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NOTE

PHYSIOLOGICAL CORRELATES OF EXTREME INTELLECTUAL PRECOCITY

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Abstract—Among extremely mathematically and/or verbally precocious students (top 1 in 10,000 in such *reasoning* ability), the following three physiological characteristics were found at high frequencies: left- or mixed-handedness, asthma and other allergies, and myopia. The first two of these *may* reflect the effects of a common influence (testosterone) on the nervous and immune systems during fetal development. Moreover, our results suggest that such highly able students may exhibit bihemispheric representation of cognitive functions. These results may bear on the etiology of intellectual talent.

INTRODUCTION

IMMUNE disorders have been found at an elevated rate among left-handers and learning-disabled individuals [16, 17]. GESCHWIND and BEHAN [16] have proposed that a physiological mechanism affecting both brain structure and the immune system plays a role in the determination of left-handedness and in learning disabilities. Specifically, they hypothesized that left-handedness and immune disorders are related to exposure in fetal life to high levels of testosterone, or to high fetal sensitivity to testosterone. Testosterone slows the development of the left hemisphere and simultaneously affects the thymus gland and hence immune development [16]. Because it has been shown in the fetal monkey that diminution of the size of one area in the cortex may lead to enlargement in the homologous region of the opposite side and in areas adjacent to the one whose development is impaired [18], Geschwind and Behan postulated that prenatal testosterone exposure may enhance right-hemisphere development and perhaps functioning in humans.

Spatial abilities, which may be important in mathematics, depend on parts of the right hemisphere and on the posterior association cortex in the left hemisphere [8, 24]. Results for mathematics are similar [28]. Thus, if Geschwind and Behan's hypothesis [16] is correct, one would predict that left-handedness and immune disorders should more frequently be found in highly mathematically talented individuals than in a control population.

The purpose of this present study was to study left-handedness and immune disorders among a group of young, but extremely precocious, mathematical reasoners and a group of extremely precocious young verbal *reasoners*. The latter were studied because Norman Geschwind (Personal communication, May 1984) postulated that this group would also exhibit an elevated frequency of left-handedness and immune disorders, since the critical component was reasoning not subject-matter (i.e. cognitive process, not content) He, therefore, postulated a strong involvement of the right hemisphere in verbal reasoning ability. This seemed consistent with previous studies [10, 13, 15].

Furthermore, in the course of studying extremely precocious students, we noted that many wore glasses. Because of this observation and because previous studies that had shown a relationship between myopia and high intelligence [1, 21, 23, 26], we also studied the incidence of myopia among the extremely talented, even though the Geschwind hypothesis does not include myopia.

If the findings were to be consistent with our predictions, they would provide evidence for physiological correlates of high intellectual ability and could also conceivably relate to the large sex difference in mathematical reasoning ability found among our intellectually talented students [4–7].

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*Some of this work was completed at Johns Hopkins University.

METHODS

Subjects

As of 31 October 1983, 416 extremely precocious students had been identified out of over 100,000 gifted students who had been tested approximately 5 years earlier than usual with the College Board Scholastic Aptitude Test (SAT), Mathematics (SAT-M) and Verbal (SAT-V), as part of a talent search covering the entire United States. The selected students had scored at least 630 on SAT-V and/or at least 700 on SAT-M *before* age 13:*291 met the mathematics criterion and 165 the verbal. Such students exhibit extreme intellectual precocity and are estimated to represent the top 1 in 10,000 of their age-group in mathematical and /or verbal reasoning ability. A sex difference in the number qualifying for the high mathematics group (i.e. 12 boys for every 1 girl) was found and has already been presented [7]. Since there were so few extremely mathematically talented girls, any additional girls making the criterion after October 1983 were added to the study. The response rate for this study was 91%, although we had information but not usable information (i.e. reported handedness) on all but 18 students [4%]. Therefore, response rate bias is improbable.

In this study, individuals of Asian ancestry were over-represented (22%) among students qualifying for selection by scoring at least 700 on SAT-M. Because left-handedness is less accepted in those cultures [27], Asians were tabulated separately. It was not considered necessary to study the Asians separately on the other variables, as no significant differences between Asians and non-Asians were seen.

Procedures

The Edinburgh Handedness Inventory of OLDFIELD [25] was mailed to the students and their parents, the latter also *reported* the handedness of their other children. Scores on the 10-item Oldfield inventory, designated as laterality quotients (LQ), range from -100 (complete left-handedness) to $+100$ (complete right-handedness). Basically, the LQ is computed by subtracting the number of actions done with the left hand from the number performed by the right, dividing this quantity by the total number of responses for both hands, and then multiplying by 100. In this study we adopted Oldfield's criterion of left-handedness, i.e. $LQ < 0$. GESCHWIND and BEHAN [16] found that 7.2% of the general adult population in Glasgow were left-handed by this criterion, a figure similar to that found by Oldfield.

