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The QEEG theta/beta ratio in ADHD and normal controls: Sensitivity, specificity, and behavioral correlates

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ABSTRACT

The purpose of the present study was to determine if the theta/beta ratio, and theta and beta separately, correlate with behavioral parameters, and if these measures discriminate between children and adolescents with ADHD and normal gender- and age-matched controls. Sixty-two patients and 39 controls participated in the study. A continuous performance test (CPT), a GO/NOGO test and two rating scales were used to measure behavior in the patient group. EEG spectra were analyzed in eyes-closed and eyes-opened conditions, and in a GO/NOGO task in both groups. Neither the theta/beta ratio at CZ, nor theta and beta separately discriminated significantly between patients and controls. When each person was compared with the database significant elevations of theta were found in 25.8% of the patients and in only one control subject (2.6%). In the ADHD group, theta at CZ was positively correlated with inattention and executive problems and negatively correlated with hyperactivity/impulsivity. Beta correlated with good attention level in the control group, but with ADHD symptoms in the patients. Omission errors in the GO/NOGO test discriminated between patients and controls with an accuracy of 85%. For theta at CZ, the accuracy was 62%. Significantly elevated theta characterized a subgroup of ADHD and correlated with inattention and executive problems.

1. Introduction

Attention Deficit/Hyperactivity Disorder (ADHD) (American Psychiatric Association. Task Force on DSM-IV, 2000) is considered to be a neurodevelopmental disorder, with a prevalence of approximately 3% to 5% in school-aged children (Faraone et al., 2003; Skounti et al., 2007; Polanczyk and Jensen, 2008). It is characterized by age-inappropriate levels of inattention and/or hyperactivity and impulsivity, creating significant impairment in social relations and in school and home environments.

Hyperactivity and inattention in children however, can have multiple etiologies. More objective and brain-based diagnostic procedures, which may contribute to our understanding of the basic mechanisms in ADHD, are needed. Quantitative EEG (QEEG) is a promising approach. QEEG results can also be of help in predicting response to stimulant medication, and in selecting protocols for neurofeedback (Monastra, 2008; Kropotov, 2009).

1.1. EEG findings in ADHD

A number of research studies have found high levels of theta and/or reduced levels of beta to be typical for patients with ADHD (Monastra et al., 1999, 2001; Barry et al., 2003; Chabot et al., 2005; Loo and Barkley, 2005; Snyder and Hall, 2006; Snyder et al., 2006; Quintana et al., 2007; Monastra, 2008; Snyder et al., 2008). Barry et al. (2003) concluded that elevated relative theta power and reduced relative alpha and beta, together with elevated theta/alpha and theta/beta power ratios are most reliably associated with ADHD. They also emphasized the heterogeneity of ADHD and the fact that different EEG profiles may be found.

One study (Chabot et al., 1996) compared 407 children diagnosed with Attention Deficit Disorder (ADD) to children in a normative database. Relative to the healthy database children, ADD patients had an increase in absolute and relative theta, which was primarily found frontally. Another study however, (Diamond, 1997) failed to find any EEG differences between ADHD and control subjects. Clarke et al. (2001) found that children with ADHD had higher absolute and relative theta than controls. This pattern was clearer in the combined type of ADHD than in the inattentive type. Bresnahan and Barry (2002) reported that elevated theta persisted into adolescence and adulthood in patients with ADHD, and that it provided diagnostic

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power for discriminating adults with ADHD from a group of patients referred for possible ADHD who failed to meet diagnostic criteria

In a multi-center study (Monastra et al., 1999), the theta/beta ratio was found to discriminate ADHD patients and normal controls with sensitivity of 86% to 90% and specificity from 94% to 98%. Snyder and Hall (2006) concluded in their meta-analysis that the theta/beta ratio has much higher predictive power than rating scales do, for separating ADHD and clinical controls.

The absolute and relative power of theta is higher in young children than in adolescents and adults (Monastra et al., 2001; Kropotov, 2009). Studies showing high theta/beta ratios and high theta values in ADHD may be seen as reflecting a developmental delay. Therefore, EEG patterns seen in ADHD children should be normal when compared to a younger age group of children, a result that has been found in some studies; yet others report EEG deviances not typical for a younger age group (Chabot et al., 1996; Clarke et al., 2001). Barry et al. (2003) argue, however, that the maturational lag model cannot explain the fact that ADHD is found in adults.

