Neuropsychologia, Vol. 28, No. 2, pp. 211–216, 1990.
Printed in Great Britain.

0028-3932/90 $3.00 + 0.00

NOTE

ENHANCED RIGHT HEMISPHERE INVOLVEMENT DURING COGNITIVE PROCESSING MAY RELATE TO INTELLECTUAL PRECOCITY

MICHAEL W. O'BOYLE and CAMILLA PERSSON BENBOW

Department of Psychology, Iowa State University, Ames, IA 50011-32180, U.S.A.

(*Received* 31 *March* 1989; *accepted* 21 *August* 1989)

Abstract—In the present study, intellectually precocious and average ability youths performed a dichotic listening task (Experiment 1) and a free-vision chimeric face task (Experiment 2). Patterns of hemispheric lateralization and the relative involvement of the left and right hemispheres during cognitive processing were assessed. In Experiment 1, the average ability youths demonstrated a right ear/left hemisphere (re/LH) superiority for identification of CV syllables, while the gifted subjects failed to show any ear/hemisphere advantage. In Experiment 2, members of both groups tended to judge the leftside smile/rightside neutral half-faces as "happier", a pattern indicative of enhanced right hemisphere (RH) arousal. Notably, the degree of RH involvement was significantly greater in the gifted as compared to average ability youths. Moreover, laterality scores of the precocious on the chimeric face task correlated with their performance on the College Board Scholastic Aptitude test (SAT), i.e. the greater the leftward bias, the higher the SAT score. These findings, taken in composite, suggest that a high level of RH involvement during cognitive processing may be related to intellectual precocity.

BENBOW [1, 2] has recently identified several physiological correlates of intellectual precocity, including left-handedness and immune disorders. Because cerebral hemisphere asymmetry can be reduced or reversed in individuals exhibiting such characteristics [6, 9, 10, 17–19], Benbow proposed that the underlying brain organization of the intellectually precocious may differ from that of average ability youths. Specifically, she hypothesized that their RH may be more actively engaged during cognition.

In keeping with this hypothesis, BENBOW and BENBOW [3] describe two pilot studies in which gifted children were tested for patterns of hemispheric lateralization. In the first study, a rotated "R" was presented to either the left or right visual field and subjects were to determine if the target letter had been presented in a normal or mirror-reversed orientation. Although a RH advantage was expected in this task due to its apparent emphasis on visuospatial processing, no differences between the hemispheres in either response latency or accuracy were observed. Though inconclusive, this finding is suggestive of a pattern of lateralization among the gifted that is somewhat different from the prototypical hemispheric processing arrangement.

In a second pilot study, a verbal matching task was employed. A letter was flashed in central vision, followed by presentation of another letter to either the right or the left visual field. Subjects were to determine if the two stimuli were the same or different letters. On the basis of a previous study using a similar procedure [13], a LH advantage was anticipated in this task. For gifted youths, however, the RH rather than the LH produced faster response times and greater accuracy. This pattern is suggestive of an uncharacteristically high level of RH involvement during cognition, even for the processing of ostensibly linguistic stimuli.

Unfortunately, several methodological ambiguities in these pilot studies, as well as the fact that no control subjects were tested, prohibit any strong conclusions about the underlying pattern of hemispheric asymmetry characterizing the intellectually precocious. Hence, the purpose of the present investigation is twofold: (1) to determine if the hypothesized difference in lateralization between gifted and average ability youths can be verified using a pair of well-documented laterality tasks, and (2) to determine if the source of any observed difference in this pattern can be attributed to an enhanced role of the RH during cognitive processing.

EXPERIMENT 1

In Experiment 1, both the gifted and matched control subjects were required to recognize consonant–vowel (CV) syllables presented dichotically. This task is known to produce a robust re/LH advantage for right-handed subjects [6, 10, 11, 17, 18]. It was expected that the average ability subjects would demonstrate the prototypical re/LH superiority for the processing of these linguistic stimuli. In keeping with the hypothesis that gifted individuals are characterized by enhanced RH activity during cognition, it was anticipated that they would show little asymmetry (or perhaps a RH advantage) in this task.

