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Enhanced Right Hemisphere Activation in the Mathematically Precocious: A Preliminary EEG Investigation

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A preliminary electroencephalographic (EEG) investigation was conducted to determine if the pattern of hemispheric activation in mathematically precocious youth differs from that of average math ability subjects. Alpha activity at four brain sites (frontal, temporal, parietal, and occipital lobes) over the left and right cerebral hemispheres (LH/RH) was monitored while 12- to 14-year-old, right-handed males: (a) looked at a blank slide (baseline condition), (b) judged which of two chimeric faces was "happier," and (c) determined if a word was a noun or a verb. At baseline, the LH of the precocious group was found to be more active at all four brain sites relative to that of the average ability group. During chimeric face processing, the gifted subjects exhibited a significant reduction in alpha power over the RH, primarily at the temporal lobe, while no such alpha suppression was observed in the average ability subjects. For noun/verb determinations, no significant alpha power reductions were obtained for either group. These electrophysiological data generally corroborate the behavioral findings of O'Boyle and Benbow (1990a) and support their contention that enhanced RH involvement during cognitive processing may be a correlate of mathematical precocity. Moreover, the pattern of activation observed across tasks suggests that the ability to effectively coordinate LH and RH processing resources at an early age may be linked to intellectual giftedness.

Recent reviews on the relationship between patterns of hemispheric specialization and cognitive functioning have established that there are large individual differences among human beings in their information processing abilities and propensities (Hellige, 1990; O'Boyle & Hellige, 1989). Moreover, it has been suggested that the degree and/or the di-

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rection of hemispheric dominance patterns may relate to individual differences in intellectual ability (Benbow, 1986; Hellige, 1990; Lewis & Harris, 1988, 1990; O'Boyle, & Benbow, 1990b; O'Boyle & Hellige, 1989). For example, some early empirical studies found a small but reliable deficit for left-handers on tests of spatial ability (Levy, 1969; Miller, 1971; Nebes, 1971). The proposed hemispheric explanation for this effect was that the bilateral development of the language faculties thought to characterize left-handers encroached upon the neural space allotted for the development of the spatial faculties in the RH, leading to a decrement in spatial abilities (Levy, 1969; Harshman & Hampson, 1987; Harshman, Hampson & Berenbaum, 1983). Notably, however, several failures in replicating these results (Hardyck, 1977a,b, Hardyck & Petrinovich, 1977; Hardyck, Petrinovich, & Goldman, 1976) have brought the notion of intellectual deficits in left-handers into question. Nonetheless, a reliable relationship between handedness and ability may exist, but it appears to be a more complex issue than originally anticipated (Lewis & Harris, 1990; O'Boyle & Benbow, 1990b; O'Boyle & Hellige, 1989).

Underlying differences in cerebral organization also have been relied upon to account for reported sex differences in intellectual performance; specifically, that males tend to outperform females on tests of spatial and mathematical ability, while the latter excel on tests of verbal ability, rote memory, and tasks requiring fine-detailed motor skills (Benbow & Stanley, 1980; Halpern, 1986; Kimura & Hampson, in press; Linn & Peterson, 1985; Maccoby & Jacklin, 1974; O'Boyle & Hoff, 1987; Voyer & Bryden, 1990; Watson & Kimura, 1990). One explanation offered for these gender-related differences is similar to that proposed for spatial deficits in left-handers, with females having a more diffuse or bilateral representation of cognitive functions compared to the highly lateralized hemispheric organization characterizing males (Hassler, 1990; McGlone, 1978; 1980; Ray, Morell, Frediani, & Tucker, 1976; Semmes, 1968). An additional factor, which may influence such gender-related ability levels, is a proposed sex difference in anterior/posterior organization for various cognitive functions; specifically, females exhibiting a frontal–temporal organizational bias, and males demonstrating a propensity for temporal–parietal localization patterns (Kimura & Hampson, in press).