1.1.1. The theta/beta ratio and elevated theta as diagnostic tools in ADHD

The literature related to the theta/beta ratio and elevated theta as diagnostic tools in ADHD is inconclusive. In one study (Rabiner, 2001) the theta/beta ratios of 209 subjects with ADHD were compared with those of a mixed clinical group with oppositional defiant disorder, mood disorder, or anxiety disorder without comorbid ADHD. An increased theta/beta ratio was found in 78% of ADHD subjects, and was not present in 97% of the other subjects. Matsuura et al. (1993) compared a group of 91 ADHD children with normal age-matched controls and children with conduct disorders; excessively slow wave activity was found only in the ADHD group.

In a study of adult patients, it is argued that increased theta is a nonspecific EEG abnormality that can also be found in disorders like epilepsy, substance abuse, dementia, alcoholism, and schizophrenia (Coutin-Churchman et al., 2003). Budzynski (2009) has added a subtype of OCD to this list.

In a pilot and follow-up study (Quintana et al., 2007; Snyder et al., 2008), children referred for possible ADHD were diagnosed with the use of clinical interviews and rating scales. They were also examined with QEEG. A sensitivity of 87%, a specificity of 94%, and an overall accuracy of 89% was reported for the theta/beta ratio. Accuracy was between 47% and 58% for the rating scales.

Coolidge et al. (2007) did not confirm these findings. Parents of 183 children (mean age 12.2 years) referred to an outpatient clinic for evaluation of behavioral and emotional problems completed the Coolidge Personality and Neuropsychology Inventory (CPNI). EEG was recorded for 3 minutes with eyes opened and 3 minutes eyes closed, and analyzed blindly. T-scores for the ADHD subscale of the CPNI and EEG theta/beta categorical classification of ADHD showed no correlation.

In a review of cognitive neuroscience and ADHD (Vaidya and Stollstorff, 2008), symptoms of ADHD were associated with dysfunction in four neural circuits. Johnstone et al. (2005) and Arns et al. (2008) argue that the general population can be separated into nine EEG phenotypes with the same phenotypes found in the ADHD population. Some of these phenotypes ("frontal slow", "slowed alpha peak frequency" and "low voltage EEG") discriminated between ADHD and normal controls, with ADHD patients showing more extreme values. It seems unlikely therefore, that a high theta/beta ratio or elevated theta characterizes all ADHD.

1.1.2. Behavioral correlates

Few published studies have addressed the behavioral correlates of the theta/beta ratio or elevated theta in ADHD. In a study of 24 adults with ADHD and 24 normal controls, a high theta/beta ratio correlated with quick responses to choice stimuli, but the quick-response group evidenced more errors (van Dongen-Boomsma et al., 2010).

In the present study, we hypothesized that elevated theta/beta ratio and theta power, as well as reduced power in the beta band, registered at CZ in eyes open condition, would correlate with behavior ratings related to ADHD. We also hypothesized that the accuracy of these EEG measures in discriminating between ADHD and normal controls would be 80% or better.

2. Methods

2.1. Patients and controls

Sixty-two patients (7 to 16 years) were examined; they had been referred to a neuropsychiatric team that is part of the child and adolescent psychiatry system in the county of Østfold, Norway. The school psychology service and the general practitioner had screened the cases and made a tentative diagnosis of ADHD. The parents gave written consent for their children to participate in our project, which was approved by the Regional Committee for Medical Research Ethics (REK). All diagnoses were according to DSM IV-TR (American Psychiatric Association. Task Force on DSM-IV, 2000) and accepted clinical guidelines (American Academy of Pediatrics, 2011). A senior neuropsychologist (GO) was responsible for diagnostic conclusions after discussions in the team which included a pediatrician and a clinical psychologist. The diagnoses were based on 14 sources of information; the first four enclosed the referrals. 1) medical examination; 2) intelligence testing (WISC III by school psychology, four patients tested by us with the abbreviated form, WASI); 3) ADHD screening; 4) a report from the school psychology service; 5) a thorough anamnesis/medical and developmental history; 6) the clinical interview, Development and Well-Being Assessment (DAWBA) (Goodman et al., 2000), including 7) the screening instrument, Strengths and Difficulties Questionnaire (SDQ) (Goodman and Goodman, 2009); 8) informal interview with children and parents; 9) Conners' Rating Scale Revised (CRS-R) (Conners et al., 1998), long edition, parent form and 10) CRS-R, teacher form; 11) Behavior Rating Inventory of Executive Function (BRIEF), Norwegian translation (Gioia et al., 2000) for parents; 12) BRIEF for teachers; 13) attention testing with the Quantitative Behavior Test (QbTest, www.qbtech.se) carried out by our team when parents were interviewed); and 14) meeting with parents, teachers, and the school psychology service for feedback and discussion. A diagnosis of learning disabilities was based on reports from the school and school psychology service, including formal testing. Diagnosis of emotional and behavioral disorders and Asperger's syndrome built on data from clinical interview, rating scales and meetings with all involved. Patients with IQ and adaptive level below 70 were excluded. None of the patients were on medication when evaluated.

