Emotional deficits in adult ADHD patients: an ERP study

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This study examined general deficits in positive stimuli evaluation in adults with Attention Deficit Hyperactivity Disorder (ADHD). We investigated the event-related potentials to positive, negative and neutral pictures in 32 adults with ADHD and 32 control subjects. For this study we measured 21 electrodes placed in accordance with the international 10-20 system and calculated the early posterior negativity (EPN), which physiologically is characterized by more negative values for emotional as compared to neutral stimuli. We found significantly reduced EPN values for the ADHD patients compared to the healthy controls, but only in the positive stimuli condition, without any significant differences in the negative stimuli condition. Our data indicate that ADHD patients show less reactivity to positive visual stimuli which might be relevant in the context of described dysfunctions of the motivational-reward system in ADHD.

Keywords: emotion processing; adult ADHD; EEG; EPN; neural correlates

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is a common behavioural disorder characterised by excessive inattention, hyperactivity, and impulsivity (APA, 2000). Previous studies focused on an impairment of executive functions in patients with ADHD (for a review see: Willcutt et al., 2005). Recently, a dual pathway model postulating both deficits in executive-inhibitory functions and an impairment of the motivational-reward system as possible causes of ADHD has been proposed (Sonuga-Barke, 2003, 2005). The impairment of the motivational-reward system is supposedly based on alterations in a neurobiological reward circuit that is comprised of the ventral striatum and the amygdala, among other structures, and leads to a weakened signalling of delayed rewards and in turn to impulsiveness and failures in effective operations.

The dysfunction of the ventral striatum during reward anticipation that this model postulates has been found in ADHD populations (Scheres et al., 2007; Ströhle et al., 2008) as well as in a student population with an increased number of ADHD-related symptoms (R. Stark et al., submitted). Recent studies also found preliminary evidence of disrupted dopamine (DA) release and turnover in the amygdala in subjects with ADHD (Ludolph et al., 2008; Volkow et al., 2007). In addition, Williams and colleagues found a decreased accuracy in facial affect recognition—a function thought to be mediated by the amygdala (Siebert et al., 2003)—and a corresponding decrease in face specific EEG potentials (Williams et al., 2008). So far, however, it has not been tested whether ADHD patients also show deficient brain activation during the processing of general emotional stimuli like emotional scenes.

Based on these findings as well as on the studies of reward processing (Scheres et al., 2007; Ströhle et al., 2008), one may argue that ADHD patients might show reduced reactivity not only to rewards but to positive stimuli in general. To investigate this hypothesis we measured event-related brain potentials (ERPs) during the processing of emotional stimuli.

One major component of the ERPs during emotional processing is the early posterior negativity (EPN), which can be detected over the occipital cortex (bilaterally with a maximum over Oz) between 170 ms and 300 ms after stimulus presentation (Junghofer et al., 2001; Schupp et al., 2003; Wieser et al., 2006). Schupp and colleagues (2003) argued that this EPN reflects facilitated sensory encoding of affective stimuli by naturally occurring selective attention. Interestingly, this component is also associated with the 5-HTTLPR and the tryptophan hydroxylase (TPH2) (Herrmann et al., 2007) and COMT genotype (Herrmann et al., 2009). A similar link has previously been shown for amygdala activity during the processing of emotional stimuli. In addition, the EPN was found to be sensitive for disorder related stimuli processing (Mühlberger et al., 2009; Van Strien et al., 2009).

A second major component of the ERPs to emotional pictures is a slow wave (Keil et al., 2002) with a positive deflection over parietal electrode positions (~400–600 ms...
after stimulus onset), which is thought to reflect the process of stimulus evaluation. Although both components reflect emotional processing, they can be differentially modulated by a secondary cognitive task. For example, it has been shown that emotion potentiated attention effects during later stages of processing (for the slow wave) but not for the EPN (Schupp et al., 2007b). In addition, the slow wave but not the EPN can be found in children as young as 5–8 years of age (Hajcak & Dennis, 2009).

For these reasons and because of its high temporal resolution (within milliseconds), EEG recording offers an excellent tool for the investigation of emotion discrimination in humans. The early emotional tagging reflected by the EPN can be differentiated from later conscious processing using an event-related potential paradigm. Based on findings that the EPN is modulated by genes associated with ADHD, one might argue that especially the EPN should be sensitive for deficits in ADHD patients. A second reason for expecting a possible change in the EPN of ADHD patients is its seemingly higher sensitivity with regard to developmental effects when compared to the slow wave (Hajcak & Dennis, 2009). In combination with deficits in amygdala functioning (Sonuga-Barke, 2003) and reward processing (Scheres et al., 2007; Ströhle et al., 2008) we hypothesised that ADHD patients would show reduced reactivity to positive stimuli which would be reflected in a reduced EPN to positive but not to negative stimuli.