Another manifestation of the relationship between patterns of brain organization and individual differences in cognitive ability can be found in the case of dyslexia, a connection proposed as early as the 1930's by Orton (1937). He believed that dyslexia was related to symmetrical (as opposed to asymmetrical, LH dominant) hemispheric organization. As support for this hypothesis, Orton relied upon clinical observations that the incidences of ambiguous hand/eye preference and stuttering, which he considered to be signs of enhanced RH development, were unusually high in the reading disabled. Although the notion of dyslexia as a byproduct of bilateral brain organization has fallen into disfavor (see Moscovitch, 1987; Springer & Deutsch, 1989), such theorizing did set the stage for further work investigating the relationship between reading disability and patterns of hemispheric lateralization. It is now believed that dyslexia stems from a breakdown of the language functions, which, just as in good readers, are localized primarily to the LH (Levy, 1985; Moscovitch, 1987, O'Boyle & Hellige, 1989). Problems with interhemispheric transfer of information are also thought to contribute to this deficit in reading ability (Badian & Wolff, 1977; Gladstone & Best, 1985). Moreover, recent theorizing by Semrud-Clikeman and Hynd (1990) suggests that some nonverbal forms of learning disability (e.g., difficulties with social skills, prosody, spatial orientation, problem solving, and the recognition of nonverbal cues) may emanate from primarily RH dysfunction.

A rather recent addition to the brain/individual differences literature concerns the relationship between underlying patterns of hemispheric asymmetry and intellectual giftedness. Geschwind and his colleagues (Geshwind & Behan, 1982; Geschwind & Galaburda, 1984, 1987) have hypothesized that prenatal exposure to high levels of the predominantly male hormone testosterone may influence underlying brain organization by enhancing the development of the RH relative to that of the LH. Guided by such theorizing, Benbow (1986) discovered several physiological characteristics of the intellectually gifted that may be anatomical markers of enhanced RH development. Specifically, she found an overabundance of males compared to females in her gifted group, as well as an unusually high incidence of left-handedness and immune disorders, each of which may be considered neurological by-products of advantaged RH development, perhaps induced by prenatal testosterone (Geschwind & Behan, 1982; Geschwind & Galaburda, 1984, 1987).

O'Boyle and Benbow (1990a) have further investigated this latter issue by advancing the hypothesis that the RH of gifted individuals plays an uncharacteristically prominent role during cognitive processing. Support for this claim rests on the findings of two experiments in which intellectually gifted and average ability subjects (12–14 years old) performed a verbal dichotic listening task (Hellige & Wong, 1983) and a free-vision chimeric face task (Levy, Heller, Banich & Burton, 1983a,b). O'Boyle and Benbow (1990a) found the prototypical hemispheric processing asymmetries associated with each of the above tasks for subjects of average intellectual ability. Specifically, in dichotic listening for syllables, a right ear/LH advantage was observed; for chimeric faces, a significant leftward/RH bias was obtained (i.e., choosing the leftside smile/rightside neutral composites as "happier"). The latter pattern is thought to be related to the enhanced role of the RH in the processing of facial affect (Sackheim & Gur, 1978; Sackheim, Gur, & Saucy, 1978). In contrast, subjects of extreme intellectual giftedness (i.e., the top 1/2% of intellectual ability as measured by the Scholastic Aptitude Test) exhibited a somewhat different pattern of hemispheric organization. In the dichotic listening task, gifted subjects failed to show the usual LH advantage. In fact, their RH was equally effective as their LH in the processing of these linguistic stimuli. In the free-vision chimeric face task, the gifted subjects also exhibited a leftward/RH bias. As anticipated by the active involvement of their RH during dichotic listening, however, this bias was significantly greater than that found in the average ability group. Interestingly, degree of RH involvement was correlated with intellectual ability—the greater the RH bias, the higher the score on the SAT.

The O'Boyle and Benbow (1990a) results suggest that the RH of the intellectually precocious may be particularly engaged during cognitive processing. To lend credence to this somewhat controversial hypothesis, it seems necessary to demonstrate at the physiological level that there is also evidence for enhanced RH activation in the gifted. The purpose of the present investigation is to use the electroencephalogram (EEG) to provide such empirical support. Other studies have utilized this ongoing brain wave measure in an attempt to verify relationships between hemisphere-specific functioning and various intellectual abilities, including IQ (Ellingson, 1966; Ellingson & Lathrop, 1973; Gaser, von Lucadou-Muller, Verleger, & Bacher, 1983; Giannitrapani, 1985; Vogel & Broverman, 1964, 1966), spatial ability (Ray, Newcombe, Semon & Cole, 1981), and reading comprehension (Roberts & Harter Kraft, 1989).