The 39 normal control subjects were Swiss children and adolescents from the Human Brain Index (HBI) database (www.hbimed.com), matched in sex and age with the patients. The database comprised only healthy children with no psychiatric diagnosis, developmental disorders, learning disability, or brain injury. The same equipment and procedures were used for patients and controls when QEEG and ERP were recorded.

Table 1 shows demographic information for patients and controls. Table 2 presents comorbidities in the patient group. The mean IQ of the patients was 91 (SD = 15). The male/female ratio of this group and the pattern and frequency of comorbidities are in accordance with the ADHD literature (Barkley, 2006). As can be seen, the greatest differences between male and female patients were more behavioral problems in males and more anxiety and depression in females.

2.2. Procedures and tasks

Most testing (intelligence, school subjects) was completed before our team met the children. In our first session with the patients some interviewing and attention testing took place while the parents were interviewed and informed about the rating scales to be filled in at home. Within two weeks the children returned to the clinic for QEEG (and event related potentials-ERPs). This session lasted about an hour.

EEG was recorded using a Mitsar 201 (www.mitsar-medical.com), a PC-controlled 19-channel electroencephalographic system. The input signals referenced to the linked ears were filtered between 0.5 and 50 Hz, and digitized at a sampling rate of 250 Hz. Impedance was kept below 5 kOhm for all electrodes. Electrodes were placed according to the International 10–20 system, using an electrode cap with tin electrodes (Electro-cap International Inc.). Quantitative data were obtained using WinEEG software (www.mitsar-medical.com), common reference montage prior to data processing. Eye-blink artifacts were corrected by zeroing the activation curves of individual ICA components corresponding to eye blinks (Vigario, 1997). In addition, epochs of the filtered

Table 1
Demographics of the sample (Mean age 11 (SD = 3); ADHD and controls).

ADHD- I		ADHD-C		Normal controls	
20 (32.3%)		42 (67.7%)		39	
male	female	male	female	male	female
13	7	29	13	24	15

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Table 2
Comorbidities in patient group.

Comorbidity	N	%	Male	Female
No Psychiatric comorbidity	22	35.5%	17 (40.5%)	5 (25%)
Asperger's syndrome	5	8.1%	3 (7.1%)	2 (10%)
Oppositional defiant disorder – Conduct disorder	21	33.9%	16 (38.1%)	5 (25%)
Anxiety /depression	12	19.4%	4 (9.5%)	8 (40%)
Other comorbidity	3	4.8%	2 (4.8%)	1 (5%)
No learning disability	27	45%	19 (45.2%)	8 (40%)
General learning disabilities*	18	30.0%	12 (28.6%)	6 (30%)
Specific learning disabilities**	15	25.0%	11 (26.2%)	4 (20%)

*General learning disabilities: IQ below 80 and significant learning problems in several school subjects, requiring special education. ** "Specific learning disabilities" includes patients with dyslexia and dyscalculia and IQ above 80. Other comorbidity: Tourette's syndrome, reactive attachment disorder, brain abnormality.

electroencephalogram with excessive amplitude (>100 μV) and/or excessively fast (>35 μV in 20 to 35 Hz band) and slow (>50 μV in 0 to 1 Hz band) frequency activities were automatically marked and excluded from further analysis. Finally, EEG was manually inspected to verify artifact removal. The GO/NOGO task (Visual Continuous Performance Test, VCPT) is a modification of the visual two-stimuli GO/NOGO paradigm. Three categories of visual stimuli were selected: 20 pictures of animals, 20 pictures of plants, and 20 pictures of humans (presented with an artificial "novel" sound). The trials consisted of the presentation of pairs of stimuli: animal-animal (GO trials), animal-plant (NOGO trials), plant-plant (IGNORE trials), and plant-human (NOVEL trials). The task was to press a button as fast as possible in response to all GO trials. During the task, subjects were seated in a comfortable chair, 1.5 m in front of a computer screen. The stimuli were presented on a 15-inch monitor using the Psytask (Mitsar Ltd.) software (Mueller et al., 2010). The VCPT, with 400 pairs of pictures, takes 20 minutes to complete. In addition to EEG and ERP recordings, behavioral data are also registered.

