to low-risk boys. In contrast, risk-group differences in girls were much less prominent. Results of the ANOVA revealed no significant main effects or interactions of risk group for the girls in any of the stances tested, with one exception, a significant group by age interaction for the Romberg stance was seen, indicating that the low-risk girls displayed a steeper decrease in postural sway with age (greater improvement) than did the high-risk girls (Table 5).

EFFECT OF COVARIATES. Five variables were used as covariates (phase of menstrual cycle, prenatal drinking quantity, notations of poor motivation, total time in position, and noise disruptions) and the four-way analyses repeated to determine the effect of these possible contaminating factors. As might be expected, the amount of sway each child produced was found to be linearly related to the time in position for all four stances, indicating that those children who spent less time out of position swayed less overall. Environmental noise proved to be a significant contaminating factor, with more sway being produced in a "noisy" environment when the two most difficult stances were being performed (right and left monopedal); however, none of the covariates altered the significance levels observed for the main effects. No relationship was seen between sway and "poor motivation," prenatal drinking

Table 5. Summary of Analysis of Variance Findings for Female Children

	Lipscomb[a]		Romberg		Left monopedal		Right monopedal	
Factor (df)	*F*	*p* value	*F*	*p* value	*F*	*p* value	*F*	*p* value
Group (1,265)	—	NS	—	NS	—	NS	—	NS
Age (10,265)	3.28	.001	4.11	< .0001	—	NS	2.83	.002
Eyes (1,265)	165.80	< .0001	329.35	< .0001	220.89	< .0001	135.35	< .0001
Group × Age (10,265)	—	NS	2.17	.020	—	NS	—	NS

[a] For Lipscomb stance, degrees of freedom are 264.

quantity of the mother, or menstrual cycle phase (for females) for any stance.

Linear Trend Analysis

Finding a significant main effect of age in the ANOVA provided the justification for undertaking growth-curve analyses. First, a linear trend analysis (BMDP 4V) was conducted for the eyes closed condition as a preliminary step to the growth curve analysis. The eyes closed condition was selected because the risk groups were the most different when the visual cues were removed. Analyses were conducted using the maximum number of follow-up evaluations for all children, including families with siblings, to assess the development of postural control with age. Any *p* value less than .05 was considered significant. A significant linear trend with age was seen in each of the four stances for high-risk children, as well as in analyses conducted separately for high-risk boys and high-risk girls. Additionally, for low-risk children, the linear trend was significant in the Lipscomb, Romberg, and left monopedal procedures. From these results, it was determined that the regression of body sway on age was linear.

Latent Growth Curve Analysis

The change in postural sway with age can be captured by random coefficients, known as latent variables in the latent curve analysis (Muthén and Curran 1997). Latent growth curve models can be used to examine the overall group growth trajectories and to test for individual variability over time. Therefore, using the power provided by the longitudinal design, up to 7 waves of data were available for analysis. Analyses were performed separately for each of the four stances. The BMDP 5V procedure, which allows for utilizing a variable random effect design matrix across subjects, provided the latent growth curve modeling of the data. Linear and quadratic growth curves were then fit to the data from 629 assessments of postural sway using the default Newton–Raphson algorithm to compute the maximum likelihood estimates. The child's age was treated as a single within-subject (time varying covariate) factor, risk group as a between-subject factor (time-invariant covariate), and the amount of sway as a repeated measure. Thus, the hypothesis that improvement in postural sway was acquired at differing rates in high- and low-risk children and adolescents when visual cues are denied could be tested.

Linear growth curves were found to be the better fit for each of the stances compared to the quadratic curve (all *p* values $<.0001$). In fact, neither of the regression coefficients involving the quadratic terms approached statistical significance. This confirmed the hypothesis that sway is represented by a linear trend.