In the present study, mathematically precocious and average math ability subjects were asked to: (a) gaze at a blank slide, (b) judge which of two chimeric faces appears happier, and (c) determine if a word is a noun or verb. During each of these conditions, EEG activity was monitored at four brain sites (frontal, temporal, parietal, and occipital lobes) over the RH and the LH. In light of previous research relating patterns of hemispheric specialization and intellectual functioning as described above, the following predictions were made:

(1) Guided by the previous work of Benbow (1986) relating intellectual giftedness to soft neurological signs of enhanced RH development, it was anticipated that, even at baseline, the characteristic activation level of the RH would be higher in the precocious than in the average math ability subjects (O'Boyle & Benbow, 1990a). Hence, lower RH (compared to LH) alpha power should be observed for the gifted group in light of the fact that the alpha frequency is considered a reliable index of "resting" compared to "engaged" hemispheric activity (Butler, 1988; Galin & Ornstein, 1972; Gevins, 1985). This finding would be in keeping with the hypothesis that an unusually active RH may be a physiological correlate of intellecutal precocity.

(2) For the chimeric face task two predictions were made—one behavioral and the other electrophysiological. At the behavioral level, both

gifted and average ability subjects should show a leftward/RH bias; that is, a tendency to choose the leftside smile/rightside neutral face composites as being "happier" (Levy et al., 1983a,b). Yet, given the hypothesis of enhanced processing involvement of the RH in the mathematically gifted, this leftward/RH bias should be significantly larger in the precocious than in the average math ability group. Such a finding would replicate the previous work of O'Boyle and Benbow (1990a, Experiment 2). Correspondingly, at the electrophysiological level, both groups should show a marked reduction in RH alpha power during performance of the chimeric face task. In keeping with earlier theorizing, however, the observed RH alpha suppression should be significantly greater in the precocious group.

(3) For the word condition, both gifted and average math ability subjects are expected to show a LH reduction in alpha power given that noun/verb determinations of this sort are mediated primarily by language faculties localized to the LH. In keeping with earlier logic, however, this LH alpha suppression should be less pronounced (perhaps bilateral) in the math talented, as both their LH and RH may be expected to share responsibility for the processing of linguistic information (O'Boyle & Benbow, 1990a; Experiment 1).

METHOD

Subjects. The gifted group consisted of six mathematically precocious males selected from the Challenges for Youth–Talented and Gifted (CY-TAG) program at Iowa State University. These CY-TAG subjects were all right-handed as assessed by a 10-item questionnaire, designed to determine the hand used when performing the following tasks: "writing," "drawing," "throwing," "using a tooth brush," "using a scissors," "using a knife without a fork," "using a spoon," "the upper hand on a broom," "striking a match," and "opening a lid on a box." All six of the gifted subjects responded "usually right" or "always right" to at least 9 of the 10 tasks. Members of the gifted group had completed the 7th or 8th grade (mean age 13.2 years) and represented the top 1/4% in mathematical ability as measured by the SAT-Math exam. The mean 7th-grade SAT-Math score for the gifted group was 670, ranging in value from 550 to 800 (scale = 200 minimum, 800 maximum). The control group comprised eight right-handed males who also responded "usually right" or "always right" to a minimum 9 of 10 items on the handedness questionnaire. Each member of the average math ability group had completed the 7th or 8th grade (mean age 12.9 years) and, by definition, were *unable* to successfully negotiate the SAT-Math exam at their current level of intellectual development. Individuals in both groups were screened for neurological damage and/or neuropsychological disorder through verbal inquiry (e.g., "Have you ever been knocked unconscious?" "Have you ever been diagnosed as having a mental disorder?"). Subjects were also asked about current or recent medication use (e.g., "Are you now or have you recently taken any prescription medicines?"). One gifted and three average ability subjects were excluded from the study on the basis of this preliminary screening procedure. All subjects were paid $5.00 for their participation.

