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Extreme Mathematical Talent: A Hormonally Induced Ability?

Camilla Persson Benbow and Robert Michael Benbow

The Study of Mathematically Precocious Youth (SMPY) was founded in 1971 by Julian C. Stanley to find and help mathematically talented junior high school students. To identify such 12- to 13-year-olds, the concept of a talent search was initiated. Students in the seventh grade (and occasionally in the eighth) were eligible to participate in these talent searches if they had scored in the upper 5% in 1972, 2% in 1973 and 1974, and thereafter in the upper 3% on national norms on the mathematics part of a standardized achievement test. In the beginning these talent searches only spanned the Middle Atlantic states of the U.S. Now they are national in scope.

As part of each talent search, qualified students take the Scholastic Aptitude Test, Mathematics (SAT-M) and Verbal (SAT-V) sections, at a national administration of the SAT in their local area. The SAT-M and SAT-V were designed to measure mathematical and verbal reasoning ability, respectively, of above average 11th and 12th graders. Because the intellectually talented 12-year-olds studied by SMPY have not had much experience with abstract mathematics and have not been exposed to the content of the test, the SAT-M is an especially good measure of mathematical reasoning ability for them (Benbow & Stanley, 1983).

The importance of mathematical reasoning ability is highlighted by the performance of the 1986 U.S. Mathematical Olympiad team. Four of the six students on this Olympiad team were identified several years ago by SMPY as extremely mathematically precocious . Before age 13, each had scored at least 700 on SAT-M. These four males won 2 gold medals and 2 silver medals and were instrumental in the U. S. team's tieing with the USSR for first

*We thank Joel Abramowitz and Michael O'Boyle for helpful comments and suggestions. Support was provided by the National Science Foundation (MDR-8651737) and the Department of Education.

place in the 1986 competition (J. Stanley, Personal Communication).

In 1972 when the first talent search was conducted, the staff of SMPY did not anticipate any sex differences in SAT-M scores. Thus, it was quite surprising that a sex difference was found, which has turned out to be one of the largest ever detected. Almost 8% of the 7th-grade boys and 27% of the 8th-grade boys in 1972 scored more than 600 on SAT-M (approximately the 80th percentile of college-bound 12th grade males), while not one single girl did. The mean difference in scores was 37 points for the 7th-graders and 70 points for the 8th-graders. Initially, we believed that the sex difference was most likely an artifact. If not that, it was thought to result from environmental and sociological factors. When a large sex difference was found the following year in the talent search, the staff of SMPY was again surprised. In every talent search subsequently conducted by SMPY, however, a large sex difference has been found (Benbow & Stanley, 1980). For the 9,927 students tested from 1972 through 1979 no statistically significant sex difference in verbal ability, as measured by the SAT-V, was found. Yet there was a consistent sex difference on SAT-M, which was equivalent to about one half of a standard deviation. This was observed even when the boys and girls had been matched on achievement test scores before taking the test.

The results until 1980 were limited, however, to highly motivated mathematically talented students. In 1980 the traditional mathematics talent search expanded into verbal and general ability areas as well. The top 3% in mathematical, verbal, or general ability were now eligible to participate in a talent search. Moreover, as time went on the entire United States was covered by the talent searches conducted at Johns Hopkins, Duke, Northwestern University, and the University of Denver. Two results came from these expansions: Approximately 100,000 students now take the SAT as part of a talent search each year and equal numbers of boys and girls participate. Despite these modifications the sex difference in SAT-M scores has remained stable. For example, the sex difference in the Johns Hopkins talent searches since and including 1980 has ranged from 30 to 36 points. There has been no indication that this difference is changing.