Table 6. Latent Growth Curve Modeling of Longitudinal Data (629 Assessments) Demonstrating Risk Group Differences

	Males			Females		
	Chi-square	df	*p*	Chi-square	df	*p*
Lipscomb	5.54	1	.02	3.81	1	.05
Romberg	0.02	1	.98	0.01	1	.92
Left monopedal	4.87	1	.03	0.28	1	.60
Right monopedal	5.57	1	.02	0.27	1	.61

Overall results of the growth curve analysis also showed a linear decrease in the amount of sway observed across age. Table 6 shows the risk-group differences from the growth curve analyses performed separately by gender. Significantly different rates of change in the growth trajectory were seen between high- and low-risk males in the Lipscomb (see Figure 2-upper left), left monopedal (see Figure 2-upper middle), and right monopedal (see Figure 2-upper right) procedures. For the left monopedal stance, high-risk males exhibited a slower rate of change with respect to the low-risk males, who exhibited steeper decreases over time until early adolescence. For the right monopedal stance, a significantly slower rate of improvement was seen throughout. In the Lipscomb procedure, high-risk males showed less change over time than did the low-risk boys. Therefore, improvement in postural control appears to develop at a slower rate in high-risk males. However, high- and low-risk females displayed significantly different rates of change with age in only one condition, the Lipscomb stance (see Figure 2-lower left), with slightly more sway being observed in high-risk girls as they become older compared to the decreasing amounts seen in low-risk girls.

Discussion

A number of studies have investigated sway in children at high risk for developing alcoholism, comparing them to control children without family histories of alcoholism. College-aged students or young adults under the age of 30 years have frequently been studied because a number of investigators have tested the effects of alcohol administration on sway in family history positive and negative subjects (Lex et al 1988; Lipscomb et al 1979; McCaul et al 1991; Nagoshi and Wilson 1987; Schuckit 1985). Five studies have used minor children (Behar et al 1983; Hegedus et al 1984; Hill and Steinhauer 1993b; Hill et al 1987; Lester and Carpenter 1985), but all have used cross-sectional samples.

The present results, which were based on a longitudinal assessment of minor children, allowed for testing the hypothesis that high-risk children fail to show age-related improvement in sway at the same rate as control children. This