Method

Subjects. The gifted group consisted of 47 (33 male, 14 female) intellectually precocious youths selected from the CY-TAG (Challenges for Youth-Talented and Gifted) program at Iowa State University. The CY-TAG students were all right-handed as assessed by the Edinburgh Handedness Inventory [20], had completed either 7th or 8th grade, and represented the top $\frac{1}{2}$% in intellectual ability as measured by the SAT. The control group consisted of 20 (12 male, 8 female) right-handed, 7th- and 8th- graders of average intellectual ability.

Apparatus and stimulus materials. The dichotic tape used in this study was a copy of the one employed by HELLIGE and WONG [11]. The six CVsyllables to be recognized were /*pa*/, /*ta*/, /*ka*/, /*ba*/, /*da*/, and /*ga*/. Each of the 30 possible CV pairs were presented in each of two sets, for a total of 60 dichotic trials. Within each set, the order of presentation for each CV pair was randomized with the restriction that no one syllable was presented more than three consecutive times to the same ear. The onset of each CV syllable of a given stimulus pair was simultaneous within +/−2.5 msec, and the amplitudes of the component vowel segments were within +/−2.5 dB of each other. The interstimulus interval between successive dichotic pairs was 6 sec. Stimuli were presented via stereo headphones connected to a Sony reel-to-reel tape deck. The intensity of each CV syllable was approx 70 dB.

Procedure. On each trial, subjects were told to identify two different CV syllables presented simultaneously, one to each ear. For each set of 30 trials, subjects were given an answer sheet numbered 1–30. For each trial, the six alternative CV syllables were listed and subjects were instructed to circle the two which had been presented. The two sets of trials were separated by a brief rest period. Following the completion of Set 1, the headphones were reversed for Set 2. This procedure was employed to control for potential audio inequalities in the listening system. Prior to beginning the experiment, subjects were given two practice trials and provided the opportunity to ask questions about the procedure.

Results and Discussion

For each subject, the total number of syllables correctly identified by the the re/LH and the le/RH were tabulated. These data were subjected to a 2 × 2 × 2 × 2 mixed design analysis of variance (ANOVA) with Group (gifted/control) and Sex (male/female) as between subject factors, and Set (1st/2nd) and Ear (right/left) as within subject factors. The results of this analysis revealed significant main effects for Group ($F(1, 63) = 4.39$, $P < 0.04$), Set ($F(1, 63) = 5.39$, $P < 0.02$), and Ear of presentation ($F(1, 63) = 11.98$, $P < 0.001$). By way of summary, the gifted subjects recognized significantly more syllables than the controls; Set 2 produced a greater number of CV recognitions than Set 1; And, the re/LH demonstrated superior recognition as compared to the le/RH.

In addition, a reliable Set × Ear interaction was in evidence: $F(1, 63) = 4.37$ $P < 0.03$. Post-hoc analysis using Duncan's Multiple Range test [8] indicated that for Set 2 trials, the re/LH was superior to the le/RH ($P < 0.05$). There was no difference between the Ear/Hemispheres on Set 1 trials.

Of particular interest is the presence of a significant Group × Set × Ear interaction: $F(1, 63) = 4.48$; $P < 0.02$. Additional post-hoc analyses revealed that on Set 1 trials, there was no difference between re/LH and le/RH performance for either group of subjects. However, on Set 2 trials, the average ability youths showed a significant re/LH superiority ($P < 0.05$), while the gifted group failed to demonstrate any reliable hemispheric advantage. These relationships are illustrated in Fig. 1.

These findings taken in composite suggest that the pattern of lateralization characterizing precocious individuals is somewhat different than that of average ability youths. Specifically, the prototypical re/LH advantage for linguistic processing is attenuated in the gifted, as evidenced by an uncharacteristically high level of performance achieved by the RH in the recognition of CV syllables.

