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Developmentally advanced EEG alpha power in gifted male and female adolescents

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Abstract

An electroencephalographic (EEG) study of gifted and average ability male and female adolescents, as well as college students of both sexes, was conducted to investigate further the relative contributions the left and right cerebral hemispheres during an eyes open (baseline) task in all groups. A total of 90 subjects had baseline EEG recorded in three groups with equal numbers of males and females: 30 gifted adolescents, 30 average ability adolescents, and 30 college-age subjects. Overall alpha power (8–12 Hz resting potential) was significantly greater in average ability subjects compared to both college-age and gifted adolescent subjects. Moreover, there were no significant differences in overall alpha power between college-age and gifted adolescent subjects. However, college-age and gifted adolescent subjects had different RH/LH patterns of activation such that at temporal and parietal locations college-age subjects had greater LH alpha power levels whereas gifted adolescents had greater RH alpha power. These findings suggest that gifted adolescents may have a developmentally enhanced state of brain activity, one that more closely resembles that of college-age adults to whom they also resemble in terms of cognitive development.

Keywords: EEG alpha power, advanced; Gifted adolescent

1. Introduction

Recent electrophysiological studies (O'Boyle et al., 1991, 1995) suggest that adolescents of gifted intellectual ability exhibit enhanced right hemisphere (RH) involvement (as compared to those of average ability) during basic information processing. One potential explanation for this finding may be that gifted individuals are characterized by a developmentally advanced state of brain activation and functional organization that is related to their advanced abilities.

It is known that the power of specific EEG bandwidths change during childhood development (Matousek and Peterson, 1973; Matsuura et al., 1985; Thatcher et al., 1987), with the most notable of these being a decrease in alpha power (and thus, this implies increased brain activation) as a child grows older. There appear to be two critical periods in which alpha power decreases occur as a function of age, one at 3–4 years and the other at 10–11 years (Hudspeth and Pribram, 1992). It has been suggested that as a by-product of these periods of alpha power

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decreases, a fundamental reorganization of attentional, executive, and self-reflexive processes follows, thus leading the child into more adult-like levels of brain activity (Case, 1992). It is now well documented that in terms of overall power, adult levels of brain activity across the cortex are typically not reached until 18–21 years – with much of the research focused on frontal lobe development (Matsuura et al., 1985; Buchsbaum et al., 1992; Bell and Fox, 1988). Thus, research has demonstrated that distinct developmental changes occur in the electrophysiological activity of the brain during childhood adolescence, when cognitive abilities are in the process of developing to their eventual adult levels. However, it has not been demonstrated conclusively whether individual differences in cognitive development (e.g. intelligence) are related in some way to changes or differences in electrophysiological activity in the brain.

Classically, the application of the EEG to intellectual functions was pursued with vigor 40–50 years ago (Kreezer, 1937; Knott et al., 1942). The basic findings routinely showed a correlation between EEG and intellectual functioning levels, however these were often correlational studies utilizing IQ scores and a restricted range of subjects. With the advent of power analyses and computerized collection systems, only recently are some of these original intelligence issues being reexamined via the EEG.

In more recent studies the electrophysiological correlates of intelligence have been actively studied in the ERP literature. Studies have indicated that ERP latency and amplitude reflect ability levels on a variety of intellectual tests and functions, including digit span, memory span, and verbal processing (for extensive review see Stelmack et al., 1995). Many of the recent applications have been directed toward learning disabled children with some significant success. Given these success with ERP and the relationship of the ERP to EEG alpha power (Intriligator and Polich, 1995) and recent advances in EEG technology, it seems an appropriate step to revisit the issue of the relationship between EEG and intellectual functioning.

The present investigation was conducted to determine if gifted adolescents (male and female) exhibit a pattern of brain activation that is different from those of average ability youths, and specifically, one that resembles that of college-age adults to whom gifted adolescents also resemble in terms of their level of cognitive abilities. Should this pattern of activation be manifest it would suggest that gifted youths, despite their chronological age, are characterized by a developmentally advanced level of brain electrophysiology, one that may contribute to or be a by-product of their intellectual precocity.