2.2.1. Behavioral data recorded in the patient group

Behavioral data from the GO/NOGO task (omission and commission errors, reaction time, and variability of response) were recorded in patients and controls. Raw scores were used in the statistical analysis. Additional quantitative behavioral data were recorded from CRS-R, BRIEF, and Qb test for patient group members:

The Conners' Rating Scales – Revised (CRS-R)(Conners et al., 1998) contains 80 items in the parent form and 59 in the teacher form, resulting in T-scores on 14 subscales of the parent form and 13 on the teacher form. Diagnostic criteria for ADHD are included, in addition to screening of behavioral and emotional problems.

Behavior Rating Inventory of Executive Function (BRIEF) (Gioia and Isquith, 2000) parent and teacher forms contain 86 items. The Global Executive Composite (GEC) is the average of the Behavior Regulation Index (BRI) and the Metacognition Index (MI). The BRI consists of three subscales: Inhibit, Shift, and Emotional Control. The MI comprises five subscales: Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. Results are displayed in T-scores.

Quantitative Behavior Test (QbTest) www.Qbtech.se is a CPT test measuring impulsivity, inattention and activity (a headband and infrared camera recording head movements during the 15-minute test session). We used three global scores: activity, impulsivity, and inattention. The QbTest-Plus (Qb+) with corresponding norms is used for adolescents and adults. The results are displayed in graphics and tables containing Q scores (mean = 0, SD = 1) and percentiles.

2.2.2. EEG data used for analysis

The band ranges for theta and beta were set at 4–8 Hz (theta) and 13–21 Hz (beta) registered at CZ, in the eyes-opened (EO) condition, in accordance with the literature (Monastra et al., 1999). We used absolute power of these measures in the statistical analysis; with age as covariate (ANCOVA and partial correlations).

In addition to comparing patients and controls on theta/beta ratio, theta and beta, at CZ, EO condition, and behavior measures from the GO/NOGO task, patients and controls were *individually* compared with the HBI database. Significant deviances of absolute and relative power in the theta band, centrally and frontally, were recorded. For a person to be judged as deviant, the statistical deviance had to be seen in at least two of the three conditions: eyes closed (EC), EO, or GO/NOGO task. The pattern had to be confirmed in relative power as well. Statistical significance was set at $P<0.01$.

2.2.3. Statistical methods

To compare measures of theta/beta ratios and theta and beta separately in patients and controls, raw scores with age as covariate, (ANCOVA), were used. Effect size was evaluated by eta squared (eta^2) and characterized as small (<0.06), medium (0.06 – 0.14), or large (>0.14), according to guidelines (Cohen, 1988). When correlating EEG measures and behavior, partial correlations were used (controlling for age).

The ROC curve is a statistical validation tool for determining the association between a continuous variable and a binary outcome used to determine the efficacy of logistic regression models in predicting a particular binary outcome. The accuracy of the test depends on its ability to separate the group being tested into those with and without the disease in question. Accuracy is measured by the area under the ROC curve. An area of 1 represents a perfect test; an area of 0.5 represents a worthless test. Using a rough guide for classifying the accuracy of a diagnostic test, 90% – 100% = excellent, 80% – 90% = good, 70% –80% = fair, 60% –70% = poor, and 50% – 60% = failure.

The ROC curve for the ADHD and control classification is shown in Fig. 3. All data were analyzed using the Statistical Package for the Social Sciences (SPSS) volume 15 (www.spss.com). The significance level was set at 0.05.

3. Results

Fig. 1 shows spectra in the EO condition at FZ, CZ, and PZ split into age groups; child patients and controls (7 to 11 years) and adolescent patients and controls (12 to 16 years). (Data from FZ and PZ were not used in statistical analysis in this study). Fig. 2 shows maps of the theta/beta ratio for the same groups.