**MATERIALS AND METHODS**

Thirty-two patients diagnosed with ADHD (15 female and 17 male subjects, with a mean age of 33.0 ± 9.9 years, range 18–55 years) and 32 healthy subjects (matched for age and gender; 15 female and 17 male subjects, with a mean age of 31.9 ± 9.6 years, range 20–50 years, without psychiatric or neurological disorder or pharmacological treatment) participated in this study after their written informed consent had been obtained. The study design complied with the revised Declaration of Helsinki and was approved by the local ethics committees. The patients were recruited from out-patients treated at the Department of Psychiatry at the University of Würzburg, Germany. All patients were diagnosed by an experienced consultant in psychiatry (C.J.) and were of the combined subtype according DSM-IV (APA, 2000). The diagnosis of childhood manifestation of ADHD was retrospectively assessed with the DSM-IV symptom list for ADHD and the Wender Utah Rating Scale (Retz-Junginger et al., 2003). In order to ensure diagnostic validity, additional information was collected from partners, relatives, friends, and from school report certificates. Patients were without medication for three days before testing.

ADHD patients were excluded from participation if they had a current axis-I mood, substance-related, psychotic, or anxiety disorder and/or a concurrent axis-II disorder according to DSM-IV (following a structured clinical interview [SCID I and II for DSM-IV conducted by C.J.]).

Further exclusion criteria were a history of illegal drug or alcohol dependence, or any current psychotropic medication (both based on self-report).

**Task**

During EEG measurement subjects passively viewed two presentations of the same 120 pictures chosen from the International Affective Picture System (IAPS) (Lang et al., 1999). The pictures were presented in a randomized order for a duration of 1000 ms with a variable inter-stimulus interval between 1000 and 2000 ms. The sample of IAPS pictures used in this study consisted of 40 positive (mean arousal = 5.6, mean valence = 7.1), 40 negative (arousal = 6.3, valence = 2.3) and 40 neutral (arousal = 2.8, valence = 4.9) pictures, based on norm ratings of arousal and valence (values ranging between 1 and 9; in the arousal dimension 1 = low arousal; in the valence dimension 1 = negative).

**Electrophysiological recording and data analysis methods**

EEG was recorded from 21 electrodes according to the extended International 10-20 system (Fp1, Fp2, F3, F4, F7, F8, T3, T4, C3, C4, T5, T6, P3, P4, O1, O2, Fpz, Fz, Cz, Pz and Oz) with a Synamps amplifier in AC mode using the software Scan 4 (Neuroscan, Inc., Hamburg, Germany). Signals were analyzed off-line with the BrainVision Analyzer Software of BrainProducts, Inc. (Munich, Germany). Three additional electrodes were placed at the outer canthi of both eyes and below the right eye to register horizontal and vertical eye movements. The recording reference was placed at FCz; the ground electrode was placed at AFz. Electrode impedances were kept below 5 kΩ. EEG was sampled continuously at a rate of 1000 Hz with a bandpass filter from 0.1 to 70 Hz and a notch filter of 50 Hz.

Time epochs lasting from −200 before to 1000 ms after stimulus presentation were extracted and recalculated to average reference. Epochs containing artefacts (±100 μV) were removed from further analyses. All subjects had a sufficient number of trials (on average 60.3 epochs without effects for group or condition) of which the event-related potentials (ERPs) were averaged. The ERPs were filtered using a bandpass filter from 0.5 to 20 Hz. Baseline was corrected using the 200 ms before stimulus presentation. For the EPN, we calculated the mean amplitudes over the electrode position Oz (between 216 and 296 ms; defined on the basis of visual inspection and the literature; e.g., see (Schupp et al., 2007a) [with a time window between 200 and 300 ms]) of the difference curves between the emotional conditions (positive and negative separately) and the neutral condition for each subject and condition.

As indicated by the name EPN, this component is more negative for emotional stimuli as compared to neutral ones albeit the amplitudes are positive for all conditions, which
means that more activity is reflected by more negative EPN values. Additionally, we calculated the mean amplitudes of the difference curves over the electrode Pz between 276 and 430 ms for the early slow wave, and between 431 and 750 ms to determine the late slow wave. These electrode positions were specifically chosen to test our hypotheses as previous studies reported that these regions show the main effects for a comparison of emotional versus neutral stimuli. In order to allow further inspection of the comparison between ADHD patients and healthy controls (HCs) with regard to emotional processing we mapped the statistical comparison between ADHD patients and controls in difference maps (for neutral versus positive and negative stimuli) for all electrode positions (Figure 2).

**Statistical analysis**

We analysed the amplitudes of the ERPs using an ANOVA with the within subject factor condition (positive and negative minus neutral stimuli condition) and the between subject factor group (ADHD, controls) and gender (male, female). Two-sided t-tests were used for post-hoc analyses. For all analyses, P-values lower than 0.05 were considered significant.

**RESULTS**

We found a significant interaction condition × group (F[1,60]=4.2, P<0.05), without main effects of group (F[1,60]=1.1, n.s.), condition (F[1,60]=0.5, n.s.), or gender (F[1,60]=0.8, n.s.) for the EPN over the electrode position Oz (see Figure 1). All other interaction effects did not reach significance (all P>0.5). As can be seen in Figure 2, the electrode position Oz is within the area of the maximum difference between ADHD patients and HCs. Figure 2 also shows that the difference between the two groups extends to right temporal areas, a finding which must be replicated in future studies. The interaction condition × group over Oz described above can be explained by smaller EPN values in the ADHD group (M=−0.36, SD=1.19; t[62]=−2.0, P<0.05) as compared to the HC group (M=−0.88, SD=0.90) for the positive stimuli condition. There were no significant group differences for the negative stimuli condition (HC group: M=−0.71, SD=1.14; ADHD group: M=−0.71, SD=1.27; t[62]=0.0, n.s.). A comparison of the amplitudes for the three different conditions (positive, negative, neutral) did not reveal any significant differences between ADHD patients and HCs.