EXPERIMENT 2

In Experiment 1, intellectually precocious youths demonstrated an atypical pattern of lateralization relative to matched controls. The data from this study indicate that the absence of the prototypical re/LH asymmetry in the gifted was related to the enhanced involvement of the RH during cognition. Experiment 2 was conducted to provide corroborating evidence for this notion by using a qualitatively different laterality task, one which is thought to engage more RH than LH processing (i.e. involving judgement of facial emotion as compared to the recognition of CV syllables).

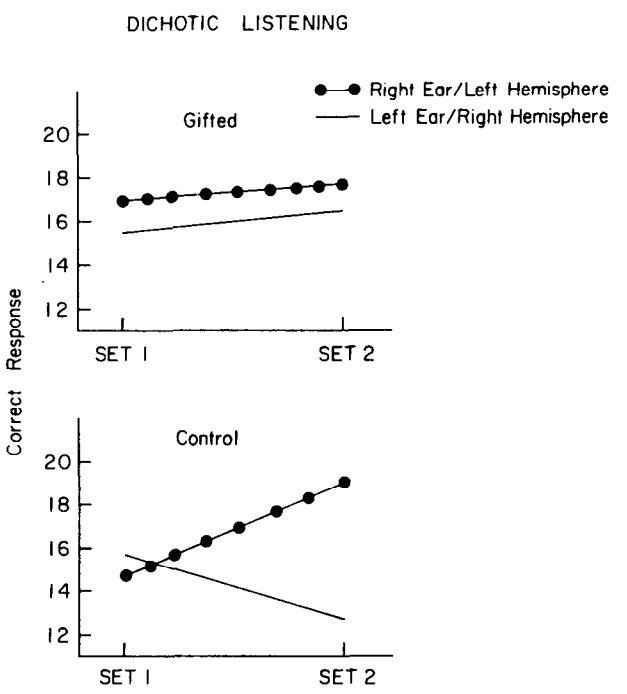

Fig. 1. Mean number of CV syllables identified ($N = 30$) by each ear/hemisphere as a function of Set.

In Experiment 2, both groups of subjects were asked to perform the free-vision chimeric face task devised by LEVY *et al.* [15, 16]. This task has been used previously to index the relative involvement of the RH and LH during cognitive processing [12, 14–16]. In this task, subjects view pairs of chimeric faces and are asked to judge which of the two is "happier". Each chimeric stimulus consists of two joined half-faces, either a leftside smile and a rightside neutral pose (leftside/neutral), or a rightside smile and a leftside neutral pose (rightside/neutral). It was expected that both groups would tend to choose more often the leftside/neutral combinations since an enhanced role of the RH in the judgement of facial emotion has been proposed [21, 22]. In addition, this task has produced strong leftward preferences in several previous studies [12, 14–16]. Given the high level of RH activation observed in Experiment 1, it was anticipated that the leftward bias exhibited in the chimeric face task would be significantly stronger for gifted as compared to average ability youths.

Method

Subjects. The 37 gifted participants from Experiment 1 plus 23 additional precocious youths drawn from the same CY-TAG program served as subjects in Experiment 2 (Total $N = 60$, 42 males and 18 females). All were right-handed, had completed either the 7th or 8th grade and represented the top $\frac{1}{2}$% in intellectual ability as measured by the SAT. The mean 7th-grade score for the gifted youths on the combined SAT-Math and the SAT-Verbal was 1016, with SEM of 98 (two 8th grade scores were age-adjusted). The control group consisted of the same 20 average ability subjects utilized in Experiment 1.

Stimulus materials. The 36 pairs of human chimeric faces developed by LEVY *et al.* [15, 16] were used as stimuli. Each of the 18 chimeric photographs and their mirror-images were reproduced as 22 × 28 cm overhead projection transparencies. Each chimeric face was paired with its mirror image: once with the normal print at the top of the transparency and its mirror image below, and once with the two positions reversed. The same random sequence of presentation was used for gifted and control subjects alike. Each projected face was approx 60 cm square.

Procedure. Members of each group were seated in a large classroom and given an answer sheet numbered from 1 to 36. Subjects were shown 36 pairs of faces. For each pair, their task was to judge which of the two faces appeared happier: "top", "bottom", or "can't decide". Subjects were allowed to view each pair for 10 sec at an average distance of approx 3 m.