How well the theta/beta ratio, theta and beta, (absolute power, EO condition) at CZ and omission errors from the GO/NOGO task discriminate patients and controls is shown in Table 3. As can be seen in the table, none of the EEG measures reached statistical significance in separating patients from controls, even when split into young and older age groups. Omission errors separated patients and controls

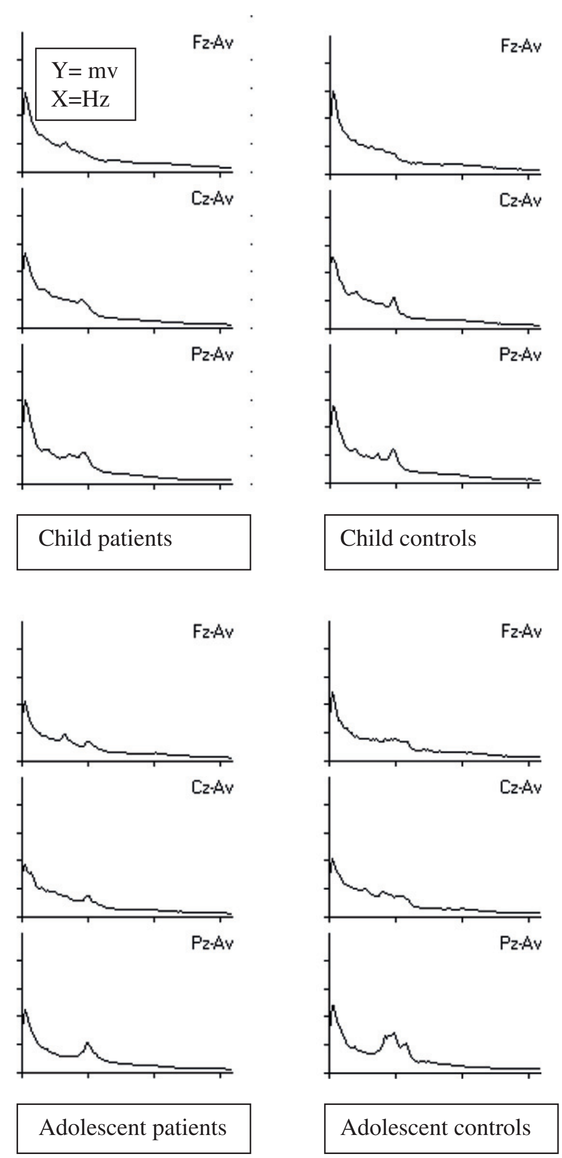

Fig. 1. Spectra at FZ, CZ and PZ in child patients, child controls, adolescent patients, and adolescent controls. X-axis is frequency (Hz), and Y-axis is power (mv).

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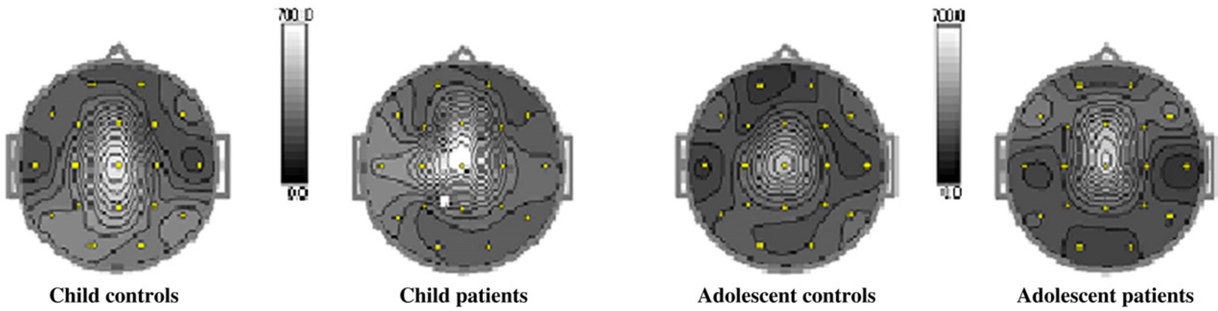

Fig. 2. Maps of the theta/beta ratio in patients and controls split into age groups. The ratio is highest among the child patients and lowest among adolescent controls.

with a large effect size (eta² >0.14). A comparison of the two subtypes of ADHD showed no significant differences.

We also analyzed the data for age effects. In the patient group the theta/beta ratio and theta were significantly higher in the younger group. Beta and omission errors did not discriminate between young and older patients. In the controls theta was significantly higher in the young group; they also had significantly more omission errors.

