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Dynamic changes in quantitative electroencephalogram during continuous performance test in children with attention-deficit/hyperactivity disorder

Mohammad Ali Nazari [a],*, Fabrice Wallois [b], Ardalan Aarabi [b], Patrick Berquin [c]

[a] *Department of Psychology, University of Tabriz, Tabriz, Iran*
[b] *GRAMFC, EA4293, Research Group on Functional Cerebral Multimodal Analysis, Faculty of Medecine, Amiens, France*
[c] *Department of Paediatric Neurology, Lab. Neurosciences Fonctionnelles & Pathologies (CNRS UMR8160), CHU Amiens, Amiens, France*

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ABSTRACT

To establish whether dynamic EEG changes in children with attention-deficit/hyperactivity disorder (ADHD) differ from those observed in controls, the authors investigated the effect of the continuous performance test (CPT) on delta, theta, alpha and beta frequency bands. High-resolution electroencephalography (EEG) was recorded during eyes-open resting and CPT performance in 16 right-handed children meeting the DSM-IV criteria for ADHD and 16 age-matched controls. Significant CPT vs. eyes-open differences in EEG activities was observed in children with ADHD. In particular, switching to CPT induced an alpha power increase in children with ADHD and an alpha power decrease in controls. This may reflect a primary deficit associated with cortical hypoarousal in ADHD. These EEG results agree with behavioral findings leading the authors to suggest that dynamic changes in neural network activities are impaired in children with ADHD.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is the most common behavioral childhood disorder, affecting approximately 5% of children (American Psychiatric Association, 1994). The disorder comprises a variable cluster of hyperactivity, impulsivity and inattention symptoms which substantially affect the individual's normal cognitive and behavioral functions.

Quantitative electroencephalography (QEEG) techniques can be used to explore various electrical activities of the brain (Arciniegas and Beresford, 2001), particularly local synchronization of neural networks. Synchronization is related to the network's integrative capacities and the nature of its inputs and can be markedly modified by the brain's activity state. Attention impairment can therefore be monitored by QEEG.

Most studies of the electrophysiological correlates of ADHD have compared the QEEG from ADHD sufferers with those of healthy children under resting conditions. A considerable number of these studies have reported an increase in low-frequency power (predominantly in the theta band) and a decrease in high-frequency power (especially the beta1 band) in children with ADHD compared with age-matched controls (for a review, see Barry et al., 2003; for a meta-analysis, see Snyder and Hall, 2006). However, the allocation of neural resources differs when the subject directs his/her attention to an experimentally controlled situation (Thatcher, 1998). It is therefore important to evaluate a neural network's ability to change from a passive to an active condition (during a cognitive task, for example (Petsche et al., 1986)).

A number of researchers (Lubar, 1991; Mann et al., 1992; Janzen et al., 1995; Monastra et al., 1999, 2001; Swartwood et al., 2003) have used EEG to investigate how children with ADHD perform various cognitive tasks (such as reading, listening or drawing). However, none of these tasks take into account inattentiveness and distractibility — the major symptoms of ADHD. Assessment of these symptoms would require tasks specifically designed to highlight attentional deficits, such as the continuous performance task (CPT) or the go/no-go task. Although some QEEG studies have been performed in healthy adults performing a CPT paradigm (Valentino et al., 1993; Arruda et al., 1999; Bearden et al., 2004), only one study has reported QEEG changes during an attentional load task in children with ADHD (El-sayed et al., 2002). These authors observed an altered QEEG activity pattern (higher levels of slow cortical activity and lower levels of fast cortical activity) in ADHD children, especially during the attentional task itself. However, the delta power and theta/beta power ratio were not reported. Given the paucity of data in the literature, it is not known how the various EEG bands change during performance of a CPT. Hence, in the present study, we set out to establish the functional reactivity of frequency-specific EEG activities during eyes-open resting and CPT in children with ADHD.

According to the hypoarousal hypothesis, inattention and hyperactivity in ADHD result from cortical underarousal (Satterfield and

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* Corresponding author at: 29 Bahman St., Department of Psychology, University of Tabriz, Tabriz 5166616471, Iran. Tel./fax: +98 411 3356009.
E-mail address: nazaripsycho@yahoo.com (M.A. Nazari).

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Cantwell, 1974; Barry et al., 2009). This model is supported by the observation of lower skin conductance level (SCL) values in several studies (for a review, see Barry et al., 2003). In this respect, the results of EEG studies have prompted researchers to suggest that an elevated theta/beta power ratio is a marker of hypoarousal in ADHD (Mann et al., 1992; Barry et al., 2009). However, Barry et al. (2009) did not find any correlation between theta/beta power ratio and SCLs in either normal or ADHD children, but did observe that high SCLs were associated with low alpha power in both groups (Barry et al., 2009). An overall enhancement in arousal levels (including higher SCLs) occurred in healthy children during a CPT (Barry et al., 2005a,b). Based on the hypoarousal model of ADHD, it can be hypothesized that children with ADHD have trouble shifting arousal levels from resting conditions to CPT conditions. To be consistent with studies of the EEG–SCL link (Barry et al., 2004, 2005a,b, 2007, 2008, 2009), an increase in alpha activity (rather than theta/beta activity) is expected for the transition from eyes-open resting to a CPT in children with ADHD.