2. Method

2.1. Subjects

A total of 90 subjects participated in the study. The gifted group consisted of 15 males and 15 females (mean age = 13.2 years), the average ability subjects included 15 males and 15 females (mean age = 13.3 years), and the college group was comprised of 15 males and 15 females (mean age = 20.2 years). Members of both the average and gifted groups were in either the 7th or 8th grade (USA); the collegians were primarily university freshmen and sophomores (USA). The gifted group was selected primarily on the basis of their superior SAT-MATH and SAT-VERBAL exam performance. Gifted subjects have a composite SAT score that averages 1100 on a scale from 200 minimum to 1400 maximum), thus representing the top 1/2 of 1 percent in overall performance when adjusted for age (Benbow, 1986). Note that by definition, the average ability 7th or 8th grader is unable to successfully negotiate either of these exams at their current level of intellectual development – when given the exam in past studies it was found that their mean score was 200 (i.e. a floor effect).

Therefore, average ability subjects were drawn from a pool of American junior-high school students, and identified as average ability by their teachers and administrative staff. These students reported that they had never received any advanced or special educational instruction. Gifted subjects were solicited from the Iowa State University program for talented and gifted youths (CY-TAG). Both average ability and gifted subjects received $5.00 for their participation; collegiate subjects were volunteers from an undergraduate psychology subject pool and were participating for extra course credit.

All subjects were screened for neurological damage, neuropsychological disorder, current medication use and hand preference via a brief questionnaire (e.g. which hand do you write with, use a scissors, strike a match, etc.). Participation was restricted to those who were right-handed (at least 9 out of 10 indications of right-hand use on the handedness questionnaire) with no evidence of familial sinistrality. After completing the experiment, subjects were debriefed and offered paper records of their EEG.

2.2. Recording methods

EEG activity was recorded from the left and right frontal (F1, F2), temporal (T7, T8), parietal (P3, P4), and occipital (O1, O2) lobes (Scharbrough et al., 1990) using tin electrodes (Polich and Lawson, 1985). All leads were referenced to linked ear lobes and impedance was maintained below 10 KΩ. Each channel of the polygraph was calibrated to a standard of 50 μV to ensure that all related measures were