EEG methodology. Brain wave activity was recorded using a Grass Model 6 polygraph and an ECI Electro-Cap (Blom & Anneveldt, 1982; Polich & Lawson, 1985). Using the Jasper (1958) Ten–Twenty Electrode Placement System of the International Federation, EEG activity (1–35 Hz) was monitored over the left and right frontal (F1, F2), temporal (T3, T4), parietal (P3, P4), and occipital (O1, O2) lobes. All leads were referenced to linked ear lobes (A1 and A2), and electrode impedance was maintained below 10 kohms. Each of the eight channels of the polygraph were calibrated to a standard of 50 μV. One hundred samples per second were taken for each 2-sec recording epoch, and all of the EEG data were digitized and recorded on-line using a Zenith 286 PC and UnkelScope Level 2+ Software.[2] By employing a narrow bandpass filter, alpha wave (8–12 Hz) activity was extracted and a spectral power average was obtained for each recording site. Subjects were tested in a sound and light attenuated room.

Stimulus materials. The 20 pairs of human chimeric faces previously employed by O'Boyle and Benbow (1990a), but originally developed by Levy and her colleagues (Levy et al., 1983a), served as the face stimuli. Each chimera consisted of two joined half-faces, either a leftside smile and rightside neutral composite or a rightside smile and a leftside neutral composite. In the free-vision face task, each chimera was paired with its mirror image: once with the normal print at the top of a visual display and its mirror image below and once with the positions reversed. All face stimuli were presented using a Kodak Ektagraphic projector and viewed at an average distance of 1.5 m. Each chimeric face was approximately 50 cm square. The word stimuli consisted of 10 nouns (e.g., "array," "gratitude") and 10 verbs (e.g., "think," "improvise"). The relative frequency of the stimulus words was 49.4 per million (Thorndike & Lorge, 1944), and average word length was 6.9 letters. The mean imagery rating of the 10 nouns was 3.21 on a scale of 1 = low to 7 = high imagery (Paivio, Yuille, & Madigan, 1968). Each word was printed in black capital letters, presented in the middle of the visual display, and viewed under the identical conditions as the face stimuli.

Design. All subjects received three blocks of trials, one block consisting of 5 baseline slides, one block of 20 faces, and one block of 20 words, for a total of 45 trials. For the six gifted subjects, the order of presentation of each block was counterbalanced using a Latin Square procedure. Specifically, two subjects received the baseline trials first, two viewed the face stimuli first, and two had the word stimuli first. For the average ability group, the first six subjects received the same counterbalanced sequence of blocks as the gifted group. For the remaining two control subjects, one had the face stimuli first, while the other began the presentation sequence with the word stimuli. Within a given block, the same random order of slides was used for both gifted and average ability subjects.

Procedure. After EEG preparation was complete, subjects were seated in a reclining chair and given their instructions. On each trial, they were told to close their eyes, at which time a slide was projected onto the viewing screen. The experimenter then requested that they open their eyes and make a decision about the stimulus presented. In the case of the face stimuli, subjects were to judge which of the two faces was happier, top or bottom; In the case of the word stimuli, they were to decide if the word was a noun or a verb. The "eyes open" cue from the experimenter initiated a 2-sec EEG recording epoch. At the end of this recording interval, subjects were asked to voice their decision aloud (i.e., "top" or "bottom," "noun" or "verb"), and their responses were recorded on an answer sheet. In the baseline condition, subjects merely looked at a blank slide.

RESULTS

EEG analysis. During the collection process, all of the digitized EEG data were displayed on a graphics screen in wave form and, on the basis of visual inspection, were edited for obvious eye blink and/or muscle movement. Those trials contaminated with either artifact were excluded

[2] UnkelScope Level 2+ is a data acquisition control and analysis software package developed by Unkel Software Inc. (a trademark of M.I.T.), 62 Bridge Street, Lexington, Massachusettes 02173. Questions concerning the technical specifications of the software's capabilities can be secured from either the second author or by writing UnkelScope, Inc.

