



## EEG coherence in children with attention-deficit/hyperactivity disorder and comorbid reading disabilities

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### ABSTRACT

This study investigated EEG coherence differences between two groups of children with attention-deficit/hyperactivity disorder Combined type (AD/HD), with or without comorbid Reading Disabilities (RD), and normal control subjects. Each group consisted of 20 children between the ages of 8 and 12 years, and groups were matched on age and gender. EEG was recorded during an eyes-closed resting condition from 21 monopolar derivations. Wave-shape coherence was calculated for 8 intrahemispheric electrode pairs (4 in each hemisphere), and 8 interhemispheric electrode pairs, within each of the delta, theta, alpha and beta bands. In the intrahemispheric comparisons, the AD/HD groups compared to controls showed across-hemisphere reductions in coherences in the delta band at longer inter-electrode distances. Interhemispheric coherences in the frontal areas were elevated in theta and reduced in alpha; in the temporal area, coherences were reduced in alpha. Compared with children with AD/HD without comorbid RD, intrahemispheric coherences at shorter inter-electrode distances in children with comorbid RD were reduced in the left hemisphere for slow wave activity, particularly delta. Across hemispheres, the comorbid group also showed a reduced level of intrahemispheric coherence at longer inter-electrode distances in alpha. There were no interhemispheric differences associated with RD. The present results indicate that children with AD/HD and comorbid RD show deficits additional to those found in AD/HD patients without comorbid RD. These involve reduced lateralisation and impaired coupling of frontal and occipital brain regions in children with comorbid RD. Results confirm and clarify the additivity of brain dysfunctions in children with comorbid AD/HD and RD, previously reported by EEG power studies. Findings suggest that optimal treatment of these children should recognise the need to specifically address the RD, in addition to employing a medication regime focussed on the AD/HD symptoms.

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### 1. Introduction

A review of EEG studies in children with AD/HD (Barry et al., 2003) reported a fairly consistent EEG signature associated with the disorder. Its major characteristics include increased theta activity (Satterfield et al., 1972; Janzen et al., 1995; Clarke et al., 1998, 2001a,b) primarily in the frontal regions (Mann et al., 1992; Chabot and Serfontein, 1996; Lazzaro et al., 1998), increased posterior delta (Matousek et al., 1984; Clarke et al., 1998, 2001b,c), and decreased alpha and beta activity (Dykman et al., 1982; Callaway et al., 1983), also most apparent in the posterior regions (Mann et al., 1992; Clarke et al., 1998, 2001b,c; Lazzaro et al., 1998). While such EEG studies have found consistent differences between children with and without AD/HD, this is often a highly comorbid disorder, being found in conjunction with anxiety and depressive disorders (Cohen et al., 1989; Velez et al., 1989), Conduct Disorder (CD) or Oppositional Defiant

Disorder (ODD) (Jensen et al., 1997), and reading disabilities (RD) (Biederman et al., 1995; Pliszka, 1998). Studies have reported that between 10% and 92% of children with AD/HD have RD (Biederman et al., 1995).

EEG studies of reading-disordered children have usually reported atypical activity—e.g., John et al. (1977) found EEG anomalies in 87% of such children. Increased levels of delta and theta have been reported in parieto-occipital areas (Ahn et al., 1980; Lubar et al., 1985; Chabot et al., 1996), with a predominance in the left hemisphere (Rebert et al., 1978; Duffy et al., 1979; Harmony et al., 1990). These results suggest atypical functioning in the left posterior regions of the brain. Few studies have compared EEG differences in AD/HD children with or without comorbid RD. Ackerman et al. (1994) found that a comorbid group showed less parietal and midline beta activity than an AD/HD-alone group during a reading task, but did not investigate resting EEG differences. Clarke et al. (2002) investigated EEG power topographies in children with AD/HD with/without comorbid RD, and matched controls. There were substantial differences between the AD/HD groups related to the RD diagnosis. The comorbid group had more relative theta, and less relative

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alpha, than the AD/HD-alone group. Regionally, the comorbid group had elevated left posterior absolute delta, elevated right posterior relative delta, reduced left posterior absolute alpha, and reduced left hemisphere relative alpha. These results indicated that EEG correlates of AD/HD were added to by the presence of comorbid RD, and confirmed that the RD comorbidity had a substantial neurological basis, as indicated in the separate RD literature cited above.

Both cognition and behaviour depend on the integration of activity in different brain regions (Luria, 1973), and hence a focus on the coupling between regions should help our understanding of brain function in these clinical groups. EEG power measures alone provide no coupling information, but the *coherence* of the EEG activity between two sites has been shown to provide useful insights into underlying cortical coupling. EEG coherence is equivalent to a correlation in the time domain between two signals in a given frequency band (Shaw, 1981), and has been used to provide insights into brain connectivity in AD/HD (Barry et al., 2002), and to track development and gender differences in normal boys and girls (e.g., Barry et al., 2004), and in children with AD/HD (Barry et al., 2005, 2006). Like any correlation, coherence is independent of the relative magnitudes of the variables being correlated. In particular, coherence between an electrode pair for a particular band is defined as the cross-spectral power between the sites, normalised by dividing by the square root of the product of the power at each site within that band (following John et al., 1987). This means that coherence data is independent of power data, providing another window into brain function.