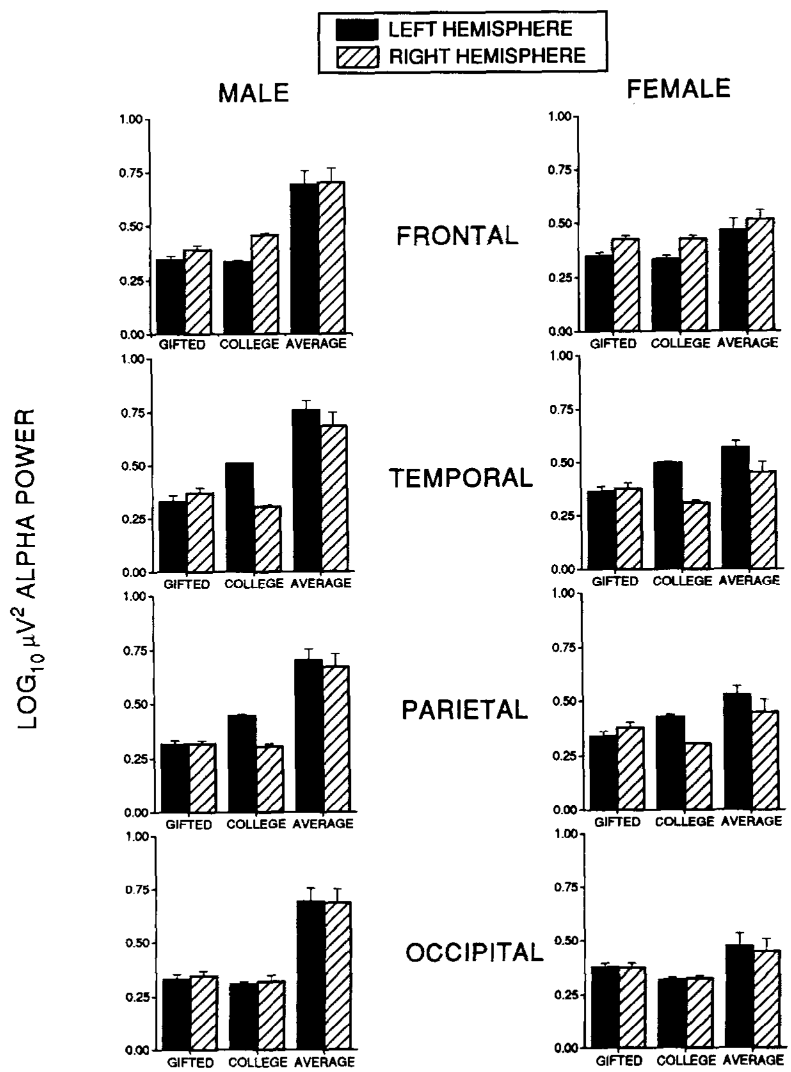

Fig. 1. Mean (+1 SE) alpha power (log μV^2) for male and female subjects as a function of group and hemisphere for each electrode location.

equitable across channels. The EEG was digitized at 100 Hz with a highpass of 0.1 and a low pass of 35 and stored on computer disc. Subjects were tested in a sound and light attenuated chamber. For all subject groups, a minimum of 32 s of artifact free EEG was recorded during which subjects focused their attention on a fixation point in the center of a screen.

3. Results

3.1. EEG data

All analyses of variance employed Geisser–Greenhouse corrections to the degrees of freedom (df) and thereby adjusting for violations of the sphericity assumption inherent in repeated measure designs (see Jennings, 1987). Probability and epsilon values also are reported. During collection of the EEG data, all digitized waveforms were displayed and visually edited for eye blink and/or other muscle movements (> 50 μV). Trials contaminated with either artifact were dropped from the analysis. Spectral power analysis within the alpha frequency range was conducted for each subject. A total of 8 mean power values were computed for each subject as defined by the orthogonal combination of four recording locations (frontal, temporal, parietal, and occipital) and two hemispheres (left and right). The spectral power data (μV^2) were subjected to a $\log_{10}$ transformation prior to all statistical analyses in an effort to normalize the data distributions (Pollock et al., 1990, 1992).

Three separate mixed-design ANOVAs were performed on these data: one comparing gifted and college subjects, a second comparing average ability and college subjects, and a third contrasting average ability and gifted adolescents. These analyses were conducted independently to isolate the pre-existing differences in EEG power between younger and older subjects. The reported significance values are adjusted to reflect the repeated use of the ANOVA statistic.

The mean (log μV^2) power values at each recording location are presented in Fig. 1. Mean (log μV^2) power values as a function of Sex, Hemisphere, and Group are presented in Fig. 2. A post-hoc Newman–Keuls test ($p < 0.05$) was used to evaluated significant effects with df > 2. Complete data sets were available for all 90 subjects.