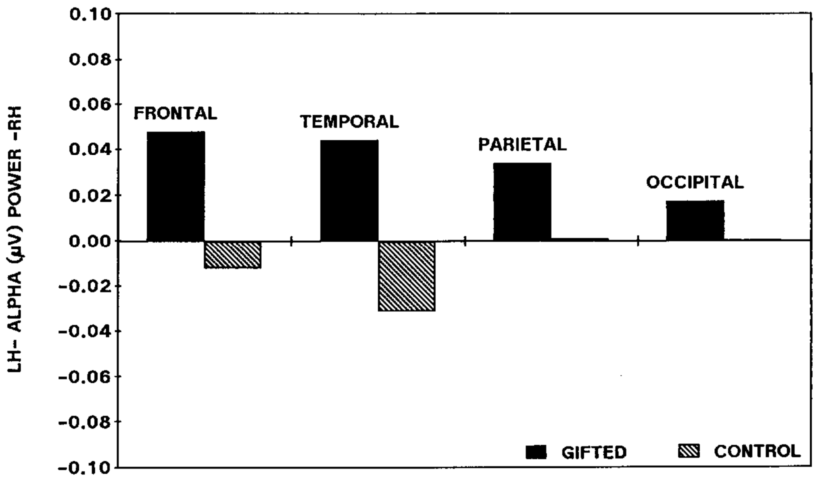

FIG. 1. Baseline alpha power (μV) for math gifted and average ability countrol youths.

from the analyses. Such trials comprised less than 6% of the total and never more than five instances per subject. The remaining raw data (1–35 Hz) were then bandpassed on-line through an 8- to 12-Hz filter, and using the aforementioned UnkelScope Level 2+ software package, spectral power analyses within the alpha frequency range were performed. Subsequently, 24 mean alpha power values (μV) were calculated for each subject. These 24 means were defined by the orthogonal combination of three stimulus types (blanks, faces, words), four recording locations (frontal, temporal, parietal, and occipital), and two hemispheres (right, left).

Baseline data: The data from the control condition were transformed for analysis using a standard asymmetry index of $(R - L)/(R + L)$. Thereby, alpha power at homologous locations over the RH and LH could be compared. Using the transformed alpha power data, a 2 (Group) $\times$ 4 (Location) mixed design analysis of variance (ANOVA) was conducted with Group (gifted/average) serving as a between-subjects factor and Location (frontal, temporal, parietal, occipital) serving as a within-subjects factor. This analysis was performed to determine if at rest enhanced RH activation in the mathematically gifted was in evidence. The results of the ANOVA revealed a significant main effect for Group: $F(1, 12) = 7.84, p < .015$, with no other effects achieving statistical reliability. As can be seen in Fig. 1, in an ostensibly neutral cognitive state, alpha power is significantly *greater* (not lower as predicted) over the RH in the math gifted group, a finding indicative of enhanced activation of their LH at baseline.

Given the preliminary nature of this study, and the fact that symmetric alpha activity at any one of the four cortical locations may have masked

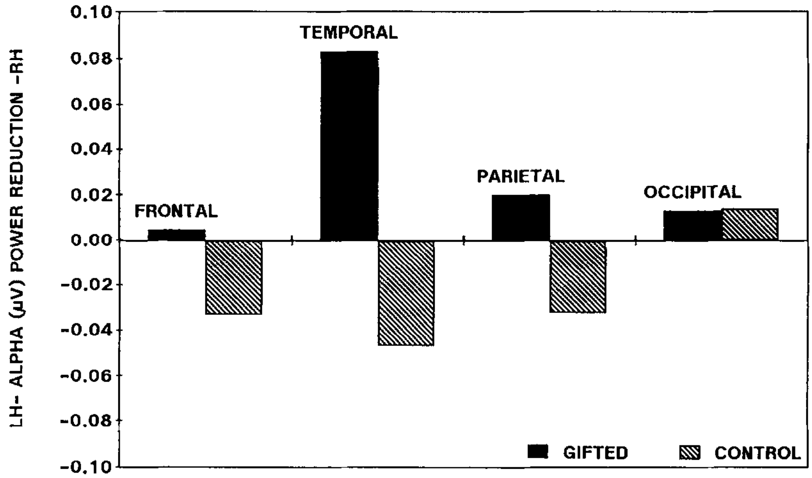

FIG. 2. Alpha power reduction (μV) for math gifted and average ability control youths during the chimeric face task.