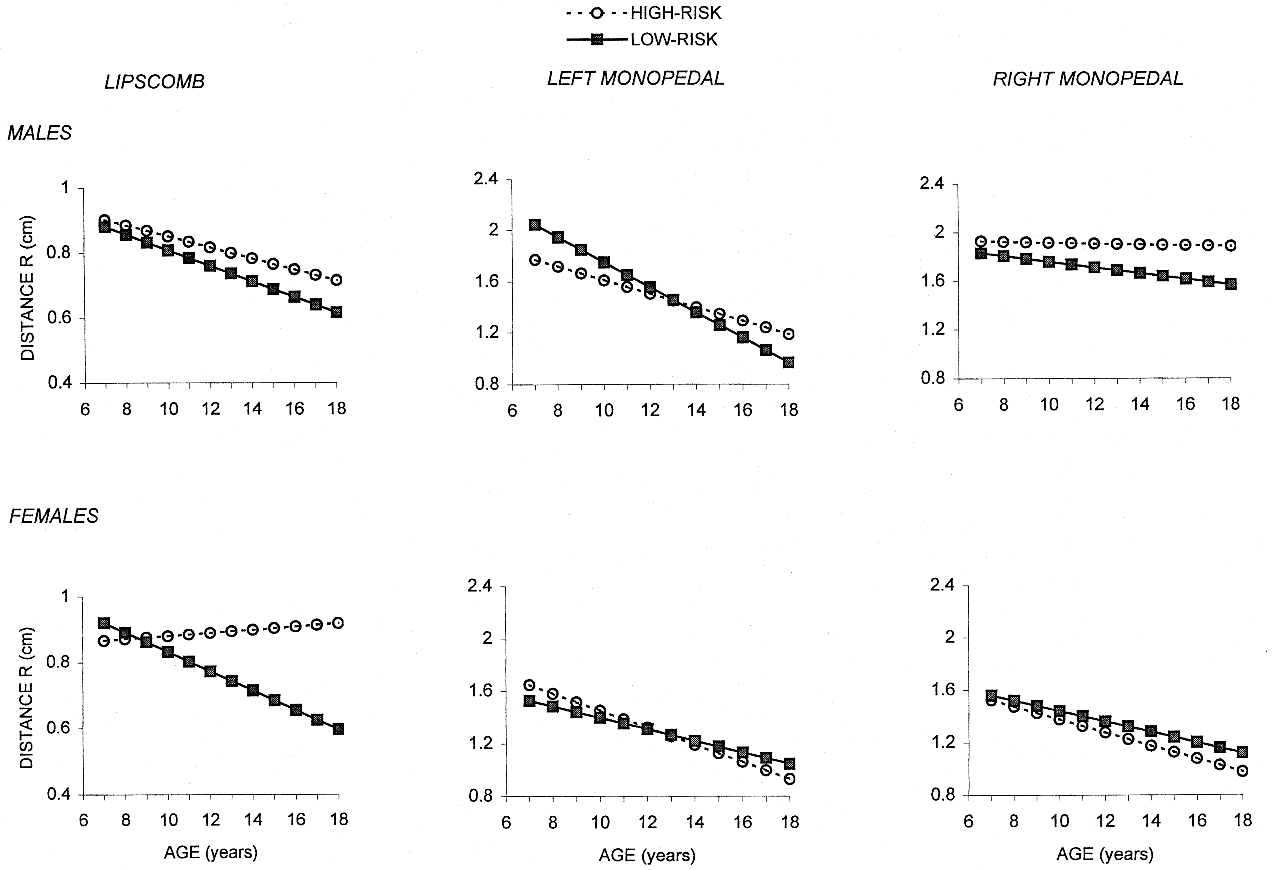

Figure 2. Latent growth curves of the amount of sway (eyes closed condition, distance R) observed for high- and low-risk children are presented by stance and by gender. **Upper left:** In the Lipscomb stance, high-risk males had a greater amount of sway and exhibited a slower rate of change over age than low-risk males. Note the significant sway difference in the older age group. **Upper middle:** In the left monopedal stance, high-risk males showed slower rates of change over age than low-risk males. **Upper right:** In the right monopedal stance, male high-risk individuals had significant greater amount of sway at each age group, and a slower rate of change over age than low-risk males. **Lower left:** In the Lipscomb stance, high-risk females had greater amount of sway and much slower rate of change over age than low-risk females. Note the significant sway difference at the older age group. **Lower middle and lower right:** No differences were found with age in females for either the left or right monopedal stances.

hypothesis was based on several studies that have reported an age-related effect in postural stability among children (Hayes and Riach 1989; Riach and Hayes 1987; Schultz et al 1997; Shumway-Cook and Woollacott 1985; Usui et al 1995). As predicted, significant age effects were noted, with older children showing lesser postural sway than younger ones. Confirming the work of others (Schultz et al 1997; Usui et al 1995), gender differences in postural sway were found. Boys displayed greater sway than girls. Also, a linear trend in the amount of sway exhibited with age was seen in combination with both risk group status and gender for each of the four procedures in the eyes closed condition. Significant linear age trends were seen by risk group among males, females, and combined samples. Based on the growth curve analyses, differing rates of change in the amount of sway observed could be noted between the two risk groups of males for the Lipscomb, left monopedal, and right monopedal procedures. Thus, male high-risk children exhibited less improvement with age than did low-risk boys. Also, differences between risk groups were seen for females for the Lipscomb stance, indicating that high-risk girls similarly showed less improvement in sway with age than did control girls.

Thus, the present results confirmed previous reports from this laboratory (Hill and Steinhauer 1993b; Hill et al 1987) and that of others (Hegedus et al 1984; Lipscomb et al 1979), indicating a significant difference in the amount of sway observed between high- and low-risk children. However, it is uncertain why this laboratory consistently reports the absence of risk-group differences in the Romberg stance. Casual observation of this stance reveals that children use different strategies to compensate for difficulty in maintaining balance (i.e., in spite of being instructed to keep their weight evenly distributed on both feet, children will shift their weight onto their back foot, using the front foot to stabilize balance). With the exception of the Romberg stance, these results are consistent in showing risk-group differences in the maturation of postural control.