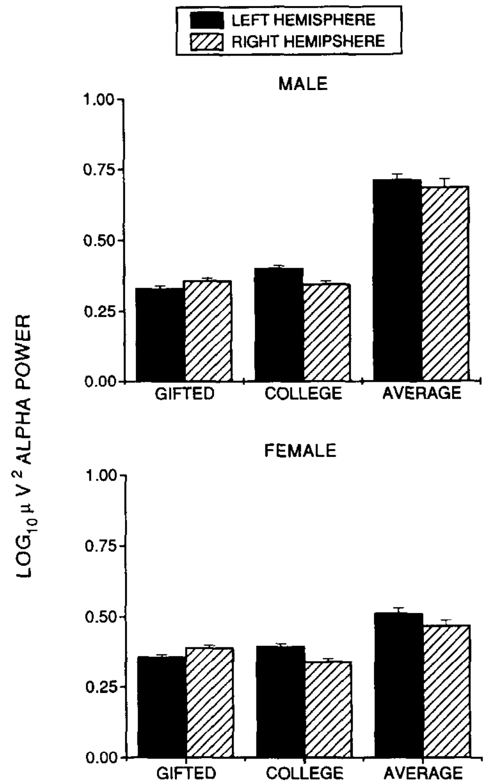

Fig. 2. Mean (+1 SE) alpha power (log μV^2) for male and female subjects as a function of group and hemisphere collapsed across electrode locations.

3.2. Gifted and college subjects

A 2 (Group) × 2 (Sex) × 2 (Hemisphere) × 4 (Location) ANOVA revealed no significant difference in overall alpha power between gifted and college subjects ($p > 0.45$); however, two interactions were obtained. As can be seen in Fig. 1, college and gifted subjects had the same RH alpha power superiority at the frontal location, but at temporal and parietal locations college subject exhibited greater alpha power at LH recording sites (NK < 0.05); this is in contrast to equal RH and LH alpha power (NK < 0.05) evinced by gifted subjects at these locations, Sex × Group $F(3,168) = 16.5$, $p < 0.001$, epsilon = 0.9235. As can be seen in Fig. 2, gifted subjects had greater alpha power over the RH as contrasted with the college sample who showed greater alpha power over the LH, Group × Hemisphere $F(1,56) = 92.9$, $p < 0.001$.

3.3. Average and college subjects

A 2 (Group) × 2 (Sex) × 2 (Hemisphere) × 4 (Location) ANOVA indicated that the average ability group had distinctly greater overall alpha power than did the college group, $F(1,56) = 36.7$, $p < 0.001$. Moreover, a number of interactions were also obtained. Average ability males exhibited greater alpha power across all electrode locations as compared to average ability females and college level subjects of both sexes (NK < 0.05). Additionally, average ability males showed more equivalent power over the right and left sides – primarily at frontal and occipital locations, whereas the other three groups exhibited greater lateralization of RH/LH alpha power, Sex × Group × Hemisphere × Electrode interaction $F(3,168) = 4.3$, $p < 0.01$, epsilon = 0.7058 (NK < 0.05). Notably, the largest difference between LH and RH alpha power in the college group occurred at frontal (RH > LH) temporal (LH > RH), and parietal lobes (LH > RH), Group × Hemisphere × Electrode $F(3,168) = 30.5$, $p < 0.001$, epsilon = 0.7058(NK < 0.05).

3.4. Gifted and average subjects

A 2 (Group) × 2 (Sex) × 2 (Hemisphere) × 4 (Location) ANOVA indicated that gifted subjects had significantly less overall alpha power than the average ability subjects, $F(1,56) = 37.9$, $p > 0.001$. As can be seen in Fig. 1, gifted subjects had greater RH alpha power compared to average subjects who had greater overall LH alpha power, $F(1,56) = 44.7$, $p < 0.001$. Additionally, gifted subjects had marginally greater alpha power at frontal locations (means/SDs: $F = 0.38/0.07$, $T = 0.36/0.09$, $P = 0.34/0.08$, O = 0.36/0.08), whereas average ability subjects had the greatest alpha power at temporal locations (means/SDs: $F = 0.59/0.23$, $T = 0.62/0.21$, $P = 0.59/0.22$, O = 0.58/0.25), $F(3,168) = 3.1$, $p < 0.05$, epsilon = 0.8908 (NK < 0.05).

4. Discussion

The results of the present study pinpoint important similarities and dissimilarities in brain activity between gifted and average ability subjects, as contrasted with a college-age sample. Specifically, gifted adolescents had significantly less overall alpha power than the average ability group, yet the same overall level of alpha power as college-age subjects. Although the overall level of alpha power was similar between both the college and gifted groups, the pattern of activation as a function of electrode site differed between college and gifted groups. This pattern of differences was such that college and gifted subjects had the same RH alpha power superiority at the frontal and occipital locations. However, at temporal and parietal recording sites the college subjects exhibited greater LH alpha power compared to the gifted subjects who evinced greater RH alpha power.

