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Cortical activation and attentional control in ADAH subtypes[1]

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ABSTRACT. One of the disorders that affects school performance the most is isolated attention deficit disorder or attention deficit associated with hyperactivity or impulsivity disorder. This disorder poses difficulties to the students themselves, both in the verbal area and in reasoning and calculus, as well as to their teachers, as a consequence of the students' disruptive behaviors. The criteria established by the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, revised are one of the most widely accepted procedures to diagnose the deficit, distinguishing three subtypes: inattentive, hyperactive-impulsive, and combined. The main goal of this investigation is to determine whether there are differential patterns of cortical activation and executive control for these three types of subjects with Attention Deficit Hyperactivity Disorder (ADHD) and for the control group (without ADHD). The sample was made up of 220 students, ages between 6 and 12 years: 56 in the control group, 54 predominantly with attention deficit disorder, 53 predominantly with hyperactivity-impulsivity disorder, and 57 with combined. The results obtained show that the four groups of subjects were significantly different in the two variables of cortical activation assessed (central and prefrontal) and in the five variables of executive control (inattention, impulsivity,

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response time, variability, and general executive control index). Multiple group comparisons confirm the proposed hypotheses. The results reveal a new path of great interest concerning an objective and reliable diagnostic assessment, and a pharmacological and behavioral intervention adapted to each specific situation.

KEYWORDS. Cortical activation. Attention deficit. Hyperactivity. Quantified EEG. TOVA. *Ex post facto* study.

RESUMEN. Uno de los trastornos que más condiciona el rendimiento escolar es el déficit de atención aislado o asociado a hiperactividad o impulsividad. Este trastorno plantea dificultades a los propios estudiantes, tanto en el área verbal como en razonamiento y cálculo, así como también a sus profesores, como consecuencia de los comportamientos disruptivos. Los criterios establecidos por el Manual Diagnóstico y Estadístico de los Trastornos Mentales 4ª edición -revisada son uno de los procedimientos más aceptados para diagnosticar el déficit, distinguiéndose tres subtipos: inatento, hiperactivo-impulsivo y combinado. El objetivo central de la presente investigación ha sido contrastar si existen patrones de activación cortical y control ejecutivo diferenciales para estos tres tipos de sujetos con Trastorno por Déficit de Atención con Híperactividad (TDAH) y para el grupo control sin TDAH. La muestra utilizada estaba formada por 220 estudiantes, de edades comprendidas entre 6 y 12 años: 56 grupo control, 54 con predominio de déficit de atención, 57 con déficit de atención e hiperactividad y 53 con predominio de hiperactividad-impulsividad. Los resultados obtenidos muestran que los cuatro grupos de sujetos se diferencian significativamente entre sí en las dos variables de activación cortical evaluadas (central y prefrontal), y en las cinco de control ejecutivo (inatención, impulsividad, tiempo de respuesta, variabilidad e índice general de control ejecutivo). Las comparaciones múltiples entre grupos confirman las hipótesis planteadas. Los resultados obtenidos abren una vía de gran interés cara a una evaluación diagnóstica objetiva y fiable, y a una intervención farmacológica y conductual ajustada a cada situación concreta.

PALABRAS CLAVE. Activación cortical. Déficit de atención. Hiperactividad. EEG cuantificado. TOVA. Estudio *ex post facto*.

There is increasing concern in academic (Arco, Fernández, and Hinojo, 2004; Jarque Fernández, Tárraga Mínguez, and Miranda Casas, 2007; Manga, Fournier, and Navarredonda, 1995; Miranda, García, and Soriano, 2005; Weiler, Bernstein, Bellinger, and Waber, 2000) and clinical settings (Cantwell, 1996; López-Villalobos, Serrano Pintado, and Delgado Sánchez-Mateos, 2004; Servera, 1999) about the attention deficits with and without hyperactivity, because they have an important impact both on academic performance (Lucangeli and Cabrele, 2006; Mayes, Calhoun, and Crowell, 2000; Miranda *et al.,* 2005; Purvis and Tannock, 1997; Servera and Cardo, 2006; Shanahan *et al.,* 2006) and on the individual's capacity of self-regulation and control (Barkley, 1997, 2003; Brown, 2005; Contreras, Catena, Cándido, Perales, and Maldonado, 2008; DuPaul and Eckert, 1997; Merrell and Tymms, 2001; Rubia, 2002; Wagner, 2000).