The ROC curve (Fig. 3) expresses the relationship between sensitivity and specificity for, the theta/beta ratio, theta at CZ, and omission errors. The diagonal line represents the 0-hypothesis. As can be seen, theta and the theta/beta ratio separated the groups only modestly (63%, 58%), whereas omission errors had a sensitivity and specificity of 85%.

3.1. Excess theta based on comparisons with the HBI database

As mentioned, we followed the same objective rules for classifying patients and controls as normal or statistically deviant with regard to theta excess. Choosing a strict significance level of 0.01, we found that only one of the controls (2.6%) and 16 patients (25.8%) were deviant.

Table 3
Part 1: Comparing means for theta/beta ratio, theta at CZ, beta at CZ and omission errors in VCPT test; ADHD vs. control group. (ANCOVA).
Part 2: Comparing means for young and older patient groups and young and older control groups (Independent-samples *t*-test).

	Theta/beta	Theta	Beta	Omissions
	M (SD)	M (SD)	M (SD)	M (SD)
Part 1:				
Total ADHD (62)	6.21 (3.5)	10.19 (6.2)	1.87 (1.2)	21.9 (18.6)
vs.				
total control gr. (39)	5.00 (2.8) NS	9.46 (6.0) NS	2.14 (1.5) NS	3.0 (3.8) sig.<0.001*** F = 37.95 eta² = 0.28 (large)
Young ADHD (40)	7.08 (0.6)	12.08 (6.3)	2.08 (1.4)	24.2 (18.6)
vs.				
young control gr. (16)	5.64 (0.9) NS	11.79 (4.7) NS	2.38 (1.1) NS	5.2 (4.6) sig. = 0.001*** F = 13.59 eta² = 0.20 (large)
Older ADHD (22)	4.73 (2.6)	6.77 (4.3)	1.49 (0.5)	17.7 (18.1)
vs.				
older control gr. (23)	4.45 (2.3) NS	7.83 (6.3) NS	1.96 (1.7) NS	1.5 (2.1) sig.<0.001*** F = 19.02 eta² = 0.31 (large)
ADHD-C (42)	6.52 (0.5)	11.26 (6.5)	1.83 (1.0)	24.0 (19.5)
vs.				
ADHD-I (20)	5.28 (0.7) NS	7.95 (4.9) NS	1.97 (1.6) NS	17.5 (15.8) NS
Part 2:				
Young ADHD (40)	7.02 (3.7)	12.08 (6.3)	2.08 (1.4)	24.2 (18.6)
vs.				
older ADHD (22)	4.73 (2.6) sig. = 0.012* t = 2.57 (df = 60) eta² = 0.06 moderate	6.76 (4.2) sig. = 0.001*** t = 3.53 (df = 60) eta² = 0.11 moderate	1.49 (0.5) sig. = 0.070 NS	17.7 (18.1) sig.: = 0.191 NS
Young control gr. (16)	5.79 (3.3)	11.79 (4.7)	2.38 (1.1)	5.19 (4.6)
vs.				
older control gr. (23)	4.15 (2.3) sig. = 0.141 NS	7.83 (6.3) sig. = 0.039* t = 2.14 (df = 37) eta² = 0.04 small	1.96 (1.7) sig. = 0.391 NS	1.48 (2.1) sig. = 0.007** t = 3.44 (df = 37) eta²: 0.11 moderate

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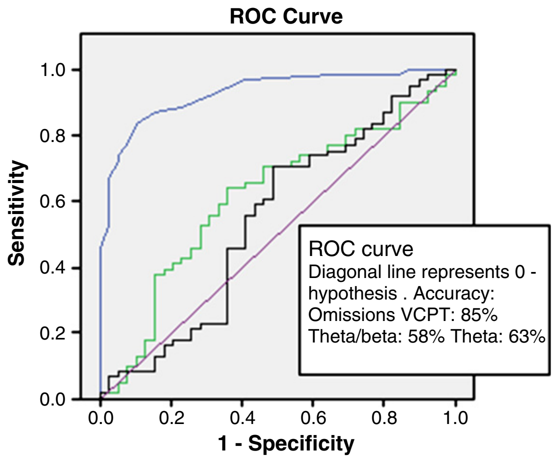

Fig. 3. ROC curve showing accuracy of omission errors, the theta/beta ratio and theta at CZ.