The above pattern of results suggests that gifted subjects may have some form of developmentally advanced levels of alpha activity that resemble adult levels of alpha power. Indeed, developmental studies utilizing EEG have indicated that the main ontogenetic trend of maturation of brain functions is a manifest increase in the specialization of cortical regions and their integration for information processing (Farber and Dubrovinskaya, 1991). Moreover, EEG coherence studies suggest that the formation of interhemispheric interaction continues throughout the period of progressive ontogeny. The most sudden increase in the formation of interhemispheric interaction is said to occur between 2 and 7 years of age, and seems to corresponds to a rapid structural maturation of the corpus callosum (Knyazeva and Farber, 1991). Additionally, the frontal lobes have been identified as a key developmental area of the brain during maturation (Bell and Fox, 1988). Given the results of the present study, gifted subjects may have had an unusually rapid and high level development of such interhemispheric interactions.

Although in most studies alpha power changes are most distinct in posterior regions, both functional and structural changes in the frontal lobes have been the focus of much research in brain maturation studies (Stuss, 1992). This focus is due to the relationship forged between frontal lobe function and higher-order cognitions – such as abstract thought. Both structural and functional changes have been studied with respect to the frontal lobes. Functional changes in EEG power indicate distinct changes occurring as early as the first year of life (Fox et al., 1988; Bell and Fox, 1992). Structural changes in brain maturation have been found to correspond directly to functional changes (e.g. cognitive and verbal functions) as a child develops (Hiraiwa et al., 1988). Moreover, the area where structural and functional development are most closely related are the frontal lobes. In the present study there were no differences in alpha power at the frontal and occipital lobe locations between gifted adolescents and college age subjects suggesting that the two groups have a similar level of brain maturation for these regions. Unexplained is the differences between gifted and college-age subjects at the temporal and parietal recording locations. Although the overall level of alpha power is the same at the temporal and parietal locations there is a lateralization difference such that the alpha power is greater over the LH for college-age subjects and greater over the RH for gifted subjects. This RH inactivity (greater alpha) is in contrast to the previous studies that indicated greater increases of activity (decrease in alpha) at these same locations during cognitive tasks (O'Boyle and Benbow, 1990; O'Boyle et al., 1991, 1995). Perhaps, by way of speculation, in the gifted subject this area of the brain is kept reasonably unencumbered so that when cognitive processing is required there is an area that can be readily called into play.

The origins of these electrophysiological correlates of precocity are likely the result of some combination of both environmental and biological factors. With regard to the biological factors, conditions of prenatal development, such as differential levels of hormone exposure, have been proposed as a biological contributor to intellectual precocity (Benbow and Benbow, 1987; O'Boyle and Benbow, 1990; O'Boyle et al., 1991). This supposition is based on the Geshwind–Behan–Galaburda (GBG) hypothesis that states that prenatal testosterone exposure may influence underlying brain organization (Geschwind and Behan, 1982; Geschwind and Galaburda, 1984, 1987). Interestingly, Benbow (1986) discovered several similar physiological characteristics of the intellectually gifted that may be 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 have been identified as neurological by-products of advanced RH development in the GBG hypothesis.

The results of the present study indicate that gifted adolescents exhibit similarities to college-age subjects in underlying electrophysiology of the brain. Thus, it is not unreasonable to suggest that gifted adolescents may be more physiologically advanced than average ability adolescents in either brain organization, development, or utilization of brain resources. The effect of environmental factors are also undoubtedly necessary for optimal development of any biologically-based predisposition, thus a model that incorporates both factors is needed. Moreover, it remains to be seen whether the adult-like levels of alpha power in the gifted are maintained throughout the remaining years of their development, or evolve to an even higher degree as they enter into adulthood.

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