Such determinants are usually related to delay in myelinization processes during brain development (De Bellis *et al.,* 2001; Pineda *et al.,* 1998; Sowell *et al.,* 2002), the reduction of white matter in the frontal lobe (Filipek *et al.,* 1997; Mostofsky, Cooper, Kates, Denckla, and Kaufman, 2002; Overmayer *et al.,* 2001; Rivkin, 2000), or an early dysfunction of the executive functions associated with frontal-thalamus-striate pathways (Narbona and Sánchez-Carpintero, 1999), and they have a direct impact on levels of cortical activation (Álvarez, González-Castro, Núñez, González-Pienda, and Bernardo, 2008; Linden, Habib, and Radojevic, 1996; Lubar, Swartwood, Swartwood, and O‘Donnell, 1995; Martínez-León, 2006; Toomin, 2002), regulated by the noradrenergic and dopaminergic neurotransmission systems (Brown, 2005). The noradrenergic system is mainly related to the modulation of selective attention and the individual's level of general activation to focus (Parasuraman, Warm, and See, 1998), as it contributes the necessary activation to attend to each task or specific activity. The dopaminergic system, on the other hand, is associated with the capacity to control behavior, both at the executive level and at the affective-motivational level. If there is a decrease in the dopaminergic activity, the capacity for self-regulation and behavioral control also decreases. Thereby, the need to investigate the structural and functional characteristics that are specific to ADHD, instead of focusing exclusively on the identification of genetic factors that are responsible (Sherman, McGue, and Iacono, 1996).

The techniques of functional neuroimaging and the continuous performance tests (CPTs) are along these lines of research of brain structure and function. In our work, we will use quantitative analysis of the electroencephalogram (EEG), due to its lower cost and high correlation with blood flow (Toomin, 2002). By means of these techniques, Bresnahan, Anderson, and Barry (1999) associated hyperactivity with a decrease in the electrical activity or beta rhythm, and impulsivity with an increase of beta rhythm/theta activity in subjects with ADHD. Clarke, Barry, McCarthy, and Selikowitz (2001), however, found three different profiles: a) an increase of slow waves and a deficiency of fast waves (general level of brain activation), b) an increase of the amplitude of the theta wave (related to inattention) and a decrease of beta (impulsivity), and c) an excess of beta (high cortical activation). These profiles suggest the existence of heterogeneity in the electrophysiological components, perhaps due to a delay in the brain electric maturation or the existence of abnormal electroencephalographic patterns (Chabot and Serfontein, 1996; Monastra *et al.,* 1999). Likewise, Gumenyuk et al. (2001) corroborate this heterogeneity in studies with evoked potentials (by studying the P300 wave).

Along this vein of investigation, various authors (Álvarez *et al*, 2008; Angelakis, Lubar, and Stathopoulou, 2004; Angelakis, Lubar, Stathopoulou, and Kounios, 2004; Clarke, Barry, McCarthy, and Selikowitz, 1998; Clarke *et al.,* 2001; Janzen, Graap, Stephanson, Marshall, and Fitzsimmons, 1995; Lubar, 1991; Swartwood, Swartwood, Lubar, and Timmerman, 2003; Toomin, 2002) use as a measurement index the beta/theta ratio, taking into account that this has the highest correlation with cerebral blood flow, measured by the Single Photon Emission Computed Tomography (SPECT) (Sergeant, Geurts, and Osterlaan, 2002). Similarly, the theta/beta ratio best differentiates subjects with ADHD from controls and also those with combined AD/HD from inattentive (ADD) subjects (Ricardo-Garcell, 2004), although Snyder *et al.* (2008) do not recommend the use of quantified Electroencephalograph (EEG) as an independent diagnosis, but rather as a complement to a more extensive clinical assessment. In this same vein, Álvarez *et al.* (2007, 2008), using as assessment instrument the EEG neurofeedback system, Biocomp 2010, designed by the Biofeedback Institute of Los Angeles, demonstrated the power of this measurement compared to individual records. This activity is recorded at two EEG points: Fp1 and Cz. A record of the beta/theta ratio in Fp1 of less than 50% indicates low capacity of executive control, and in Cz, low arousal. This executive dysfunction, associated with a clear deficit in the attentional filter was also detected by Carboni *et al.* (2007) in subjects with combined AD/HD. Likewise, Romero-Ayuso, Maestú, González-Marqués, Romo-Barrientos, and Andrade (2006) found different neuropsychological and neuromagnetic profiles in ADD and combined AD/HD. These subtypes have less amplitude and attentional control, and poorer performance in tasks related to working memory than the subjects of the control group. Combined AD/HD displays more impulsivity and more brain activity in the ventromedial regions of both hemispheres and in the right cingular cortex than ADD.