For the control group, EPN amplitude was significantly different from zero for both the positive (t[31]=−5.5, P<0.001) and the negative stimuli condition (t[31]=−3.5, P<0.001). In contrast, for the ADHD patients a significant EPN could only be found for the negative stimuli condition (t[31]=−3.2, P<0.01), but not for the positive stimuli condition (t[31]=−1.7, P=0.1).

For the early and the late slow wave (see Figure 3 for the time course over electrode position Pz) we found neither a significant main effect of group (early slow wave: F[1,62]=0.08, P=0.78; late slow wave: F[1,62]=0.09, P=0.77) nor a significant interaction condition × group (early slow wave: F[1,62]=0.27, P=0.61; late slow wave: F[1,62]=0.04, P=0.84). For the HCs as well as for the ADHD patients, the early slow wave is significantly different from zero for the negative (HCs: t[31]=3.8, P<0.001; ADHD patients: t[31]=5.2, P<0.001), but not for the positive stimuli condition (HCs: t[31]=−0.4, P=0.70; ADHD patients: t[31]=0.3, P=0.77). In contrast, the late slow wave is significantly different from zero for the negative (HCs: t[31]=5.6, P<0.001; ADHD patients: t[31]=10.7, P<0.01) as well as for the positive stimuli condition (HCs: t[31]=3.2, P<0.01; ADHD patients: t[31]=2.9, P<0.01) for both groups.

**DISCUSSION**

In this study, we found indications of a general deficit in positive stimuli processing in adult ADHD patients. In detail, we observed reduced EPN amplitudes in ADHD patients.
patients compared to HCs after positive visual stimuli, but no differences for the negative stimuli condition. This effect was only present for the EPN component, but not for the slow wave. These results underscore the value of using an event-related potential paradigm with high temporal resolution, as this allows the differentiation of early attention effects and later conscious processing.

One limitation of this study is that we did not collect behavioural data like eye movement or target detection. However, as we did not find any group differences for the negative stimuli condition, it seems implausible that both groups should differ with regard to their viewing behaviour. To ensure that ADHD patients and HCs show a similar evaluation of the stimuli on a subjective level, further studies should also include subjective preference ratings.

Our results are in line with previous studies showing a deficit in the reward system in patients with ADHD (Scheres et al., 2007; Ströhle et al., 2008) and further extend these results. One could argue that the neurons in the amygdala evaluate the emotional and reinforcing salience of sensory stimuli (Schoenbaum et al., 2000, 2003), and in addition signal the value of specific reinforcers to the orbitofrontal cortex in order to build up expectancies of behavioral outcome to guide and reinforce behavior (Pickens et al., 2003). Interestingly, recent studies found a reduced size of the amygdala (Plessen et al., 2006) and reduced startle modification in adult ADHD patients only for positive but not for negative stimuli (Conzelmann et al., 2009).

Based on the above findings, we argue that reduced amygdala activity to positive stimuli may lead to reduced activation of the reward system and in turn to an impaired processing of positive emotional stimuli in general. However, as we only measured event-related EEG

![Brain maps for the ADHD patients and the HCs for the difference wave between neutral and positive (upper part) or between neutral and negative (lower part) stimuli with views from the front, the top and the back. On the right side the t-values for the statistical comparison between both difference waves are mapped.](image)
potentials to passively viewed emotional pictures, we unfortunately are unable to make detailed conclusions about the function of the reward system in ADHD patients. As a consequence of our results we do nevertheless suggest the inclusion of positive and negative emotional stimuli into future studies investigating the reward system in ADHD patients.

It should also be mentioned that our ADHD patients were not drug naïve. The effects described in our study might therefore be a result of long term medication. A preliminary study (Woidich et al., 2009) found, however, that all investigated ADHD patients showed improved affective startle modulation in response to positive as well as negative pictures after the intake of methylphenidate. The reduced response to positive stimuli we found in our study is therefore unlikely to be caused by long term medication. Alternatively, the disturbance of positive stimuli processing might be caused by the withdrawal of the medication. Although this explanation of the results is unlikely, our study design does not allow us to rule it out. We consequently suggest the investigation of drug naïve ADHD patients in future studies.

Altogether, we found reduced emotional reactivity to positive stimuli which might be relevant for the social dysfunction described in ADHD patients. With respect to treatment-related implications the impaired response to positive stimuli found in our study might explain deficits in positive reinforcement learning (Frank et al., 2007) found in ADHD patients, which can be improved by medication (as has been shown in a preliminary study (Woidich et al., 2009) for the deficient processing of positive stimuli).

Conflict of Interest
None declared.

REFERENCES