LQs are not normally distributed. Thus, only nonparametric statistics are appropriate. Since we were interested in differences where proportions are small (around 10%), it is difficult to obtain statistical significance unless the N is very large. Ideally, our sample size should have been larger, but this was not possible, considering the rare occurrence of the students studied. For example, it took 5 years of extensive nationwide searching to find 36 extremely mathematically talented girls.

A standardized questionnaire† that classified symptomatic atopic disease (i.e. allergies) not only by frequency but also by severity, duration, and type was also mailed to all the precocious students' parents. To ensure consistency within each family, one parent was asked to report for the entire family of the precocious student. A reported allergy was tabulated if it had occurred on a *regular* basis at any time in the person's life (see Table 1 for the rating scale). This questionnaire also included questions on any possible visual problems of the family members and the age diagnosed, if present. The actual prescription was requested, but few provided it.

Because our two samples of intellectually talented students may not be comparable to the general populations tested in the Oldfield or Geschwind and Behan studies, we also formed our own comparison group. Responses to the same questionnaires mailed to the extremely precocious students and their families were obtained from a sample of 203 students scoring least well on the SAT in the 1983 Johns Hopkins University's Regional Talent Search.‡ These individuals had, as seventh-graders, a *combined* score on SAT-M plus SAT-V of less than or equal to 540 (i.e. their scores were near or at chance). Students in the comparison group, however, should nevertheless be considered well above average in ability. Only approximately the top 5% on standardized achievement tests are permitted to participate in the talent searches [4, 7]. (The parents and siblings of the high scorers, who were too used for comparison purposes, are also much more intelligent than average.) At the time of completion of the questionnaire, the comparison group of students were approximately 13 years old. Slightly more females than males (55% vs 45%) were represented in this group, but no sex differences were found on the variables studied. Less than 2% of these low-scoring students were Asian Americans, vs the 22% of high mathematics scorers, noted above.

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*Each score defines the 95th percentile of SAT-M and SAT-V scores of college-bound male 12th-graders. This test is designed for high school students and administered nationally by the Educational Testing Service of Princeton, NJ 08541, U.S.A. The SAT seems to function far more as a reasoning test for young students than for high school students [7]. The identification procedure is cited in refs [4, 7].

†The allergy questionnaire was provided by Dr Franklin Adkinson, The Johns Hopkins School of Medicine at Good Samaritan Hospital, 5601 Loch Raven Blvd, Baltimore, MD 21239, U.S.A.

‡The Johns Hopkins regional talent search in 1983 spanned the Northeastern and Mid-Atlantic states and Virginia as well. That year 15,479 seventh grade students already known to be in the top 3% on the mathematical section, verbal section, or total score of a standardized achievement test were tested.

Table 1. Frequency of physiological traits by sex among the intellectually precocious, their families, and the comparison group

	Mathematically precocious (SAT-M ≥700)		Verbally precocious (SAT-V ≥630)		Mathematically and verbally precocious (SAT-M ≥700 and SAT-V ≥630)						Comparison	
	Males (*N*)	Females (*N*)	Males (*N*)	Females (*N*)	Males (*N*)	Females (*N*)	Fathers (*N*)	Mothers (*N*)	Brothers (*N*)	Sisters (*N*)	Males (*N*)	Females (*N*)
Left-handedness among non-Asians (LQ<0) (%)	13.8 (145)	5.9 (17)	23.5 (51)	12.3 (57)	16.7 (30)	20.0 (5)	11.4 (255)	8.1 (260)	9.1* (232)	8.8* (216)	10.5 (86)	9.9 (111)
Median LQ	75	87	69	78	75.5	86	81.8	100	—	—	82.5	88
Symptomatic atopic disease† (%)	53 (173)	54 (35)	52 (44)	48 (48)	54 (33)	14 (7)	45 (340)	44 (340)	40 (249)	30 (217)	38 (92)	33 (109)
Myopia (%)	51 (196)	61 (36)	65 (57)	70 (61)	53 (34)	63 (8)	58 (393)	51 (393)	34 (249)	39 (217)	20 (92)	25 (109)
Age myopia was diagnosed (yr)	9.0 (83)	8.5 (19)	8.5 (30)	7.8 (32)	9.4 (18)	7.4 (5)	17.5 (188)	14.2 (177)	9.7 (75)	9.6 (76)	10.1 (18)	9.2 (27)

*Handedness for siblings was self-reported.

†Severity of atopic disease was assessed using a standardized instrument with the following scale: 0 = no history; 1 = isolated event, never recurred; 2 = isolated event, recurred only once; 3 = infrequently recurring problem, now inactive, no longer recurs; 4 = active, ongoing (occurrence at least once a year) problem (mild); 5 = active, ongoing problem (moderate); 6 = active, ongoing problem (severe). *We accepted as a valid allergy only those given a rating of at least* 3.