meaningful differences in alpha power at the remaining electrodes sites (see Gevins, 1985), four exploratory *T*-Tests were conducted to evaluate differences in alpha power between the two groups at the frontal, temporal, parietal, and occipital lobes. This post-hoc analysis revealed significantly greater activation of the left temporal lobe in the gifted than in the average ability subjects: $t(12) = 2.18$, $p < .047$. None of the remaining comparisons revealed any reliable differences in activation level between the two groups.

The next step in the analysis was to transform the EEG data for the chimeric face and word conditions into values that captured alpha power reductions in reference to the previously established baseline. This was accomplished by employing an asymmetry index developed by Butler (1988). In this calculation the formula utilized was

$$\textit{Asymmetry Index} = (R-L)/(R+L) \text{ Baseline } - (R-L)/(R+L) \text{ task.}$$

In effect, a negative value suggests that alpha power is suppressed to a greater extent over the LH; conversely a positive value suggests greater alpha power reduction over the RH. Using the asymmetry index values as derived above, two separate ANOVAs were performed, one for the chimeric face data and one for the word data.

Chimeric face data. For the face condition, a 2 (Group) × 4 (Location) mixed design ANOVA was conducted. The results of this analysis revealed a significant main effect for Group: $F(1, 12) = 5.02$; $p < .042$. As depicted in Fig. 2, for the mathematically precocious subjects, alpha power was reduced at all four locations over the RH during chimeric face processing.

Neither the main effect for Location nor the two-way interaction was significant. However, the aforementioned exploratory t tests comparing the groups at each of the four electrode sites pinpoint significantly greater alpha suppression at the right temporal lobe for the gifted than for the control subjects: $t(12) = 2.80$, $p < .015$. None of the remaining comparisons revealed significant alpha power reductions between the two groups.

Notably, the EEG data for the chimeric face task are consistent with subjects' behavioral performance. As in Levy et al. (1983a), the behavioral data obtained from the chimeric face task were evaluated by tabulating the number of right-biased and left-biased choices for each subject. A laterality quotient was then computed as $(R - L)/20$, where R is the number of times the rightside smile/leftside neutral composite was chosen, and L is the number of times the leftside smile/rightside neutral combination was selected. The denominator is the total number of trials. In this ratio, a negative score reflects RH involvement in the task, while a positive score indexes LH involvement. Using this calculation, the mathematically talented group showed a strong leftward/RH bias (−.52), while the average ability group showed a slight rightward/LH bias (+.09). The difference between these two laterality indices was significant: $t(12) = -2.56$, $p < .024$. Moreover, for the mathematically precocious group, five of six individuals demonstrated this leftward/RH bias (with the remaining one having an index of .00, indicating no bias); Only two of the eight average ability subjects showed a similar leftward/RH preference, with the remaining six all rightward/LH biased.

Word data: For the word condition, a similar 2 (Group) × 4 (Location) mixed design ANOVA was performed on the alpha power data. The results of this analysis revealed no significant main effects and no reliable interaction. As can be seen in Fig. 3, alpha power reductions are essentially bilateral and roughly equivalent for each group during noun/verb determinations. Exploratory T-Tests comparing activity of gifted and control subjects at each of the four brain locations also failed to reveal any significant differences between the two groups in alpha power suppression.

At the behavioral level, it should be noted that the two groups approached a reliable difference in the accuracy of their noun/verb determinations: $t(12) = 2.10, p < .055$; The math talented subjects were correct on 97% of the word trials, while the average ability subjects were correct 85% of the time.