Although this average sex difference may be important, it is not the major finding resulting from the data. Benbow and Stanley (1983) have analyzed in detail the results for the 1980 to 1983 Johns Hopkins talent searches. They determined that sex differences in mathematical reasoning ability are greatest at the top of the scale. For example, among 12-year-old students scoring at least 500 on SAT-M (the approximate average score of college-bound 17-year-old males), there is a ratio of two males (2.1) for every female (based on 5,325 cases); at $\geq$ 600 SAT-M (77th percentile of college-bound 12th grade males) the ratio is 4.1 to 1 (806 such cases); and at $\geq$ 700 SAT-M (94th percentile of college-bound senior males) the ratio is 12.9 to 1 for the 278 cases reported by Benbow and Stanley (1983).

On the basis of results from several 100,000 seventh grade students who have been tested through the various talent searches in the United States, it is quite clear that there are very large sex differences in mathematical reasoning ability by age 12, especially at the highest levels of that ability. Moreover, these findings have been replicated in other countries as well (e.g., Stanley, Huang, & Zu, 1986). Benbow and Stanley (1982) and Benbow and Minor (1986) have shown that the observed sex difference at age 13 can predict subsequent sex differences in mathematics and science participation and achievement in high school. Thus, the sex difference appears to have important predictive value. It is therefore important to determine why it occurs.

Extensive studies conducted over a 14 year period by the staff of SMPY and others, have been unable to find results that are consistent with an exclusively environmental explanation for the sex difference (e.g., Benbow & Stanley, 1982, 1983; Raymond & Benbow, in press). Because we have been unable to find support for an entirely environmental explanation of the sex difference in mathematical reasoning ability in SMPY's high-ability population, we began in 1980 to consider possible biological factors that might influence intellectual ability. It had been shown previously that there was a possible association between mathematical reasoning and spatial ability (which may have a biological basis). In addition, we had tested previously parents of extremely talented students, who turned out to be highly intelligent (Benbow, Zonderman, & Stanley, 1983). Thus, we had some indication that biological factors might be involved in producing extremely high ability.

Little research on possible biological correlates of extremely high reasoning ability has been conducted, possibly because of the social and political ramifications. Nonetheless, three physiological correlates of that ability have been identified to date: left-handedness, symptomatic atopic disease (allergies), and myopia (Benbow, in press). The first two appear to be related to bihemispheric representation of cognitive functions or the influence of fetal testosterone, as will be described below. New data presented in this paper are consistent with that possibility.

The striking findings of Geschwind and Behan (1982) initially prompted our investigations in this area. Geschwind and Behan had reported that left-handers suffer more frequently from immune disorders, learning disabilities, and migraines than right-handers. Their explanation for this unusual finding involved testosterone. They hypothesized that if a developing fetus is exposed to high levels of testosterone or has an increased sensitivity to it, it has two effects. The thymus gland is affected resulting in immune disorders, such as allergies. Moreover, testosterone slows down the development of the left-hemisphere of the brain. As a result, the right-hemisphere compensates and becomes stronger. This increases the likelihood of that individual being left-handed (Geschwind & Behan, 1982). Since mathematical reasoning, in contrast to computation, and spatial ability are considered to be functions more efficiently carried out by the right than the left-hemisphere, we decided to investigate the possibility that extremely mathematically talented students would be more frequently left-handed.

Students representing the top 1 in 10,000 in mathematical reasoning ability (i.e., before age 13, they had an SAT-M score of at least 700) were surveyed using the Oldfield Handedness Inventory. The criterion for left-handedness was LQ < 0. It was found that the rate of left-handedness for this group was about twice that reported for the general population (Benbow, in press). Moreover, the frequency of left-handedness among such students was greater than for their parents or siblings and a comparison group of above average ability (approximately the top 1 in 20) students (Benbow, in press).

Having found the above relationship between left-handedness and mathematical precocity, we decided to investigate the possibility that extremely mathematically talented students would also exhibit an increased frequency of immune disorders (such as, allergies). An allergy questionnaire, which was designed by Dr. Franklin Adkinson of the Johns Hopkins Medical School at Good Samaritan Hospital, was used. Allergies were classified according to type, severity, and duration. This questionnaire was completed by the parents of the students whose mathematical reasoning ability was at the top 1 in 10,000 level. The frequency of allergies found among such students (i.e., approximately 55%) was more than twice the rate found for the general population. This frequency was also greater than that reported for their parents and siblings and the comparison group (Benbow, in press).