According to Etchepareborda (2000), these different profiles of the subtypes present some diagnostic contradictions because, from the neuropsychological viewpoint, in contrast to the Diagnostic and Statistical Manual of Mental Disorders-IV-TR (American Psychiatric Association, 2000), it is possible to identify groups with more varied behavioral and academic profiles; hence, the need to integrate the different types of investigation of the diverse areas into a more normalized diagnostic model (Swanson, Castellanos, Murias, Lahoste, and Kennedy, 1998). From the behavioral viewpoint, tests to measure executive control have also been developed, such as Conners' Continuous Performance Test (Amador Campos, Idiazábal Alecha, Sangorrín García, Espadaler Gamissans, and Forns Santacana, 2002; Conners, 1997) and Greenberg's (1996) Test of Variables of Attention (TOVA). In practice, these tests have been used independently of the EEG measures, however, the study of Reyes-Zamorano, Ricardo-Garcel, Galindo-Villa, Cortes, and Otero (2003) establishes correlations between both measures which deserve closer examination.

Within this context, the main goal of our work is to identify the possible existence of a specific pattern of brain activation and executive control for each one of the three subtypes of ADHD. This pattern, in the case of ADD, could be related to low activation in the central cortex and omission errors and high response times in Continuous Performance Test (CPTs). In the impulsive-hyperactive subtype (ADHD), the low activation, this time in the left prefrontal cortex, would be associated with commission errors and high variability in CPTs. Lastly, in combined AD/HD, we would find a synthesis of both profiles. If this is so, it leads to the possibility of diagnosing more reliably and objectively, and designing pharmacological and behavioral interventions adapted to each specific case.

According to previous investigations (*i.e.,* Capdevila-Brophy, Navarro-Pastor, Artigas-Pallarés, and Obiols-Llandrich, 2007; Clarke and Barry, 2004) and clinical experience, we are guided by three working hypotheses: a) the inattentive (ADD) and combined (AD/HD) subtypes of ADHD will present significantly lower cortical activation in Cz, as well as a significantly higher level of omissions and response time than those observed in the impulsive-hyperactive subtype (ADHD) and the control group (CG); b) the impulsive-hyperactive (ADHD) and combined subtypes (AD/HD) will display significantly lower cortical activation in Fp1, as well as significantly higher levels of commissions and variability than those observed in the inattentive subtype (ADD) and the control group (CG); c) the combined subtype (AD/HD) will present a significantly higher general executive control index than the one obtained by the impulsive-hyperactive subtype (ADHD) and this group, in turn, will be significantly higher than the inattentive subtype (ADD); the control group (CG) will obtain the lowest levels in this variable.

Method

Design and data analysis

We used a design of four groups, three corresponding to the ADHD subtypes (inattentive – ADD -, hyperactive – ADHD -, and combined - AD/HD -) and one without ADHD (CG), which acted as a control group when performing the comparative analyses of the profiles of cortical activity and executive control.

As the goal of the *ex post facto* investigation (Montero and León, 2007; Ramos-Álvarez, Moreno-Fernández, Valdés-Conroy, and Catena, 2008) was to determine the potential differences between the four groups of subjects regarding cortical activation and executive control, in order to appraise the usefulness of this type of measures for differential diagnosis of these disorders, the data obtained were analyzed by means of multivariate analysis of variance (MANCOVA). The dependent variables were the measures of cortical activation and executive control, belonging to a group was the independent variable, and age, sex and the Intelligence Quotieng (IQ) were used as covariates. We used the value of Wilks' λ to determine whether there were significant differences in all the dependent variables taken conjointly. In those cases where Wilks' λ was significant ($p < .05$), we considered the results of the individual analysis of variance (ANCOVAs). We used η^2 as an index of effect size. When $\eta^2 > .15$, the effect size is large in magnitude and when $\eta^2 >.06$, the effect size is medium. Likewise, to determine between which groups there were differences, we used Bonferroni multiple comparisons test. For more clarity in the exposition of the Results section, we present the data for the two dependent variables separately.