DISCUSSION

These results, although preliminary in nature, lend support to the contention of Benbow (1986) and O'Boyle and Benbow (1990a) that enhanced RH involvement during cognitive processing may relate to extreme intellectual ability. In the present study, at baseline for the gifted group,

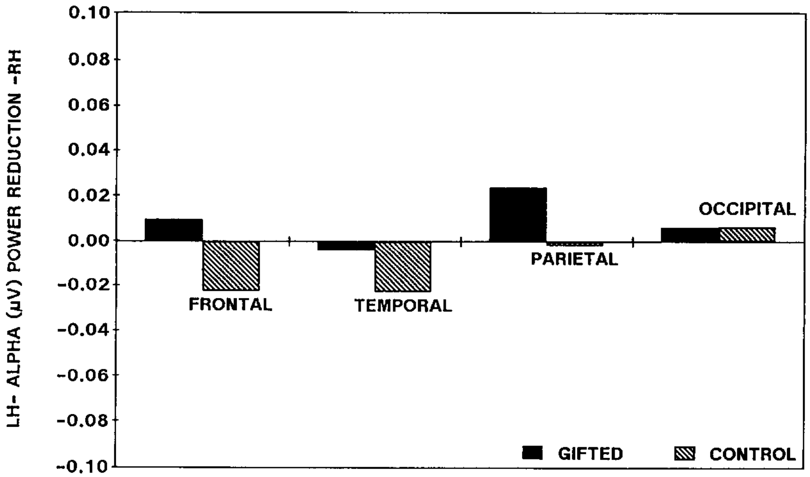

FIG. 3. Alpha power reduction (μV) for gifted and average ability control youths during noun/verb determinations.

significantly greater alpha power was obtained at all four brain sites over the RH, particularly the temporal lobe. This finding is opposite of that predicted and suggests that the LH rather than the RH is more activated in the mathematically talented during this ostensibly neutral cognitive state. Such baseline alpha asymmetry is reminiscent of previous findings suggesting that individuals with high IQ test scores often exhibit heightened LH brain wave activity as measured by the EEG (Kreezer, 1937; Knott, Friedman, & Bardsley, 1942; Mundy-Castle, 1958). It should be mentioned, however, that in at least one case, high IQ individuals have been reported to exhibit larger amplitude visual evoked potentials over the RH than over the LH (Rhodes, Dustman, & Beck, 1969). Interestingly, the average ability subjects might be characterized as having a tendency toward heightened RH or bilateral hemispheric activation at baseline. By way of speculation, it may be that this pattern of alpha asymmetry represents an early, less finely tuned stage of brain organization and activation, a neurological marker which at the electrophysiological level may differentiate the gifted from those of average ability.

The observed right temporal lobe alpha suppression for the math talented during chimeric face processing is a finding that is congruent with existing literature proposing a unique link among the RH, the temporal lobe, and the mediation of facial affect (Beaumont, 1983; Levy, et al., 1983a,b; Sackheim & Gur, 1978; Sackheim et al., 1978). When juxtaposed with the large leftward/RH bias exhibited by these gifted subjects when choosing which of two chimeric faces is happier ($-.52$), a composite pattern of results emerges that provides converging evidence at both the physiological *and* the behavioral levels for enhanced RH activation as a correlate of mathematical precocity.

One aspect of the chimeric face data that merits closer inspection is the fact that both the EEG and the behavioral data are consistent (although nonsignificant) in suggesting some LH mediation of chimeric face processing in the average math ability subjects. These findings were unexpected in light of previous research employing this task (cf. Levine & Levy, 1985; Levy et al., 1983a,b, O'Boyle & Benbow, 1990a, Experiment 2), and the source of this uncharacteristic LH reliance is unclear. Research in our laboratory is underway to determine the reliability of these tenuous findings and to gain further insight into the apparently differential hemispheric processes utilized by gifted compared to average ability subjects when performing the chimeric face task. By way of speculation, it may be that average ability subjects process the chimeric faces analytically, perhaps a single facial feature at a time (primarily, a LH operating mode), while gifted subjects rely on a more holistic form of analysis, perhaps all features simultaneously (primarily, a RH processing style) (Bradshaw & Nettleton, 1981, 1983). Alternatively, the mode of processing may be similar, but the manner in which the faces are represented in memory is different, with the average ability subjects relying on a verbal representation and the math gifted subjects utilizing a more imagery based format (Sergent, 1990).