RESULTS

Left-handedness

The frequency of left-handedness for the extremely precocious youths was much higher (15.1%, or about twice) than the 7.2% rate found by Oldfield and Geschwind and Behan [16]. Among the comparison group of low-scoring students 10.2% were left-handed, as determined by the Oldfield inventory, which was also significantly lower ($P<0.05$) than for the extremely precocious by a one-tailed test. Frequency of left-handedness among the comparison group was similar to that found among the siblings and parents of the extremely precocious (see Table 1). In addition, a sex difference in left-handedness was observed in every sample (see Table 1). Males were more frequently left-handed than females, but this was significant only for the extremely precocious by a median test ($P=0.05$). When by-sex comparisons were made separately between comparison group, siblings, and parents, none of the differences were significant, perhaps due to the small numbers and small proportions with which we were dealing and the consequent lack of statistical power.

The data for the extremely precocious were broken down not only by sex but also by area of the greatest talent (mathematics, verbal or both). When the verbally and mathematically talented were contrasted by sex, an interesting pattern emerged (Table 1). The highest frequency of left-handedness was among the ≥630 SAT-V (termed 630V) males, followed by ≥700 SAT-M (700M) males, 630V females, and then 700M females (the last based on only 17 cases, however). A median test on these differences nearly reached the 5% significance level ($P=0.057$).

The distributions of LQs for the extremely precocious, parents, and comparison group were then broken down into six categories according to natural or logical breaks in the data (see Table 2). The sample size was insufficient for further breakdown of the data by sex. The results indicated that the extremely precocious had a higher percentage of individuals in all but the strong right category (LQ = 100) than the comparison group and, especially, the parents ($P<0.05$ by a sign test). For example, only 23% of the extremely precocious vs 52% of the parents were strongly right-handed. This means that the extremely precocious students were about twice as likely as the comparison group and their parents to report using the left hand to perform any one of the 10 tasks ($P<0.01$). Moreover, a substantial majority of the extremely precocious reported using their left hand for at least one task. This was not true for the parents, and only slightly so for the comparison group.

Among Asian Americans 4.9% were left-handed. This is higher than reported for Chinese but similar to a figure reported for Oriental-American school children [27]. (Most of our students of Asian parentage were first-generation Americans of Taiwanese or Korean parentage.) The distribution of LQ > 0 did not differ among the Asians and Caucasians.

Symptomatic atopic disease

Approximately 53% of the extremely intellectually precocious students were reported to have symptomatic atopic disease, with no statistically significant differences among the extremely precocious themselves (Table 1). Using this instrument, ADKINSON (personal communication) found a frequency of symptomatic atopic disease of 20–25% for a population of average-ability individuals.

Symptomatic atopic disease was significantly (at least $P<0.05$) more frequent for extremely precocious students (53%) than for their parents (44%), their siblings (35%), and the comparison group (35%). There were no statistically significant sex differences, except between the brothers and sisters ($P<0.05$). Moreover, severity ratings were slightly higher for the precocious group than for their family members ($P<0.01$ for parents). Finally, left-handers were slightly, but not significantly, more likely to have allergies with higher severity ratings than were right-

Table 2. Distribution of LQs for the extremely precocious, the comparison group, and the extremely precocious parents

	Extremely precocious students (305)	Comparison (197)	Parents (515)
LQ ≤ −70 (strong left)*	6.9	3.6	5.0
−70 < LQ < 0 (mixed left)	8.2	6.6	4.7
0 ≤ LQ < 40 (ambidextrous)†	6.2	5.5	1.7
40 ≤ LQ < 70 (mixed right)	20.7	18.3	14.4
70 ≤ LQ < 100 (right-handed)	35.0	24.4	21.6
LQ = 100 (strong right)	23.0	41.6	52.6

* Because right-handedness is the norm and, thus, the majority of cases fall into that range, more discrete categories could be formed for it than for left-handedness.

† Since society is mainly set up for right-handers, a truly ambidextrous individual would tend to get a score shifted towards the right. Thus, we felt this was a valid label for this range of scores.

handers. Thus, symptomatic atopic disease is a physiological trait exhibited at elevated frequency by extremely precocious children.

Myopia

The possibility that extremely able students would be more frequently myopic than less able ones was investigated through the questionnaire completed by the parents. It was found that the majority of these students (over 50%) were myopic (Table 1), while less than 5% were hypermetropic (10% had astigmatism). In the comparison group and in a general population of high school students [23], significantly less ($P<0.01$) were myopic (22% and 15%, respectively), as were the siblings (36%) of our precocious students. Among the parents of the extremely precocious, 55% were myopic; however, the frequency of myopia increases dramatically with age. Again, an interesting pattern of myopia emerged among the mathematically and verbally talented males and females, which was significant by a χ^2 test (9.05, $P<0.05$). The verbally precocious students ($P<0.01$) and females ($P<0.05$) were more likely to be myopic. Statistically significant sex differences were not found among the parents. Yet among the siblings and the comparison group there was a non-significant trend for females to be more frequently myopic than males.