Participants

In this investigation, 220 students acted as participants, 122 males (55.50%) and 98 females (44.50%), ages between 6 and 12 years, classified in four groups: group ADD, students with attention deficit (n = 54; 25 men and 29 women); group ADHD, students with impulsivity-hyperactivity (n = 53; 28 men and 25 women); group AD/HD, students with combined attention deficit and impulsivity-hyperactivity (n = 57; 36 men and 21 women); and a control group of students without attention deficit or hyperactivity (n = 56; 33 men and 23 women). All the students presented an Intelligence Quotient (IQ) equal to or higher than 80 (see Table 1), assessed with the Weschler Intelligence Scale for Children – Revised (WISC-R; Weschler, 1974). The participants attended public and concerted schools in the Autonomous Community of the Princedom of Asturias (Spain) and did not receive any kind of pharmacological treatment.

The subjects of the three AD/HD groups were initially identified in the Pediatric Service of the Central University Hospital of Asturias, by means of the DSM-IV-TR (American Psychiatric Association, 2000) criteria. At a later date, in order to ensure the correct assignation of the students to their respective groups, Farré and Narbona's (1997) scale for the assessment of attention deficit with hyperactivity - *Evaluación del Déficit de Atención con Hiperactividad* (EDAH) was administered to the students' parents and teachers. When both the results of their observations coincided (agreement for each subtype higher than 90%), the students were assigned to their corresponding reference group. In the next step, each student was definitely assigned to a specific AD/HD group when the pediatric and psychoeducational diagnoses coincided.

Lastly, all the subjects who presented cognitive deficit (n = 14), comorbidity with behavior disorders (n = 12), Asperger (n = 3), Guilles de la Tourette (n = 1), anxious-depressive disorders (n = 4) and learning disorders (n = 8) were eliminated.

TABLE 1. Means and Standard Deviations of the Intelligence Quotients (IQ) and age of the four used groups.

Groups		*Intelligence Quotients (IQ)*		*Age*	
	n	*M*	*SD*	*M*	*SD*
Control	56	100.96	11.36	10.38	1.58
ADD	54	103.33	12.45	9.57	1.46
ADHD	53	101.58	12.54	9.79	1.49
AD/HD	57	99.40	13.12	9.60	1.52
Total sample	220	101.29	12.38	9.84	1.54

Note. ADD = Attention deficit disorder, ADHD = Hyperactivity-Impulsivity Disorder, AD/HD = Combined disorder.

Variables and measurement instruments

We used three scales for the identification, selection, and assignation of the students to the groups: DSM-IV-TR (American Psychiatric Association, 2000), the *Evaluación del Déficit de Atención con Hiperactividad* (EDAH) scale of Farré and Narbona (1997), and the WISC-R (Weschler, 1974). Assessment of the degree of cortical activation of the participants was carried out with the beta/theta ratio of the quantified EEG (Biocomp 2010), and the variables of executive control were estimated by means of the five Test of Variables of Attention (TOVA) indexes: Omissions, response time, commissions, variability, and general executive control index, attributable to ADHD (Greenberg, 1996).

– Assessment of the symptoms. As indicated, this information was initially estimated by means of the DSM-IV-TR scales and, subsequently, by means of the EDAH scales. The EDAH are observational scales completed by parents or teachers and they provide information about the possible existence of the three types of ADHD: with predominance of inattention (ADD), with predominance of impulsivity-hyperactivity (ADHD), and combined type (AD/HD). These instruments present good reliability and validity in Spanish population.

- Assessment of cortical activation. We used the Biocomp 2010 (www.biocompresench.org). This is a computerized EEG system, adapted by Toomin (The Biofeedback Institute of Los Angeles), which provides the levels of cortical activation via the beta/theta ratio. It measures attention in general, independently of the task to be performed. For this purpose, an electrode is placed on the subject's corresponding cortical area (Cz, Fp1) to record the beta/theta ratio, and two more control electrodes are placed on the subject's left and right earlobe. Lastly, an EMG system is placed on the right forearm to identify the degree of movement. Once the electrodes are in place, participants are asked to remain relaxed, without moving, breathing slowly and evenly, concentrating exclusively on the computer screen on which the theta and beta waves emitted by them are displayed successively. After assessment, the results obtained are interpreted. When the beta/theta ratio is lower than 50% at Cz, there is a clear deficit of sustained attention and if, in addition, the ratio is lower at Fp1, then the attentional deficit is associated with a lack of executive control, attributable to hyperactivity.
- Assessment of executive control. To appraise executive control, we used the Test of Variables of Attention (TOVA; Greenberg, 1996). The TOVA has two simple images; the first one presents the stimulus at the top and the second one at the bottom. The participant holds a push-button switch and must press it when the first image appears, but not when the second one appears. There is a prior 3-min training session and the test itself lasts 20-24 min, depending on the subject's age and characteristics. The following profile is obtained: inattention, response time, impulsivity, variability, and a general executive control index, attributable, according to the test manual, to a profile of attention deficit with hyperactivity. When inattention and response time are lower than one standard deviation below the mean, the result is interpreted as deficit of sustained attention. This deficit can be associated with impulsivity or hyperactivity (variability) if these variables are also more than one standard deviation below the mean. The general executive control index is obtained by adding the standard deviations of the response time (first half), D' (second half), and total variability. If this sum is lower than -1.80, there is deficit in executive control, thereby the need for a subsequent stimulation.