Results and Discussion

The total number of right-biased and left-biased choices were tabulated for each subject. A laterality index was computed as $(R-L)/36$, where R equals the number of times the rightside/neutral combination was selected and L is the number of times the leftside/neutral combination was chosen. A negative score reflects RH involvement in the task, while a positive score indexes LH involvement. Less than 10% of the trials produced "can't decide" responses.

Both groups demonstrated a reliable leftward preference (Gifted $= -0.37$, t (59) $= -8.368$, $P < 0.0001$, one-tailed t-test; Control $= -0.12$, t (19) $= -1.827$, $P < 0.05$, one-tailed t-test). Notably, the number of controls demonstrating a leftward bias (13/20 = 65%), a rightward bias (6/20 = 30%), or no preference (1/20 = 5%) were proportional to the figures previously reported by LEVINE and LEVY [14]. These percentages attest to the representativeness of control groups performance on the task.

Additionally, a 2×2 repeated measures ANOVA was performed on these laterality scores with Group (Gifted/Control) and Sex (Male/Female) as between subject factors. This analysis revealed that the gifted youths had a significantly stronger leftward bias than the average ability subjects: $F(1, 76) = 6.48$, $P < 0.01$. The Sex variable was not significant, nor did it reliably interact with Group membership.

Examination of individual scores indicated that there were more gifted than average ability youths at the extreme negative end of the distribution ($P < 0.01$; see Table 1). The average laterality score for young adults on this task is reported to be -0.30 (see [14]); 72% of the gifted subjects but only 35% of the average ability youths had laterality scores more negative than this value ($P < 0.01$). Moreover, 33% of the intellectually talented males and 17% of such females had laterality scores which exceeded -0.60. The most extreme score for the average ability group was -0.47. Notably, the median laterality score for the gifted subjects was equivalent to the most negative score exhibited by the average ability group.

Table 1. Grouped distributions (in proportions) of laterality scores for intellectually talented (Gifted) and average ability students (Controls) by sex, along with mean (SD) and median laterality scores

Laterality score Range	Gifted		Controls	
	Male	Female	Male	Female
$-0.90 \leq x < -0.40$	57%	50%	25%	25%
$-0.40 \leq x < -0.00$	31%	33%	33%	50%
$0.00 \leq x < +0.40$	10%	6%	33%	25%
$+0.40 \leq x < +0.90$	2%	11%	9%	0%
Mean	−0.42	−0.29	−0.08	−0.17
SD	0.32	0.41	0.31	0.23
Median	−0.43	−0.40	−0.08	−0.15

In an effort to determine if enhanced RH involvement might be related to intellectual precocity, a Pearson Product–Moment correlation was computed between the gifted subjects' laterality scores and their SAT scores. This correlation was significant ($r = -0.294$, $P < 0.02$); The more negative the laterality score, and hence, the greater the processing involvement of the RH, the higher the score on the SAT.*

GENERAL DISCUSSION

In the present investigation, the average ability youths exhibited the prototypical re/LH advantage for the recognition of dichotically presented CV syllables, while the precocious subjects failed to demonstrate any ear/hemisphere advantage in the task. The absence of asymmetry in the gifted group was due to the surprisingly successful performance of the RH in the processing of these linguistic stimuli. In fact, the overall performance of the

*Originally, we had planned to correlate laterality scores with performance on the SAT-MATH and SAT-VERBAL subtests. Given the hypothesized link between mathematical ability and RH mediation, our expectation was that a high level of RH arousal might relate to SAT-MATH scores, while relatively low levels might correlate with higher SAT-VERBAL scores. It should be noted, however, that the gifted subjects were primarily selected for participation in the CY-TAG program on the basis of extremely high quantitative ability; In fact, 70% had SAT-MATH scores of 500 or better. Their corresponding SAT-VERBAL scores were much more evenly distributed, and if anything, shifted towards the low-end of the distribution. In light of this differential "restriction in range", computing the correlations of interest seemed statistically unwise.

precocious group was significantly better than the average ability youths, perhaps as a result of this enhanced RH involvement. Such findings confirm the earlier speculations of BENBOW and BENBOW [3] that (a) the pattern of hemispheric asymmetry characterizing gifted youths is different from those of more moderate ability, and (b) that an unusually active RH is the probable cause of this altered hemispheric processing arrangement.

