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EEG in adults with Attention-Deficit/Hyperactivity Disorder

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ABSTRACT

Attention-Deficit/Hyperactivity Disorder (AD/HD) is the most common psychiatric disorder of childhood, but it is becoming increasingly apparent that more than half the childhood sufferers will continue to manifest symptoms of the disorder as adults. While the EEG of children with AD/HD has been extensively examined, comparatively little research has been conducted into the EEG of adults with the disorder. This study thus investigated the EEG of 20 adult males with AD/HD, and an age- and gender-matched control group, during an eyes-closed resting condition. The EEG was Fourier transformed to provide absolute and relative power estimates for the delta, theta, alpha and beta bands. The AD/HD group had significantly less absolute delta and more relative theta, across the entire scalp, than the control group. In absolute beta, the AD/HD group had less power at the midline, and an enhancement in power in the right posterior region. These results are similar to those found in children with AD/HD, and may suggest the presence of a processing deficit. A right posterior elevation in beta activity was also found, which could be related to the ongoing presence of reading disabilities in these subjects.

1. Introduction

Attention-Deficit/Hyperactivity Disorder (AD/HD) is one of the most common psychiatric conditions of childhood, affecting between 4% and 6% of school-age children (Lindgren et al., 1990; Pelham et al., 1992; APA, 1994). However, it is becoming increasingly recognized that while AD/HD might have its origins in childhood, between 40% and 70% of those individuals with childhood AD/HD will continue to suffer the disorder as adults (Bellak and Black, 1992).

The EEG of children with AD/HD has been extensively studied. Those studies typically report that children with the disorder have increased theta activity, which is often maximal in the frontal regions (Satterfield et al., 1972; Janzen et al., 1995; Chabot and Serfontein, 1996; Lazzaro et al., 1998; Clarke et al., 1998, 2001a,c; Barry et al., 2003), increased posterior delta (Matousek et al., 1984; Clarke et al., 1998, 2001a,c) and decreased alpha and beta activity (Dykman et al., 1982; Callaway et al., 1983; Barry et al., 2003), also most apparent in the posterior regions (Clarke et al., 1998, 2001a,c; Lazzaro et al., 1998; Barry et al., 2003).

These EEG abnormalities have been interpreted as representing a number of different dysfunctions. One model in the literature is the maturational-lag model, which proposes that AD/HD results from a developmental lag in CNS functioning. Children with AD/HD are developmentally inappropriate for their age, but act in a way that would be normal in younger children (Kinsbourne, 1973). From an electrophysiological perspective, for this model to be accurate, their EEG measures would need to be considered as normal in younger children.

With normal maturation, EEG frequencies increase as a function of age, with slow wave activity apparently being replaced by faster waveforms (Matousek and Petersen, 1973; Matthis et al., 1980). John et al. (1980) developed 32 linear regression equations predicting the frequency composition of the EEG as a function of age. The results indicated that development of the normal EEG was linear in nature. Benninger et al. (1984), in a longitudinal study of 96 boys and girls, found that theta activity decreased as alpha increased and that the speed of change in occipital areas was almost twice that of central areas. Gasser et al. (1988a) found that certain regions of the brain matured before other regions. Absolute power in delta, theta and alpha 1 frequency bands was found to decrease and amplitudes became similar with age. The decline was found to be greatest in posterior regions. Frontally, delta and theta amplitudes were found to develop in parallel, whereas theta dominated delta in all other areas. Alpha activity showed a strong posterior increase. At frontal and central regions, the increase started later and remained small. All beta activity showed a decline in amplitude with age. Except for alpha 2 activity, all frequency bands and total power showed a continuous decrease in amplitude with age. For relative power, a strong complementary replacement of theta by alpha 2 activity was found up to

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the age of 14. Delta, theta and alpha 1 frequencies decreased with age, and higher frequencies increased. All of these studies found a decrease in relative delta and theta and an increase in relative alpha and beta activity with age, with this change being linear in nature.

Topographic studies of maturation have found changes take place from posterior to anterior regions. Gasser et al. (1988b) found that delta, theta and alpha waves developed earliest occipitally, followed by parietal, central and frontal regions. Beta waves developed earliest in central regions followed by parietal, occipital and then frontal regions. In the central area, the midline was found to have more low frequency activity than the two hemispheres, whereas high frequency activity was found to be more evenly distributed between the two hemispheres and the midline. Following from these results, the increased delta and theta, and decreased alpha and beta activity found in children with AD/HD has been interpreted in some studies as representing a maturational-lag (Satterfield et al., 1972; Matsuura et al., 1993; John et al., 1987; Clarke et al., 1998).

A second model that has attempted to explain the EEG abnormalities in AD/HD is the hypoarousal model. This was initially proposed by Satterfield and Dawson (1971), who investigated skin conductance levels (SCL) in hyperactive children. The experimental hypothesis was that hyperactive children had an overaroused central nervous system, and therefore would have increased SCL. However, what they found was that 50% of their sample actually had decreased SCL, which led them to suggest that hyperactivity was due to underarousal of the central nervous system. This model was then further developed within the EEG literature by Lubar (1991), who proposed that a specific link existed between power in the theta and beta bands, which was the basis for a number of researchers using calculations of the theta/beta ratio, rather than separate frequency bands, to differentiate AD/HD and normal children (Lubar, 1991; Janzen et al., 1995). From the wider EEG literature, it is known that beta activity increases during both physical and mental activity (Andreassi, 2000; Ackerman et al., 1994, 1995), and a number of studies have found that children with AD/HD, compared to control subjects, have lower levels of beta activity during cognitive tasks (Lubar, 1991; Mann et al., 1992). This decrease in beta activity, with the typical increase in theta activity, has been interpreted as representing cortical hypoarousal in children with AD/HD (Lubar, 1991). This model has also received support from regional cerebral blood flow and positron emission tomography studies (Lou et al., 1984, 1989, 1990; Zametkin et al., 1990).