Procedure

As mentioned, the identification of the participants was carried out according to the DSM-IV-TR criteria in the Pediatric Service, and the EDAH (parent-teacher agreement equal to or higher than 90%), administered in the reference educational centers. Once the three ADHD groups were configured, we proceeded to select the students who made up the group without ADHD so the groups would be as equivalent as possible. For this purpose, all the participants completed the WISC-R, and their age was also taken into account. Once identified, if their IQ was equal or higher than 80, they completed the TOVA. Both tests (WISC-R and TOVA) were interpreted according to their corresponding instruction manuals and they were administered in an adequate place.

After psychological assessment and the appraisal of executive control, the level of cortical activation was identified by means of the quantitative EEG analysis, using the Biocomp 2010. The surface electrodes were placed at points Fp1 and Cz. To control participants' movement, an Electromyogram (EMG) electrode was placed on the right forearm and the reference electrodes were placed on the earlobes. The recording was carried out in a sound-proof room, with low illumination, electrically isolated, and always at the same time, between 4 p.m. and 6 p.m. The EEG was administered to each participant, with open eyes, for a maximum duration of 10 min and prior instructions of even abdominal breathing to carry out the test in the best possible performance conditions. To interpret the results, we used values of the beta/theta ratio lower than 50% as measures of low cortical activation, whereas values higher than this ratio were interpreted as positive measures of cortical activation. The TOVA measures were standardized, interpreting scores lower than 1.2 standard deviations as negative measures. Lastly, a general executive control index with recordings lower than -1.80 was interpreted as ADHD. For the partial correlations, we took age into account because activation and executive control both tend to decrease with age.

Results

Cortical activation

In Table 2 are displayed the means and standard deviations corresponding to the two indicators or measures of cortical activation.

TABLE 2. Means and Standard Deviations of the measures of central (Cz) and prefrontal cortical activation (Fp1) for the four groups

Groups		*Cz*		*Fp1*	
	n	*M*	*SD*	*M*	*SD*
Control	56	.55	.05	.60	.09
ADD	54	.39	.06	.56	.07
ADHD	53	.60	.10	.39	.07
AD/HD	57	.43	.05	.38	.06
Total sample	220	.49	.11	.48	.12

Note. ADD = Attention deficit disorder, ADHD = Hyperactivity-Impulsivity Disorder, AD/HD = Combined disorder

The MANCOVA shows that the main effects of the independent variables on the dependent variables were statistically significant, $\lambda_{Wilks} = .14$, $F_{(6, 424)} = 121.66$, $\eta^2 < .000$, $\eta^2 = .63$. The size of this relation is relevant, as 63.30% of the variability is attributable to group differences, once the effect of age, sex and IQ is controlled. With regard to the covariates, whereas IQ and sex did not show any effects, - $\lambda_{Wilks} = .99$; $F_{(2, 212)} = 1.06$, $p < .349$, $\eta^2 = .01$, and $\lambda_{Wilks} = .99$; $F_{(2, 212)} = .80$, $p < .451$, $\eta^2 = .01$, respectively - , age did present a low but statistically significant effect, $\lambda_{Wilks} = .96$, $F_{(2, 212)} = 4.45$, $p < .013$, $\eta^2 = .04$.

With regard to the analysis of the effect of the variable group on the two measures of cortical activation, the results of the ANCOVA showed statistically significant group differences, both for Cz, $F_{(3, 213)} = 109.77$, $p < .000$, $\eta^2 = .61$, and for Fp1, $F_{(3, 213)} = 121.17$, $p < .000$, $\eta^2 = .63$. According to Cohen's (1988) criterion applied to the value obtained for corrected eta square, the size of the differences can be considered large for both variables. The results obtained with the Bonferroni multiple comparisons test indicate that, in the case of the variable Cz, there were statistically significant differences for the six possible comparisons. In contrast, for the Fp1 variable, the data show that there were statistically significant differences among all the groups, except for the comparisons of control group with ADD and AD/HD with ADHD. The direction of the differences can be seen in Table 2.