Moreover, the frequency of left-handedness and allergies was also investigated among a group of students who represented at least the top 1 in 10,000 in verbal reasoning ability. They also exhibited these traits at a frequency similar to the mathematically talented students. Although this may seem counterintuitive, this finding may be explained by the nature of the ability studied. We studied verbal <u>reasoning</u>. This ability may be more strongly under the influence of the right-hemisphere, especially in contrast to language production (Gardner et al., 1983).

The above findings are, therefore, consistent with the hypothesis that students with extremely high mathematical or verbal reasoning ability are exposed prenatally to higher than normal levels of testosterone. The late Norman Geschwind, upon learning of our results, suggested that we study when such students were born. He predicted that these students would be conceived more frequently in months when daylight occupies more than 12 hours per day. [Daylight affects pineal gland secretion, altering the level of melatonin, which in turn has an inhibitory effect on reproductive hormones (Lewy, 1983; Lewy et al., 1980).] Because of previous controversies in this area, caution was exercised in dealing with this hypothesis. Moreover, the biological basis of Geschwind's hypothesis is not entirely clear. Nevertheless, as is shown below, the data did bear out Geschwind's prediction remarkably well.

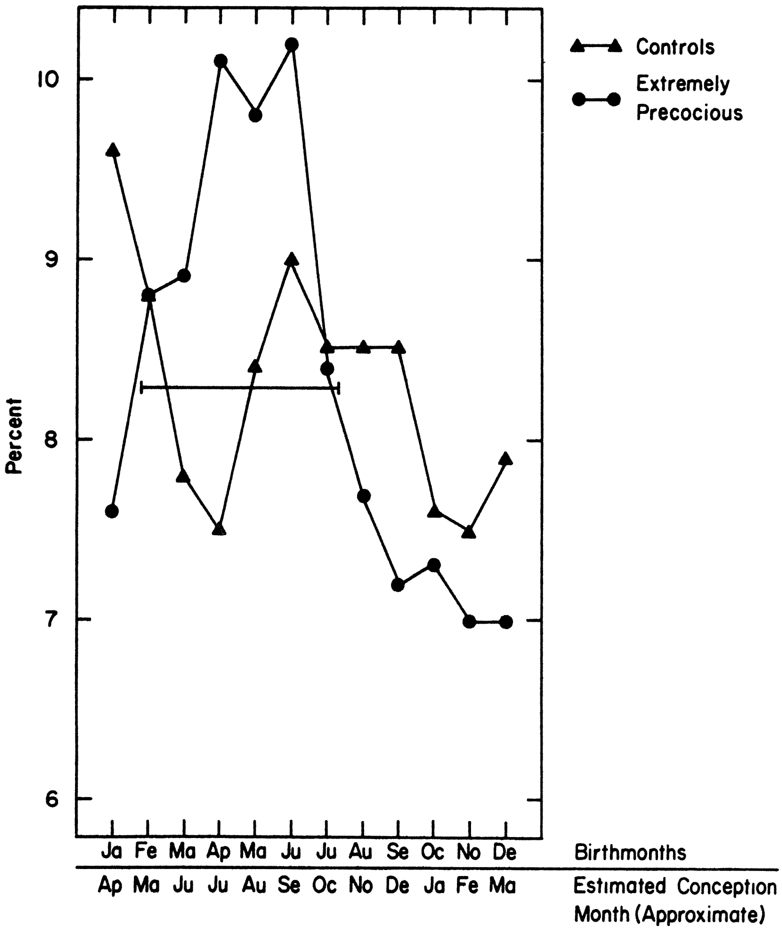

Figure 1

The proportion of extremely talented students born in each month was computed and adjusted for the length of the month. The average length of a month is 30.4375 days. The data, which are in the form of a moving average, are presented in figure 1. This yielded a smooth curve with the maximum in June and a minimum in December, exactly six months apart. Moreover, the six months February through July are all above the mean for the year and the six months August through January are below. The probability that the figures for any six consecutive months will all be higher than the other 6 months is less than .05. The equinoxes are March 21 and September 21; as shown in figure 1, most of the extremely precocious students were conceived in the months when daylight occupies more than 12 hours per day. Moreover, birthmonth data for average ability students born in the same years as the intellectually precocious students in this sample were reported by Badian (1984). The data for these students are also depicted in figure 1. Clearly, there is no seasonal pattern to be found in the birthmonths of the control group.

An article by Maccoby et al. (1979) suggested another possible avenue of research. Maccoby et al. (1979) reported that first-born children are exposed to higher hormone levels (i.e., progesterone and, for boys only, testosterone) than later-born offspring. Thus, we decided to investigate what proportion of students in the top 1 in 10,000 in either mathematical or verbal reasoning ability were first-borns. Moreover, for comparison purposes we also studied those students whose abilities were in approximately the 95th percentile and were in the same age range as the extremely talented. It was found that 62% of the extremely precocious students and 48% of the comparison group were first-borns, a difference that was statistically significant at the .05 level.