2. Methods

2.1. Participants

Thirty-two right-handed children participated in the study. There were 16 children with ADHD (15 boys; mean ± SD age: 9 ± 1.5) and 16 age-matched healthy children (11 boys; mean ± SD age: 8.7 ± 1.5) (see Table 1). Children with ADHD were all recruited from the pediatric neurology department at Amiens University Hospital. None had ever been treated with methylphenidate. The diagnosis was based on DSM-IV criteria and inclusion was dependent on meeting the full diagnostic criteria for the ADHD combined subtype (APA, 1994). For all participants, the Child Behavior Checklist (CBCL) (Achenbach and Edelbrock, 1983) was completed by the parents and the Swanson, Nolan, and Pelham IV Questionnaire (SNAP-IV) (Swanson et al., 1998) was filled out by parents and teachers. The diagnosis was then established after a semi-structured interview, a clinical neurological examination and a set of ADHD-oriented neuropsychological and behavioral tests (including the ADHD Rating Scale-IV (DuPaul et al., 1998), the full version of the Wechsler Intelligence Scale for Children (WISC-III) (Wechsler, 1991), Conners' Continuous Performance Test (CPT-II) (Conners, 2002), the Attentional Capture Test (ACT) (Deltour et al., 2007) and the Stroop test (Albaret and Migliore, 1999)). These cases were reviewed independently by a pediatric neurologist and a psychologist blinded to each other's findings and were included in the ADHD group only if both clinicians agreed on the diagnosis. Participants were administered a modified A-X version of the CPT while high-resolution EEG was recorded.

Table 1
Demographic characteristics and behavioral results.

	ADHD	Control	Test statistic
GENDER	M = 15, F = 1	M = 11, F = 5	$x^2 = 3.28$ (ns)
AGE	9 (1.5)	8.7 (1.5)	$t = 0.72$ (ns)
SNAP-IV_In	2.26 (0.39)	.52 (0.57)	$t = 10.05$**
SNAP-IV_Hyp	2.15 (0.80)	.47 (0.41)	$t = 7.43$**
IQ_Full	93.6 (9.5)	106.1 (16.1)	$t = 2.63$*
IQ_Per	87.8 (10.4)	104.8 (15.2)	$t = 3.7$**
IQ_Verb	100.1 (11.5)	105.2 (15.1)	$t = 1.06$ (ns)
ACT_RT	455 (106)	439 (109)	$t = 0.69$ (ns)
ACT_Var	158 (62)	114 (38)	$t = 2.22$*
ACT_Error	10 (12)	5 (4)	$U = 68$ (ns)
CPT-II_RT	53.8 (12.5)	51.5 (9.1)	$t = 0.56$ (ns)
CPT-II_Var	55.2 (10.5)	47.8 (11.5)	$t = 1.84$ (ns)
CPT-II_Error	54.9 (8)	43.9 (6.8)	$t = 4.16$*
CPT-AX_RT	497 (86)	503 (125)	$t = 0.15$ (ns)
CPT-AX _Var	193 (89)	148 (65)	$t = 0.11$ (ns)
CPT-AX _Error	18 (3)	11 (9)	$U = 84.5$*

ns = not significant.
** $p<0.01$.
* $p<0.05$.

Control subjects were tested with the WISC-III, CPT-II, attentional capture and CPT-AX during recording of high-resolution EEG. Their parents completed the SNAP-IV and CBCL questionnaires, to ensure the absence of behavioral problems.

All participants had a full-scale IQ score of at least 80 and normal or corrected-to-normal vision. Exclusion criteria for all children included a history of problematic prenatal or neonatal periods, central nervous system diseases, convulsive disorders, EEG spike wave activity, sensorimotor deficits and/or learning difficulties.

The study protocol was approved by the local independent ethics committee. Parents received detailed information about the study protocol before giving their written, informed consent. After being shown the study apparatus, children verbally consented to participation. No monetary compensation was awarded.

2.2. Procedure

Participants were seated in an armchair in a quiet room and were asked to look at a computer screen placed 70 cm away. Sixty-four-channel EEG recording sessions were performed as follows: first session, eyes-closed resting (EC); second session, eyes-open resting (EO1); third session: the A-X version of the CPT; and fourth session: eyes-open resting again (EO2). During the task, the participants were instructed to press a button with their right index finger as soon as the letter “O” (warning) was directly followed by the letter “W” (the “go” condition) but not to press the button if the letter was a “non-W” (the “no-go” condition) (Fallgatter et al., 2004).

Each recording session lasted between 180 and 240 s (except for the CPT, which lasted about 10 min) with a two-minute rest period between conditions.

2.3. Recording methods

A continuous EEG was recorded, using 64 surface electrodes (Easy cap®), Berlin, Germany. The EEG was amplified by A.N.T.®, Enschede, The Netherlands DC-50 Hz filtered and recorded with a right mastoid reference at a sampling rate of 512 Hz. The impedance of electrodes was kept below 10 kΩ. The spatial positions of the 64 electrodes were digitized using a magnetic, three-dimensional position digitizer (the 3Space Fastrak® from Polhemus, Colchester, USA).

2.4. Data processing

Three parameters were used to assess each subject's behavioral performance: (i) reaction times for correct responses; (ii) variability (standard deviation of reaction times) and (iii) the sum of errors, including the number of omission errors (i.e. no response in the “go” condition), the number of commission errors (responses occurring after stimulus presentation other than in the “go” condition) and anticipation errors (responses occurring less than 150 ms after stimulus onset).

Artifact rejection was based on both visual inspection and computerized selection (the amplitude threshold detection algorithm in Eemagine® software, Enschede, The Netherlands). The threshold for electrooculographic rejection was set at 50 μV. An expert also visually appraised each epoch and decided whether or not to accept it. After artifact removal, the EEG signals were analyzed using a common hardware average reference and were then filtered between 0.3 Hz and 30 Hz, 3 dB/octave.

Although the total amount of artifact-free EEG epochs (2.5 s) varied from one participant to another, 36–48 epochs (i.e. 90–120 s of data) were randomly selected for each baseline condition. Forty-eight random epochs were selected for the CPT condition. The EEG epoch