With regard to our hypotheses, in the first one, we stated that the ADD and AD/HD subtypes would present significantly lower cortical activation at Cz than that observed in the ADHD subtype and in the control group. The data obtained (see Table 2) indicate that, in effect, the means of groups ADD and AD/HD were significantly lower than those obtained by the ADHD group, $M_{ADD-ADHD} = -.21$, $p < .000$ and $M_{AD/HD-ADHD} = -.17$, $p = .000$; the control group also displayed significantly higher levels in this variable than groups ADD and AD/HD, $M_{CG-ADD} = .15$, $p < .000$ and $M_{CG-AD/HD} = .11$, $p < .000$, respectively, but significantly lower than the ADHD group, $M_{CG-ADHD} = -.06$, $p < .000$.

With regard to the second hypothesis, we stated that the ADHD and AD/HD subtypes would display significantly lower cortical activation at Fp1 than that observed in the ADD group and in the control group. The results obtained (see Table 2) support this hypothesis in regard to the comparison of the three ADHD subtypes, $M_{AD/HD-ADD} = -.18$, $p < .000$, and $M_{ADHD-ADD} = -.18$, $p < .000$, but not completely with regard to the control group, because, although it had higher pre-frontal activation compared to the AD/HD and ADHD subtypes, $M_{CG-AD/HD} = .21$, $p < .000$, and $M_{CG-ADHD} = .20$, $p < .000$, it was not significantly higher than that of the ADD subtype, $M_{CG-ADD} = .03$, $p < .362$.

Executive control

In Table 3 are displayed the means and standard deviations corresponding to the five indicators of executive control (inattention, response time, and general executive control index). To interpret the information provided by the TOVA correctly, the lower the score, the greater the deficit, and vice versa.

TABLE 3. Means and standard deviations of the measures of executive control for the four groups.

Groups	*OM*	*RT*	*COM*	*VAR*	*GECI*
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Control	101.05 (8.31)	100.93 (11.25)	103 (12.24)	97.77 (10.70)	.19 (1.50)
ADD	74.68 (14.99)	77.33 (10.77)	95.75 (11.58)	91.70 (6.61)	-2.27 (1.44)
ADHD	91.28 (16.64)	98.92 (9.89)	79.41 (13.34)	71.09 (15.27)	-3.27 (2.06)
AD/HD	74.87 (21.49)	77.01 (15.66)	85.05 (14.20)	67 (12.63)	-4.93 (1.84)
Total sample	85.44 (19.59)	88.46 (16.64)	90.89 (15.75)	81.88 (17.60)	-2.57 (2.55)

Note. ADD = Attention deficit disorder, ADHD = Hyperactivity-Impulsivity Disorder, AD/HD = Combined disorder, OM = omissions, RT = response time, COM = commissions, VAR = variability, GECI = general executive control index.

The MANCOVA revealed statistically group significant differences in executive control, $\lambda_{wilks} = .16$, $F_{(15, 577)} = 36.44$, $p < .000$, $\eta^2 = .46$, which suggests that 45.80% of the variability of these measures is attributable to group differences. Likewise, no statistically significant differences were found for age and IQ, but they were observed for the covariant sex ($\lambda_{wilks} = .94$, $F_{(5, 209)} = 2.55$, $p < .029$, $\eta^2 = .06$.

The ANCOVAs, taken individually, show statistically significant differences for the five measures: inattention, $F_{(3, 213)} = 34.12$, $p < .000$, $\eta^2 = .37$, impulsivity, $F_{(3, 213)} = 38.60$, $p < .000$, $\eta^2 = .37$, response time, $F_{(3, 213)} = 60.73$, $p < .000$, $\eta^2 = .48$, variability, $F_{(3, 213)} = 92.91$, $p < .000$, $\eta^2 = .58$, and general executive control index, $F_{(3, 213)} = 84.73$, $p < .000$, $\eta^2 = .56$. The Bonferroni post-hoc multiple comparisons test showed the following results: a) for inattention, only the differences between groups ADD and AD/HD were nonsignificant; b) for response time, only the differences between the control group and ADHD, and groups ADD and AD/HD were nonsignificant; c) for impulsivity and variability, only the comparisons between groups AD/HD and ADHD were nonsignificant; d) with regard to the general executive control index, all the comparisons were statistically significant. The direction of the differences can be seen in the means in Table 3.