The data reported above provide several lines of converging evidence that are consistent with the hypothesis that extremely precocious students may be exposed to high levels of hormones during fetal development. This may be important since it has been shown that progesterone exposure enhances numerical ability and androgens affect spatial ability (e.g., Reinisch, Gandelman, & Spiegel, 1979). Moreover, Levy and Gur (1980) proposed that high levels of fetal sex hormones promoted the maturational rate and cognitive capacity of the right hemisphere, which has been implicated as being specialized for non-verbal abilities, such as spatial and mathematical reasoning. Geschwind and Behan (1982) made a similar proposal for testosterone as discussed above.

Although the evidence is only circumstantial that high levels of prenatal hormones or testosterone exposure may be correlated with extreme intellectual talent, this may not be the case for myopia. Among the students who represent the top 1 in 10,000 in either mathematical or verbal reasoning ability, we found that approximately 55% were myopic at this early age. This was about the same as reported for their parents and much greater than for their siblings (36%) and the comparison group (22%) (Benbow, in press). The rate of myopia for the extremely precocious students was about four times the frequency found even for high school students.

One last area of our research deserves to be mentioned even though it is preliminary. The above left-handedness findings have broader implications that can be examined directly. Left- and mixed-handers and right-handers with left-handed relatives have been found more frequently to have bilateral or diffuse representation of cognitive functions (Bradshaw & Nettleton, 1983). Since the majority of extremely precocious students fit into one of the above three handedness groupings, this may imply that bilateral representation of cognitive functions per se (rather than greater specialization of the hemisphere) is associated with extremely high mathematical and/or verbal reasoning abilities. Some preliminary results have been obtained that are consistent with this hypothesis.

A subset of students identified by SMPY as being in the top 1 in 10,000 in either mathematical or verbal reasoning ability (N = 72) were tested with a computer simulation of a tachistoscope using a letter matching and a rotation task. In the rotation task the subjects were to decide if the letter "R," which was presented in one of four rotational orientations on the computer screen to the subject's right or left visual field, was in a normal or mirror-image position. In the letter matching task subjects compared two pairs of letters, which were presented sequentially and the second pair (the test stimulus) to either the right or the left visual field, and decided if the letter pairs had the same or a different name. The letter-matching task was developed by Posner et al. (1969) and the experimental procedures for this task were essentially a replication of those utilized by Kroll and Madden (1978).