3.2. Behavioral correlates of the theta/beta ratio, theta and beta at CZ

The three QEEG measures were correlated with the following VCPT results: omission errors, commission errors, reaction time, and reaction time variability. These data were available for patients and controls. The only significant correlation in the control group was a negative correlation of $r = -0.37$ ($P = 0.02$) between omission errors and beta, supporting the assumption that beta represents a good attention level. The same correlations were conducted in the patient group; in addition, data from the QbTest were also available for them. We used the three global indexes: activity, impulsivity, and inattention.

We had a large number of behavioral measures in the ADHD group (See Section 2.2.1.). We found no correlations between IQ and the theta/beta ratio. Other results are shown in Table 4. As can be seen the theta/beta ratio did not correlate significantly with scores from CRS-R. A number of significant correlations were found between theta and CRS-R. Theta at CZ correlated positively with measures of inattention (four parent and one teacher subscale), and negatively with measures of hyperactivity and impulsivity (two teacher scales, parent scales not reaching significance). Beta activity correlated *positively* with inattention (parent and teacher scales) and the overall diagnosis of ADHD (parent scale). The strongest correlation was between social problems (parent scale) and theta.

A correlation between BRIEF scales and theta values showed positive correlations with meta-cognition/executive problems (parent and teacher scales), but a negative correlation with inhibition (teacher scale), which is closely related to hyperactivity/impulsivity. Beta correlated positively with several teacher scales reflecting problems of metacognition.

We found no significant correlations between scores on the QbTest and the three QEEG measures.

4. Discussion

We hypothesized that the accuracy of the theta/beta ratio, and theta and beta separately to discriminate between ADHD and normal controls would be 80% or more. This was not found. In fact none of the three EEG measures were significantly different in patients and controls. Omission errors in the GO/NOGO task discriminated between patients and controls with 85% accuracy compared with theta (63%) and the theta/beta ratio (58%).

When the individual spectra were compared with the HBI database, elevations ($P<0.01$) of theta were found in 25.8% of the patients, and in only 2.6% of the control group. This means, however, that almost 75% of the patients were not identified by this measure; a sensitivity much lower than reported by Snyder et al. (2008). Our study is more in line with Coolidge et al. (2007), who found no correlation between the theta/beta ratio and ADHD. However, finding significant elevations of power in the theta band may be seen as supporting evidence for an ADHD diagnosis. Based on our data one would predict that these patients are behaviorally characterized by inattention and executive problems, a pattern seen in ADHD-C as well as in ADHD-I. Elevated theta as a marker of inattention and executive problems in ADHD is perhaps the most important finding of this study.

4.1. Validity of our data

Associations between a large number of subscales from CRS-R and BRIEF on one hand, and EEG measures on the other, were tested, increasing the risk of type 1 errors. Comparing patients and controls on several EEG measures also increases this risk. The significant correlations, however did not seem to be random, but formed a consistent pattern of subscales reflecting executive function and inattention. If we had changed the significance level from 0.05 to 0.005, all significant differences related to omission errors, and the difference in theta level between young and older patients would still be preserved. Nine of the reported correlations between EEG and behavior measures would still be significant. On the other hand, our findings should be seen as tentative, needing confirmation from other studies.

In our sample 30% of the patients had IQs below 80, which is lower than in most other ADHD studies. We found that omission errors discriminated between patients and controls with an accuracy of 85%. This might to some extent reflect differences in IQ between the groups. We did not have IQ tests for the controls, but we correlated IQ and omission errors in the patient group. No correlation was found ($r = -0.11$), and we argue that the accuracy of omission errors was not related to IQ. The high number of patients with IQs between 70 and 80 may limit the generalizability of our results. However, as we see it, our patients are representative of ADHD patients that are seen in clinics.

Valid results are often in agreement with other research. As reported in “Introduction”, previous research related to the theta/beta ratio is equivocal. Our results do not confirm research showing that elevated theta/beta ratio captures most ADHD, but are more in accordance with research showing several EEG patterns in ADHD. The diversity in results may reflect different methods of recording and artifacting. Our method of automatic artifacting (see 2.2.) is used in patients, controls, and the HBI database. The results of this method are highly similar to those obtained by the traditional method of manual artifacting (Tereshchenko et al., 2009).

4.2. Theoretical implications

We found that theta and the theta/beta ratios were higher in the young groups than in the older groups. The age effect was stronger in the patients than in the controls, and may lend support to a maturational lag model of ADHD.