With regard to our hypotheses about the five measures of executive control, the data obtained (see Table 3) clearly support them.

Thus, the ADD and AD/HD groups presented a significantly higher level of omissions than that obtained by the ADHD subtype, $M_{ADD\text{-}ADHD} = -16.44$, $p < .000$, and $M_{AD/HD\text{-}ADHD} = -16.10$, $p < .000$; the ADHD and AD/HD subtypes displayed a significantly higher level of commissions than that obtained by the ADD subtype, $M_{AD/HD\text{-}ADD} = -10.10$, $p < .000$, and $M_{ADHD\text{-}ADD} = -15.86$, $p < .000$; the ADD and AD/HD subtypes presented a significantly higher response time than that obtained by the ADHD subtype, $M_{ADD\text{-}ADHD} = -21.42$, $p < .000$, and $M_{AD/HD\text{-}ADHD} = -21.87$, $p < .000$; the ADHD and AD/HD subtypes showed a significantly higher level of variability than that obtained by the ADD group, $M_{AD/HD\text{-}ADD} = -24.36$, $p < .000$, and $M_{ADHD\text{-}ADD} = -20.45$, $p < .000$; and the AD/HD group presented a significantly higher general executive control index than that obtained by the ADHD group, $M_{AD/HD\text{-}ADHD} = -1.63$, $p < .000$, and the latter was, in turn, significantly higher than that of the ADD group, $M_{ADHD\text{-}ADD} = -.98$, $p < .022$.

In the comparisons established with the control group in the five variables of executive control, this group obtained significantly lower scores (higher in Table 3) than the three subtypes of ADHD (fewer omissions, less impulsivity, less variability, and lower response time, and more general executive control), except in the case of the comparison with the ADHD subtype, for the variable response time, for which, although there were differences were in favor of the control group, they were not statistically significant, $M_{CG\text{-}ADHD} = 1.69$, $p < 1.000$.

Discussion and conclusions

The main goal of this investigation was to determine whether there are differential patterns of cortical activation and executive control for the three types of subjects with ADHD (inattentive, hyperactive, combined) and for the control group without ADHD. The results obtained show that the four groups of subjects were significantly different in the two variables of cortical activation assessed (central and prefrontal) and in the five variables of attentional control (inattention, impulsivity, response time, variability, and general executive control index). Multiple comparisons of groups confirm the proposed hypotheses.

More specifically, the differences among the four ADHD subtypes are clear regarding the levels of cortical activation assessed with the biocomp 2010, via the beta/theta ratio. Levels of activation lower than 50% in the central area of the cortex (Cz) indicate low sustained attention, either of isolated attention deficit or associated with hyperactivity. In contrast, when these levels of activation are excessively low in the left prefrontal area (Fp1), then the deficit is more closely related to executive control. This is why no significant differences appear between group ADD and the control group Fp1, because the weight of the deficit is in the central cortical area (Fp1 has no influence on either of these groups), nor between groups ADHD and AD/HD, because the key of the deficit is hyperactivity itself, which affects both groups equally. Nevertheless, we point out that, in the multivariate analyses, age explained significantly, although minimally, part of the group variability in cortical activation (especially in Fp1), perhaps due to the fact that the assessment system used does not weight the score obtained as a function of this variable (an aspect that TOVA does take into account).

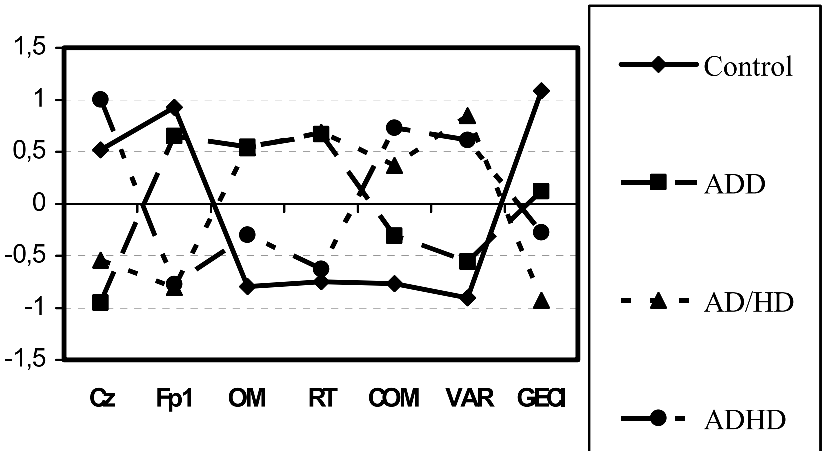
However, if these data are robust when taken alone, they will be stronger when contrasted with the results of the TOVA, extensively used in current investigation because, according to Barkley (1998), it is the only test that assesses two of the pathognomonic symptoms of ADHD: inattention and impulsivity. The results of the TOVA are overwhelming. The inattentive subtype obtains poor results in omissions and response time, and the hyperactive subtype in commissions and variability. Hyperactivity, either isolated or combined, is highly conditioned by executive control (as measured by the general executive control index).