Following form this research, a small group of children with AD/HD have been found to have excess beta activity as the dominant EEG abnormality (Clarke et al., 1998; Chabot and Serfontein, 1996). Following Lubar's (1991) theory of hypoarousal, it was hypothesized that, if reduced beta and increased theta represents underarousal, children with increased beta activity might be hyperaroused.

One problem for both the hypo- and hyper-arousal models has been recent studies of the effect of changed arousal states on the EEG. Recent research has brought into question the role of theta and beta activity as markers of arousal. Several studies have found that alpha activity is primarily involved in changes in arousal, not theta or beta activity. Barry et al. (2003) reported that increases in skin conductance level (historically a marker of arousal) were associated with global reductions in EEG alpha activity in children during an eyes-closed resting condition. Similar results have also been found during a continuous performance task (Barry et al., 2005a), and as the result of caffeine administration (Barry et al., 2005b). This has meant that the formulation of both the hypo- and hyper-arousal models of AD/HD are inaccurate, as beta activity appears to have little association with arousal. This has resulted in researchers revisiting the initial formulation of the hypoarousal model. One of the major components was that beta activity increases during both physical and mental activity (Andreassi, 2000), and as such, it is possible that the beta deficiency, found in children with AD/HD, may represent a processing deficit. However, this model still remains untested.

While the EEG of children with AD/HD has been extensively studied, the EEG of adults with the disorder has been examined in far fewer studies, using a less systematic approach than that of the childhood literature. Bresnahan et al. (1999, 2006), and Bresnahan and Barry (2002) examined the midline EEG of adults with AD/HD, during an eyes-open resting condition. These three studies found that absolute and relative theta activity was elevated in adults with AD/HD, with Bresnahan et al. (2006) also finding that absolute delta was elevated across all sites, and relative delta was reduced at the vertex. No significant differences were found in the alpha band, but the AD/HD subjects had less relative beta than the control subjects. These studies are limited in that data were reported only for the midline. Monastra et al. (2001) found that 15 to 20 year old AD/HD subjects had an increased theta/beta ratio at the vertex, during an eyes-open resting condition, and during silent reading, listening and drawing tasks. Robeva et al. (2004) piloted the use of the Consistency Index to differentiate between adult college students with and without AD/HD. This index provides a measure of the degree of change in the EEG while participants shift from one cognitive task to another. The degree of alpha attenuation was also investigated as a possible marker of AD/HD. These measures achieved 100% accurate classification of AD/HD and control subjects, although the study only used 12 subjects in total. Hermens et al. (2004) investigated sex differences in adults using an eyes-closed resting EEG. Generally, the EEG of adult male patients was more aberrant than that of adult females with AD/HD, with males having greater amplitude in the theta band. In addition to increased theta amplitude, the AD/HD groups were also found to have increased delta and decreased posterior beta amplitude compared to control subjects.

Although these studies report results with a high degree of consistency, it is difficult to integrate these studies with the bulk of the childhood literature, as they have used less common paradigms and quantification procedures. Within the childhood literature, the most common procedure is to calculate absolute and relative power from an EEG that has been recorded during an eyes-closed resting condition. To date this has not been done in an adult population. The major difference between an eyes-open and an eyes-closed resting condition is the effect of alpha desynchronization. This is a change in the dominant frequency of the EEG from alpha activity to beta activity that occurs as a result of a person opening their eyes (Andreassi, 2000). This changes alpha and beta levels, and affects relative power in all bands. An increasing number of clinicians are using qEEG as part of their diagnostic work-up. Most of the data bases used for these tests are based on an eyes-closed resting condition, so it is important that eyes-closed resting EEG data is available for clinical populations in the literature. Hence the aim of this study was to investigate the EEG of adults with AD/HD using an eyes-closed resting condition.

In a companion paper to this study (Clarke et al., 2008), coherence differences between AD/HD and control subjects were investigated. The results indicated that adults with AD/HD had substantially fewer coherence abnormalities than children with the disorder. A laterality effect was found for intrahemispheric coherence at long inter-electrode distances, with the AD/HD group showing reduced hemispheric differences in the delta band compared to the control group. In the alpha band, at short-medium inter-electrode distances, the AD/HD group also had lower coherences than the control group. The results suggest that theta coherence differences reported in children with AD/HD may be associated with hyperactivity, which is reduced in adults with AD/HD, while reduced alpha coherence could be associated with inattention, which remains in adult with AD/HD. Reduced delta coherence also appears to be an aspect of the disorder which may develop from later childhood into adolescence and adulthood. However, coherence is believed to provide information about the degree of structural connectivity underlying the pair of electrodes used to calculate the measure (Shaw, 1981), but does not provide functional information about the brain. For this reason, the present study was conducted using estimates of absolute and relative power.