The importance of visual input on postural sway is well known (Goebel et al 1997; Perrin et al 1997; Tarantola et al 1997; Woollacott et al 1987). In the present analysis, lack of visual input proved to be a significant factor in producing greater sway for all four stances tested in both boys and girls. In boys, an interaction between risk group and the eyes open/closed condition was seen for the right monopedal and Romberg procedures. This is consistent with results of an earlier analysis of cross-sectional data (Hill and Steinhauer 1993b), in which a greater decrement in postural sway occurred going from the eyes open to eyes closed condition among high-risk in contrast to low-risk children in the right monopedal stance. There are several possible neurobiological mechanisms that might explain this greater sensitivity to loss of visual input among high-risk children. Abnormal development of the cerebellar vermis (Sowell et al 1996) and reduction in size of the caudate nucleus (Mattson et al 1994) have been reported in children prenatally exposed to alcohol. Although the fetal exposure of the present sample was quite minimal, nevertheless, the alcohol exposure experienced might have had a detrimental effect. Alternatively, some of the structural abnormalities identified in clinical studies of prenatal exposure might be the result of genetic susceptibility to substance dependence affecting both the mother and child. Studies of other developmental disorders such as autism have also revealed cerebellar dysmorphology (Courchesne et al 1988). The mechanism responsible for the high-risk child’s delay in acquiring age-appropriate levels of postural control remains unknown, however, it is known that children in comparison to adults depend more on visual input for maintaining balance (Shumway-Cook and Woollacott 1985). Therefore, it would appear that children with neurodevelopmental delays might be most affected by being deprived of visual input.

In conclusion, these findings indicate that due to a developmental delay in the maturation of postural control mechanisms, high-risk children exhibit greater postural sway than low-risk control subjects at a given age. The present findings may explain why, in the absence of alcohol administration, cross-sectional differences between high- and low-risk groups have been reported in minor children (Hill and Steinhauer 1993b) but not in young adults (Schuckit 1985). Also, this observation is consistent with the notion that some neurologic “soft signs” are indicative of developmental delay. Rutter et al (1970), during their Isle of Wight study, provided the first subtyping of “soft signs,” noting that one distinguishable type is a sign of developmental delay that disappears with age.

Finally, these results for postural sway are consistent with our speculation (Hill and Steinhauer 1993a; Hill et al 1990) that reduction in P300 amplitude in high-risk compared to low-risk children may be due to a developmental delay in neural substrates producing the event-related potential (ERP). In a recent report based on a latent growth curve analysis of longitudinal ERP data from this laboratory, high-risk children showed developmental delays in P300 amplitude, exhibiting age-inappropriate levels of amplitude in comparison to low-risk children (Hill et al 1999). Therefore, analyses of these two neurobiological measures collected in the context of a longitudinal design suggest that delay in the development of specific neurobiological systems may be related to the later development of alcohol dependence.

Although the concept of developmental delay in neurobehavioral functioning as a precursor of adult substance dependence has not previously been documented, research to date on children at high-risk for developing schizophrenia generally supports the conclusion originally drawn by Fish (1977) that neurobehavioral abnormalities are indicators of an inherited neurointegrative defect that is a precursor of schizophrenia. Neurobehavioral deficits in school-age children of schizophrenic parents have been documented (Marcus et al 1993). Included among the neurobehavioral deficits seen in these children at high-risk for developing schizophrenia were soft neurologic signs including perceptual deficits and poor motor maturity, deficits which have also been reported in other studies of high-risk children (Erlenmeyer-Kimling et al 1982; Hanson et al 1976; Marcus et al 1985; Rieder and Nichols, 1979). The relative paucity of studies describing neurobehavioral deficits in children of alcoholics may be due in part to the more subtle nature of the deficits seen in these children compared to children of schizophrenics. Both information processing characteristics (P300 amplitude reduction) and postural control in high-risk children require laboratory assessment. Also, the slower acquisition of age-appropriate levels of postural control and P300 amplitude would not have been observable without the benefit of a longitudinal design.

With continued follow-up of the high-risk for alcoholism children/adolescents into early adulthood, a determination can be made about whether substance dependence occurs more frequently in the subgroup of high-risk children who show early neurobehavioral signs.

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