Hence, it can be concluded that the central cortical activation (Cz)-omissions-response time combination is a clear inattentive profile, and the left prefrontal activation (Fp1)-omissions-executive control combination configures the hyperactive profile, both isolated and associated with other profiles. Investigations like those of Clarke *et al.* (2001), Monastra *et al.* (1999), or Reyes-Zamorano *et al.* (2003) suggest this possible interrelation, that is, that certain electroencephalographic patterns could be the electrophysiological marker that identifies poor executive control.

These differences in the ADHD subtypes of cortical activation and executive control are essential for a good differential diagnosis, which will have a great impact on treatment, not only from the viewpoint of the subsequent pharmacological supports, but also, from the viewpoint of behavioral intervention and computerized administration of tasks and specific activities, either to increase the quantity and quality of sustained attention, or to develop strategies that enhance a higher capacity of self-regulation and control of behavior.

In Figure 1 the characteristic profiles corresponding to the four groups of subjects in the variables cortical activation and executive control are displayed. The scores of the seven variables were transformed to *Z* scores ($M = 0$, $SD = 1$), which allows performing a comparative analysis of all the variables (independently of the original scale). In this figure, the four groups can be seen to have clearly different profiles, and these profiles are coherent with the initial theoretical proposals.

FIGURE 1. Differential profiles corresponding to the four groups: Control, ADD, AD/HD, and ADHD.



Note. ADD = Attention deficit disorder, AD/HD = Combined disorder, ADHD = Hyperactivity-Impulsivity Disorder, Cz = central activation, Fp1= Prefrontal activation , OM = omissions, RT = response time, COM = commissions, VAR = variability, GECI = general executive control index.

Lastly, when generalizing these conclusions from the obtained data, some limitations of the investigation must be taken into account. Firstly, although the number of subjects of the sample is somewhat higher than those in other similar works, sample size should be increased so the results can be considered more reliable (if possible). Moreover, the results derived from the comparisons of the clinical and the control groups should be taken with some caution until they have been confirmed by other investigations because the age of the subjects of the control group is significantly higher than that of the other three groups (from 6 to 9 months).

Secondly, the type of tests administered should be contrasted with other tests that have been validated empirically in similar investigations, such as SPECT, Hemoencephalography (HEG), or Test D-2; the first two, in order to assess the degree of cortical activation via blood flow, and the third to appraise omissions and commissions with paper and pencil, which is used more frequently in academic achievement than computerized systems to assess students' capacity of selective and sustained attention.

Thirdly, it would also be interesting to take into account the age range, because intervals that are too broad could have a negative influence from the developmental viewpoint. In this sense, future investigations should aim at this same goal, but with younger children (as of 5 years, the diagnosis of ADHD is possible and sufficiently reliable) to determine whether the solid results found in this investigation can be generalized to other ages.

Fourthly, the results obtained in attentional control show high variability in the clinical groups, especially in AD/HD for omissions and response time, which could cast doubt on the specificity of these two measures to discriminate this subtype from the rest of the clinical groups; this could be due to the fact that the TOVA does not take omissions or response time into account for the appraisal of AD/HD (in the first half of the test). Nevertheless, although these data should be contrasted in future research, to date, the assessment of attentional control by means of the TOVA is reasonably reliable.

Lastly, although the results of this investigation seem sufficiently consistent, future research should appraise whether, for example, subjects with other clinical disorders can show profiles in cortical activation and attentional control that are similar to those obtained from subjects with ADHD, and whether they are consistent over time and at different ages. Likewise, it would be important to contrast these results with those derived from investigations that use EEG measures with standardized norms.

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