The word data from the present study are somewhat ambiguous. In hindsight, the task seemed rather trivial, particularly for the gifted group, and may not have been demanding enough (relative to face processing) to produce reliable hemispheric differences in alpha power. In light of this fact, it might have been more appropriate to present subjects with pairs of words (i.e., one "pleasant" and the other "unpleasant"), asking them to determine which of the two conveys the "happier" sentiment (e.g., "vomit" versus "smile"). In this way, the analytic processes utilized in the linguistic task might have more closely matched those relied upon in the chimeric face task, producing a more definitive pattern of results.

Despite its shortcomings, however, one nonsignificant trend in our word data that merits further investigation is the tendency for left frontal and left temporal lobe alpha suppression during noun/verb determinations for average math ability subjects. Should this pattern of LH alpha power reduction be confirmed in future studies, it would provide additional electrophysiological support for LH mediation of linguistic processes at a relatively early age. Interestingly, Roberts and Harter Kraft (1989) have reported similar LH alpha suppression during reading for comprehension in right-handed boys age 6–8 (i.e., individuals younger than our subjects), while finding bilateral alpha power reduction for those age 10–12 (i.e, individuals chronologically more similar to our subjects).

A second, yet contrasting aspect of our word data that also merits further investigation is a nonsignificant trend toward right parietal lobe activation during noun/verb determinations for the mathematically gifted subjects. Should this pattern be verified by continuing research, it would suggest heightened involvement of the RH in the mathematically precocious, even for the processing of linguistic information (cf. O'Boyle & Benbow, 1990a). It should be noted, however, that our present data are insufficient to confirm such theorizing at this time.[3]

Although it appears that enhanced RH activation does indeed relate to intellectual precocity, the origins of this correlate are unknown. It may be that the characteristic is biologically determined, such that gifted individuals have an innate superiority in accessing, coordinating, and implementing the cortical resoures of the RH. The successful orchestration and subsequent utilization of such supplementary processing power might then manifest itself as precocious intellectual ability. Alternatively, it may be that at an early age, gifted individuals have learned (perhaps, through exposure to enriched learning environments) to harness RH capacities and bring them to bear in various intellectual situations. The latter case suggests that individuals of more moderate ability might be taught to tap into such RH capacities and learn to more effectively coordinate the use of these supplementary processing resources, in an effort to enhance their present level of intellectual ability. The above notions, however, are only *speculations* at best. Notably, in either the biological or the environmental case, the impressive shift exhibited by the gifted group, from LH activation at baseline to RH activation during chimeric face processing, suggests that the ability to effectively coordinate LH and RH processing resources at an early age is particularly linked to intellectual giftedness. Such shifting and coordinating of hemispheric capabilities may be related to the enhanced metacognitive knowledge that typifies the mental functioning of gifted children (Sternberg, 1986).

In our opinion, the results of the present preliminary study merit further, more intensive investigation. From a methodological standpoint, in future EEG studies it might prove beneficial to restrict electrode sites to the frontal, temporal, and parietal lobes as they were the cortical regions that seemed to be most actively engaged in our tasks. Also, using a larger number of subjects of each sex and hand preference, as well as individuals from a broader age range, would serve to enhance the validity and re-

[3] One methodological consideration pertaining to the word data relates to the fact that the required noun/verb determinations, because of their relative simplicity, may have occurred very quickly and quite early within the 2-sec EEG recording epoch utilized. Thus, lateral differences in alpha activity for word processing may have been manifest, but were masked by unrelated EEG activity, which followed long after any noun/verb judgments had taken place. We are currently dividing the 2-sec recording epochs into 500-msec segments to evaluate relatively early compared to late stages of such linguistic determinations, which may (or may not) prove to be hemisphere specific.

liability of our initial findings. Moreover, a greater variety of physiological measures (e.g., PET, and rCBF) and a wider range of behavioral tasks, which are designed to breakdown hemispheric contributions of math talent into their elemental cognitive subprocesses, needs to be implemented to strengthen our conclusions. Continuing research conducted in reference to these methodological and conceptual guidelines will likely produce a clearer understanding of the proposed relationship between enhanced RH activation and mathematical precocity.

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