The chimeric face task (Experiment 2) was conducted to extend the findings observed in Experiment 1 to a visual rather than auditory laterality task, one thought to tap more RH than LH processing resources. In Experiment 2, both gifted and average ability youths more frequently judged the leftside/neutral chimeras to be "happier". This replicates the findings of LEVY *et al.* [14–16], and is congruent with their hypothesis that the observed leftward bias is due to a higher characteristic arousal level of the RH as compared to the LH when judging facial emotions. As anticipated, this leftward preference was significantly larger in the gifted youths. These results suggest that during cognition, the RH of the intellectually precocious may be at a higher state of arousal as compared to average ability youths. By way of speculation, this enhanced RH involvement may provide additional processing resources that are unavailable to those of more moderate ability. These supplementary capacities might then be brought to bear in a variety of learning situations, contributing to superior intellectual performance. The fact that a significant correlation exists between the gifted youths' laterality quotient on the chimeric face task and their SAT scores lends credence to this speculative notion.

Interestingly, recent research [14] has shown that leftward preference for processing chimeric faces increases with age. Notably, the degree of leftward bias demonstrated by the intellectually precocious youths exceeds that of any age group previously reported, including most adults. Moreover, this pronounced leftward preference was obtained using overhead trasparencies (rather than test booklets or slides), a technique which may mitigate the strength of the effect (M. T. Banich, personal communication, November, 1988).

As suggested by research involving other species, it might be that the enriched learning opportunities afforded to gifted youths (e.g. participation in stimulating academic course work and learning programs) alters their underlying brain organization and/or neural connectivity [7]. In this case, enhanced RH activity would be a by-product rather than an inherent cause of intellectual precocity. O'BOYLE and HELLIGE [18], however, correlated college students' performance on the free-vision face task with their SAT scores and found no reliable relationship. Their college students had laterality scores more negative than our controls (but less negative than our gifted subjects), yet had combined SAT scores which were equivalent to those of our precocious group. Thus, exposure to high-level academic course work alone does not seem to account for the increased RH activity observed in the gifted youths, although the timing of such exposure (i.e. participation in such programs at an earlier than usual age) may yet prove to be an important factor.

Gender differences in extreme mathematical precocity are known to be quite large [2–5]. Moreover, some types of reasoning are thought to involve more RH than LH capacities [23, 24]. Among the gifted youths, males were twice as likely as females to exhibit a strong leftward bias on the chimeric face task ($P<0.01$). In light of this fact, it is tempting to speculate that RH arousal level may also be related to the reported gender difference in exceptional mathematical reasoning ability.

In summary, intellectually precocious youths are known to exhibit a higher incidence of left-handedness and immune disorders [1 2]. In the present study, we believe to have identified an additional correlate of extremely high intellecutal ability: increased RH involvement during cognitive processing.

Acknowledgement—The authors wish to thank Joseph Hellige and Jerre Levy for providing the stimulus materials used in the dichotic listening and the chimeric face tasks, respectively. Also, we should like to acknowledge Edward J. Hoff and Olya Arjmand for their assistance in conducting this study, and to express our appreciation to Robert Benbow, Veronica Dark, Karl Pribram, Tony Wong, and an anoymous reviewer for helpful comments made on an earlier version of this manuscript.