Our previous studies of coherence in children with AD/HD (e.g., Barry et al., 2002) have reported elevated intrahemispheric coherences at shorter inter-electrode distances in the theta band, and reduced lateral differences in the theta and alpha bands. At longer inter-electrode distances, AD/HD children had lower intrahemispheric alpha coherences than controls. Frontally, AD/HD children had interhemispheric coherences elevated in the delta and theta bands, and reduced in the alpha band. An alpha coherence reduction in temporal regions, and a theta coherence enhancement in central/parietal/occipital regions, were also noted. Coherence anomalies were generally greater in children with AD/HD of the Combined Type compared with the inattentive type. Collectively, these results reinforced and extended the outcomes of previous studies of coherences in AD/HD (e.g., Chabot and Serfontein, 1996; Chabot et al., 1996; Chabot et al., 1999). Clarke et al. (2005) recently reported that methylphenidate did not produce any changes in coherence values in AD/HD children, despite normalisation of power values. While confirming the independence of power and coherence measures of the EEG mentioned above, the lack of sensitivity of coherence measures to methylphenidate suggests that eyes-closed resting EEG coherence measures are associated with structural connectivity of the underlying regions of the brain, rather than the degree of functionality of these regions.

Marosi et al. (1995) examined EEG coherences in 3 groups of children differing on reading-writing ability. Generally, poor performance was associated with higher coherences in the delta, theta and beta bands, and reduced coherences in the alpha band. In older children, these differences were reduced, particularly in the theta, alpha and beta bands. In a follow-up study of these same children over a 2–3 year interval (Marosi et al., 1997), group differences remained, and a general increase in coherence was noted, except in the theta band, with most changes occurring in the alpha band. Chabot's group reported that children with a learning disorder showed frontal increases and parietal decreases in coherence compared with their attention-disordered patients without learning disabilities (Chabot and Serfontein 1996; Chabot et al., 1996, 1999), but provided few details.

Our recent coherence study of children with comorbid AD/HD and Oppositional Defiant Disorder (ODD) (Barry et al., 2007) suggested that children with AD/HD and comorbid ODD have less developmental delay than is apparent in children with AD/HD without comorbid ODD. Such reduced CNS impairment in children with comorbid AD/HD and

ODD requires some additional cause contributing to their inappropriate behavioural profile, and we proposed that behavioural management problems at home and/or school might contribute to that comorbidity. In this context, the aim of the present study was to investigate whether EEG coherence differences could be found between children with AD/HD with comorbid RD, and AD/HD without RD, and to quantify the nature of these differences. Our previous coherence studies of AD/HD children led to the hypotheses that both AD/HD groups, compared to control subjects, would have elevated intrahemispheric coherences at shorter inter-electrode distances, and atypical frontal interhemispheric coherences, in a range of frequency bands. From the literature, we expected some evidence of atypical left posterior functioning in the comorbid group.

## 2. Methods

### 2.1. Subjects

Three age- and gender-matched groups of 20 children (18 male, 2 female; mean age 10.8 years) participated in this study. Parents gave written informed consent for their children to participate in the study, in line with the procedure approved at that time by the University of Wollongong Ethics Committee. All children were between the ages of 8 and 12 years, and right handed and footed. Subjects had a full-scale WISC-III IQ score of 85 or higher. This study used DSM-IV (APA, 1994) criteria for the diagnosis of both clinical groups. The groups used were children diagnosed only with AD/HD of the Combined type (AD/HD-), AD/HD (Combined type) with comorbid Reading Disabilities (AD/HD+), and a control group. Both clinical groups of children were drawn from new patients presenting at a Sydney-based paediatric practice for an assessment for AD/HD, and had not been diagnosed as having AD/HD previously, had no history of medication use for the disorder, and were tested before being prescribed any medication. The control group consisted of children from local schools and community groups. The EEG power data for these groups were reported in Clarke et al. (2002).

Inclusion in the AD/HD groups was based on a clinical assessment by a paediatrician and a psychologist; children were included only when both agreed on the diagnosis. Clinical interviews incorporated information from as many sources as were available. These included a history given by a parent or guardian, school reports for the past 12 months, reports from any other health professional, and behavioural observations during the assessment. The Neale Analysis of Reading was used to provide measures of reading accuracy and comprehension, and the spelling subtest of the Wide Range Achievement Test-R was used to assess spelling ability. Inclusion in the AD/HD- group required children to score in the average range on reading accuracy and comprehension, and have a standard score of at least 90 on the spelling test. Inclusion in the AD/HD+ group required children to score 2 years or more below their chronological age for accuracy and comprehension of reading, and have a standard score of 75 or less for spelling. Children were excluded from the AD/HD groups if they had a history of a problematic prenatal, perinatal or neonatal period, a disorder of consciousness, a head injury resulting in cognitive deficits, a history of central nervous system diseases, convulsions or a history of convulsive disorders, a paroxysmal headache or tics, or an anxiety or depressive disorder.

Inclusion in the control group was based on: an uneventful prenatal, perinatal and neonatal period; no disorders of consciousness, head injury resulting in cognitive deficits, history of central nervous system diseases, convulsions, history of convulsive disorders, paroxysmal headache, enuresis or encopresis after the fourth birthday, tics, stuttering, pavor nocturnus or excessive nail biting, a diagnosable psychiatric condition, conduct disorders such as ODD, CD or delinquency, and no deviation with regard to mental and physical development. Assessment for inclusion as a control was based on a clinical interview with a parent or guardian similar to that of the AD/HD subjects, utilising the same sources of information. Controls were required to score in the average range on the

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