Support for the finding that elevated theta is related to inattention and executive problems were found in CRS-R and BRIEF, parent form as well as teacher form. It is also of interest that the highest correlation of theta was with social problems in the parent form of CRS-R. This may be an indication that social function relies heavily on the executive system. We also found that a high level of theta was *negatively* correlated with hyperactivity and impulsivity. This does not lend support to Russel Barkley's theory that inattention in ADHD stems from impulsivity (Barkley, 2006)). This negative correlation seems a bit confusing since we also report a positive correlation between theta and ”DSM ADHD total”, which includes items of hyperactivity and impulsivity. This positive correlation with DSM ADHD total was related to the parent form of CRS-R. The significant negative correlations were found in the teacher forms of CRS-R and BRIEF. No significant

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Table 4
Significant correlations (corr.) of behavior with the theta/beta ratio, theta at CZ and beta at CZ in EO condition, absolute power. Data from parent and teacher forms shown (CRS-R, BRIEF).

		Conners' Rating Scale – Revised (CRS-R)						
		Cogn./inatt.	Hyper	Social probl.	ADHD index	DSM inatt.	DSM hy./imp	DSM total
Theta/beta	Parent corr.							
	Sign.							
	(*df*)							
	Teacher corr.							
	Sign.							
	(*df*)							
Theta	Parent corr.	0.49***		0.61***	0.42**	0.47***		0.43**
	Sign.	<0.001		<0.001	0.002	0.001		0.002
	(*df*)	(48)		(48)	(48)	(48)		(49)
	Teacher corr.	0.31*	- 0.35*				- 0.36*	
	Sign.	0.030	0.015				0.011	
	(*df*)	(47)	(47)				(48)	
Beta	Parent corr.	0.28*						0.28*
	Sign.	0.047						0.045
	(*df*)	(48)						(49)
	Teacher corr.	0.41**						
	Sign.	0.003						
	(*df*)	(47)						

		BRIEF					
		Inhib.	Initiate	Plan / organize	Working memory	Monitor	Metacog index
Theta/beta	Parent corr.		0.29*			0.31*	
	Sign.		0.045			0.030	
	(*df*)		(48)			(48)	
	Teacher corr.						
	Sign.						
	(*df*)						
Theta	Parent corr.		0.39**			0.45***	0.32*
	Sign.		0.005			0.001	0.026
	(*df*)		(48)			(48)	(47)
	Teacher corr.	- 0.39**		0.33*			
	Sign.	0.007		0.025			
	(*df*)	(45)		(45)			
Beta	Parent corr.						
	Sign.						
	(*df*)						
	Teacher corr.		0.33*	0.30*	0.31*		0.29*
	Sign.		0.023	0.041	0.037		0.046
	(*df*)		(45)	(45)	(45)		(45)

		VCPT: Ctr: Control group. Pat.: Patient group			
		Omission errors	Commission errors	Reaction time	Reaction time variability
Theta/beta	Correlation				
	Sign.				
	(*df*)				
Theta	Correlation				
	Sign				
	(*df*)				
Beta	Correlation	Ctr. - 0.37*			
	Sign.	0.021			
	(*df*)	(36)			

QB test: No significant correlations.

correlations were found for theta and hyperactivity/impulsivity in the parent scales.

Finding the generators of excess theta is beyond the scope of this study. In some patients with a marked deviance we did however apply sLoreta (http://www.uzh.ch/keyinst/loreta.htm), pointing to generators in frontal areas involved in executive function (Brodman area 6, 9, 10, 32).

We found that high levels of beta in the patient group correlated positively with ADHD symptoms (CRS-R) and problems with meta cognition (BRIEF). This was an unexpected finding, because increased beta is usually related to a good attention level, as was found in the control group. This finding may indicate that the beta we registered in the ADHD group differs from beta in the control group, and is possibly related to the ADHD subgroup of excess beta. This subgroup has been described as having behavior problems and being irritable (Barry et al., 2003). We found no significant correlation of high beta values in patients and oppositional behavior or emotional lability in the CRS-R.

This study has several limitations. We have no data that would determine if theta, beta, or the theta/beta ratio discriminate ADHD from other psychiatric or developmental disorders. Other parameters in EEG, as well as in ERP, may identify ADHD with greater accuracy, either alone or in combination. These are challenges for future research.

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