REFERENCES

1. BENBOW, C. P. Physiological correlates of extreme intellectual precocity. *Neuropsychologia* **24,** 719 725, 1986.
2. BENBOW, C. P. Sex differences in mathematical reasoning ability in intellectually talented preadolescents: their nature, effects, and possible causes. *Behav. Brain Sci.* **11,** 169 232, 1988.
3. BENBOW, C. P. and BENBOW, R. M. Extreme mathematical talent: hormonal induced ability? In *Duality and Unity of the Brain*, D. OTTOSON (Editor), pp. 147–157. MacMillan, New York, 1987.
4. BENBOW, C. P. and STANLEY, J. C. Sex differences in mathematical ability: fact or artifact? *Science* **210,** 1262 1264, 1980.
5. BENBOW, C. P. and STANLEY, J. C. Sex differences in mathematical reasoning ability: more facts. *Science* **222,** 1029 1031, 1983.
6. BRADSHAW, J. L. and NETTLETON, N. C. *Human Cerebral Asymmetry*. Prentice Hall, Englewood Cliffs, New Jersey, 1983.
7. CAMEL, J. E., WITHERS, G. S. and GREENOUGH, W. T. Persistence of visual cortex dendritic alterations induced by postweaning exposure to a "superenriched" environment in rats. *Behav. Neurosci.* **100,** 810 813, 1986.

8. DUCAN, D. B. Multiple range and multiple *F*-tests. *Biometrics* **11**, 1–42, 1955.
9. GESCHWIND, N. and BEHAN, P. Left-handedness: association with immune disease, migraine, and developmental learning disorder. *Proc. Natn. Acad. Sci. (U.S.A.)* **79**, 5097–5100, 1982.
10. HELLIGE, J. B. *Cerebral Hemisphere Asymmetry: Methods, Issuses and Application*. Praeger Press, New York, 1983.
11. HELLIGE, J. B. and WONG, T. M. Hemisphere-specific interference in dichotic listening: task variables and individual differences. *J. exp. Psychol. Gen.* **112**, 218–239.
12. HELLIGE, J. B., BLOCH, M. and TAYLOR, A. T. Multi-task investigation of individual differences in hemispheric asymmetry. *J. exp. Psychol. Hum. Percept. Perform.* **14**, 176–187, 1988.
13. KROLL, N. E. and MADDEN, D. J. Verbal and pictorial processing by hemisphere as a function of the subject's verbal scholastic aptitude score. In *Attention and Performance VII*, R. REGUIN (Editor), p. 375–390. John Wiley, New York, 1978.
14. LEVINE, S. C. and LEVY, J. Perceptual asymmetry for chimeric faces across the life span. *Brain Cognit.* **5**, 291–306, 1986.
15. LEVY, J., HELLER, W., BANICH, M. and BURTON, L. Asymmetry of perception in free-viewing of chimeric faces. *Brain Cognit.* **2**, 404–419, 1983.
16. LEVY, J., HELLER, W., BANICH, M. and BURTON, L. Are variations among right-handed individuals in perceptual asymmetries caused by characteristic arousal differences between the hemsipheres. *J. exp. Psychol. Hum. Percept. Perform.* **9**, 329–359, 1983.
17. O'BOYLE, M. W. Hemispheric laterality as a basis of learning: What we know and don't know. In *Cognitive Classroom Learning: Understanding, Thinking, and Problem solving*, G. PHYE and T. ANDRE (Editors), p. 21–48. Academic Press, New York, 1986.
18. O'BOYLE, M. W. and HELLIGE, J. B. Cerebral hemisphere asymmetry and individual differences in cognition. *Learning and Individual Differences* **1**, 7–35, 1989.
19. O'BOYLE, M. W. and HOFF, E. J. Gender and handedness differences in mirror tracing random forms. *Neuropsychologia* **25**, 977–982, 1987.
20. OLDFIELD, R. C. The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia* **9**, 97–113, 1973.
21. SACKHEIM, A and GUR, R. C. Lateral asymmetry in the intensity of emotional expression. *Neuropsychologia* **16**, 473–481, 1978.
22. SACKHEIM, A., GUR, R. C. and SAUCY, M. Emotions are expressed more intensively on the left side of the face. *Science* **202**, 434–436. 1978.
23. PERECMAN, E. *Cognitive Processing in the Right Hemisphere*. Academic Press, New York, 1983.
24. YOUNG, A. *Functions of the Right Hemisphere*. Academic Press, London, 1983.