The average age when myopia was diagnosed is shown in Table 1. For the intellectually precocious students this was approximately 8 years, significantly ($P<0.01$) younger than for the comparison group, siblings, or parents. Published data indicate that less than 1% of the population are myopic by age 8 [14, 20]. For every group in the present study females were myopic at a younger age than males ($P<0.05$).

DISCUSSION

In this paper we have identified three physiological traits that occur frequently in youths of extreme mathematical and/or verbal precocity: left- or mixed-handedness, symptomatic atopic disease (asthma and other allergies), and myopia. We also have (incidentally) found an over-representation of Asian–Americans among extremely mathematically talented students, but not in the high verbal or the comparison group. Although interesting, this finding is difficult to interpret.

GESCHWIND and BEHAN [16] have postulated that left-handedness and immune disorders are related to exposure in fetal life to high levels of testosterone or to high fetal sensitivity to testosterone and that such exposure enhances right-hemisphere development and perhaps functioning [16]. Our results are consistent with this hypothesis, although they do not constitute proof.

Why did we (and Geschwind) even expect to find a high level of left-handedness and immune disorders among the extremely precocious verbal reasoners? The key is that we studied verbal *reasoning* ability. It is probably more strongly under the influence of the right hemisphere than language production or syntactical aspects of verbal ability, because verbal reasoning ability involves comprehension and the understanding of difficult words and their relationships [10, 13, 15].

Why were mathematically talented males not more often left-handed than the verbally talented males? We postulated that this may have something to do with the frequency of mathematical and verbal talent in the population when the effects of testosterone are eliminated. In that case, one might expect to find sex differences favoring males in mathematical reasoning ability but none or perhaps a slight female advantage in verbal reasoning ability. It appears, however, that there are nonetheless slightly more males than females with extremely high verbal reasoning ability and many more with extremely high mathematical reasoning. The proportion of testosterone exposed (and, thus, left-handed) males among the extremely high verbal reasoners, we speculate, may therefore be higher than among the extremely high mathematical reasoners.

Our results on left-handedness in our specialized group may have certain implications. Left-handers, mixed-handers, and right-handers with left-handed relatives generally have been found to have differing brain organization from right-handers. They are more likely to have great bihemispheric representation of cognitive functions (e.g. [9]). Since most of our students were not fully right-handed, we speculate that bihemispheric representation of cognitive functions is associated with extreme mathematical or verbal reasoning abilities. This hypothesis is especially intriguing with regard to WITELSON'S recent findings [29]. She found that the corpus callosum is larger in left- and mixed-handers than in right-handers.

The above observations, especially the sex difference in left-handedness, may also relate to the sex difference in extremely high mathematical reasoning ability reported previously [4, 7]. In addition to the important role of environmental influences on sex differences in mathematical reasoning ability, we have suggested that they may be, *in part*, physiologically determined [4]. This did not seem unreasonable, since physiological bases for sex-related variation in abilities and behavior have been well documented in other mammalian species, even at the cellular and molecular levels [11]. Nevertheless, the current results lend credence to this viewpoint. Our data are, however, difficult to reconcile with one endogenous type of explanation of sex differences in cognitive abilities, i.e. that boys do better than girls on spatial or mathematical reasoning tasks because males exhibit greater specialization of their hemispheres (see [9] for review).

Onset of myopia *at an early age* also appears to be a characteristic of the extremely gifted, especially among the verbally talented and females. Although environmental factors such as 'eyestrain' probably play a role, it would be remarkable if they were the *sole* cause of myopia. Many studies on myopia have revealed some hereditary component [1–3, 12, 21–23], although environmental stress to the eye has been shown to lead to myopia (e.g. [19]). Moreover, the possibility that the higher rate of myopia (and allergies) is due to greater perceptiveness of intellectually talented children or their parents seems unlikely. The same parents supplied data for both the intellectually precocious children and for the rest of the family. Nevertheless, the intellectually precocious students had a much higher frequency of these conditions than their siblings. Finally, because the pattern of myopia among the extremely precocious was not similar to that found for allergies and handedness, it appears as if myopia has a different underlying cause. We, therefore, can only rule out several explanations. At present, we do not have any hypothesis for the four-fold increase in myopia seen among the extremely precocious.

In conclusion, 80% of mathematically and/or verbally extremely precocious students were left-handed, myopic, and/or had allergies. These data bear on the question: does intellectual precocity have physiological as well as environmental bases?

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