For both the rotation and the letter-matching task each student was presented with a practice block, which was then followed by three experimental blocks of 32 trials each. Each experimental block consisted of two examples of the 16 possible conditions for the rotation task and four examples of the eight possible conditions in the letter-matching task, all randomly arranged within a block. A beep signalled the beginning of each trial. For the rotation task, 1000 msec later a fixation point appeared and lasted for 1000 msec. Then the screen went blank for 135 msec and the test stimulus was flashed to either the right or the left visual field for 100 msec. A mask was flashed to the opposite side. In the letter-matching task the memory stimulus, which was presented centrally for 150 msec, followed the beep after 1000 msec. The screen went blank for 500 msec and then the fixation point appeared for 1000 msec. The screen went blank for 120 msec and then the test stimulus appeared for 100 msec. On the side opposite the stimulus a mask was flashed. Visual field of presentation was random for both tasks. The accompanying computer program recorded the response time in milliseconds, beginning at the onset of the test stimulus and ending when the subject depressed the response button using their dominant hand. Errors were also recorded.

The mean response times of the extremely talented students for each task and by the right and left visual field are located in Table 1, as are the mean number of errors. On the rotation task no significant difference in response times between the right and left visual field was found by a t-test. On the letter-matching task, however, the left visual field had significantly faster response times than the right ($t = 3.94$, $p < .001$). In terms of errors made, the same pattern of results as for response times was found. In this instance, the difference was significant for the letter-matching task at the $p < .01$ level ($t = 3.0$). Thus, the results of this study were not in the direction usually reported and indicate that such extremely talented students do have strong right hemispheres.

Table 1. Mean reaction times and number of errors, by visual field, for the rotation and letter-matching task for extremely talented students (N = 72).

Visual Field	Rotation Task		Letter Matching Task	
	Mean Time	Mean Errors	Mean Time	Mean Errors
Left	1.0447	4.8	0.8850	3.8
Right	1.0441	4.3	0.9094	4.8

Because a t-test may "disguise" a possible interaction between handedness and sex, the difference in response times between hemispheres was also subjected to an ANOVA by sex and handedness grouping. The handedness grouping was right-handed with no family history of left-handedness (N = 20) and all others (N = 34). (Because of the cultural bias against left-handedness among Asians, they were studied separately. Results did not differ for them.) Since the ANOVA was nonorthogonal, special procedures for interpretation were followed. Although the differences were for the most part not significant, the trend in the data indicated that the difference in reaction times between the hemispheres in the letter-matching task were much larger if the person was male or had a history of left-handedness, but the difference for all groups consistently favored the right hemisphere. That is, the right hemisphere was faster and more accurate for all sub-groups of subjects, but even more so for left-handers and males. (Right-handed males did not show the typically reported pattern.)

On the rotation task, the relationships were less clear.

Nonetheless, the reversal of the usual pattern of results were stronger for males and individuals with a history of left-handedness. The differences were not very large, however. This was rather surprising. We had expected that this task may have showed the greatest right hemisphere advantage rather than the letter-matching task.

It seems then that extremely intellectually talented students may have strong right hemispheres and exhibit bilateral or diffuse representation of cognitive functions. The interpretability of these results are limited at present by the fact that the hand of response was not randomized or counterbalanced, and by the lack of a control group. A co-worker of Levy (Levy, Personal Communication) has found similar results for a group of extremely intellectually talented students and did have a control group. Moreover, the letter-matching task was a standard task devised by Posner et al. (1969) and was programmed in the same manner as Kroll and Madden (1978). Nonetheless, caution should be used when generalizing from these results.

In conclusion, the Study of Mathematically Precocious Youth, now at Iowa State University, has identified several physiological correlates of extreme intellectual talent. These are left-handedness, allergies, myopia, and possibly prenatal testosterone exposure (or high hormone levels prenatally) and bilateral representation of cognitive functions. Some of these may be related to the large sex difference found in mathematical reasoning ability among intellectually talented students and bear on the etiology of extreme intellectual abilities.

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