Facial emotion recognition deficits in children with and without attention deficit hyperactivity disorder: a behavioral and neurophysiological approach

Laura Rinke[a], Gian Candrian[a], Sarah Loher[a], Andrea Blunck[a], Andreas Mueller[a] and Lutz Jäncke[b]

The current study examined the facial emotion recognition ability with a simultaneous assessment of behavioral and neurophysiological data in children with and without attention deficit hyperactivity disorder (ADHD) aged 7–7 years using a facial emotion matching task and event-related potential measurements (event-related potential components N170 and N250 at T5 and T6) in an emotional continuous performance task. Group differences and interaction effects of children's performance (both behavioral and neurophysiological) were evaluated between children with ADHD and children without ADHD as well as between younger and older children. No deficit in facial emotion recognition was found for children with ADHD compared with children without ADHD even with neurophysiological parameters. However, in terms of developmental differences, the younger children differentiated in their behavioral and neurophysiological performance from the older children. No interaction was detected between the experimental groups and the age groups, indicating that developmental progression in terms of emotional processes did not differ between children with and without ADHD. This study indicates that the facial emotion recognition is above all an age-dependent function with later processing of facial emotion expressions in younger compared with older children and suggests that a facial emotion recognition deficit is secondary in children with ADHD and might occur only with specific emotions or ADHD subtypes, but not in the whole ADHD population. ***NeuroReport*** **00:000–000 Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.**

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[a]Brain and Trauma Foundation Grisons, Chur and [b]Division Neuropsychology, Institute of Psychology, University of Zurich, Zurich, Switzerland AQ2

Correspondence to Laura Rinke, MSc, Brain and Trauma Foundation Grisons, Poststrasse 22, CH-7000 Chur, Switzerland AQ3
e-mail: lrinke@me.com

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Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder with onset in childhood [1]. According to the American Psychiatric Association [1], the prevalence rate for ADHD is about 5% for children and about 2.5% for adults in most cultures. It is characterized by inattention, hyperactivity, and impulsivity. One of the leading symptoms of ADHD is difficulties in social interactions [2]. As devastating consequences for children with ADHD, they are often rejected by their peers, are less desirable, and engage in less reciprocal interactions [3].

Facial emotion recognition is an ability that is fundamental in social interaction as it helps an individual to understand and correctly behave to the social environment [4]. Several behavioral studies reported a deficit in facial emotion recognition in children with ADHD, but could not explain the underlying mechanisms of the deficit [5,6].

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A neurophysiological approach by assessing the event-related potential (ERP) components N170 and N250, particularly involved in facial emotion recognition [7,8], might aid a more sensitive symptom detection and understanding of the neurological causes for the dysfunction in facial emotion recognition. To the best of our knowledge, no study has been carried out as yet assessing the N250 and only two studies have examined the N170 in children with ADHD in the context of facial emotion recognition. The two studies report contrasting results. Williams *et al.* [9] found, among other alterations, an increased amplitude of the right occipital N170 for the emotions of anger and fear in 8–17-year-old young males with ADHD compared with healthy controls during the presentation of facial expressions consisting of the basic emotions. In contrast to above-described findings, no alterations in the N170 in the context of facial emotion processing were found by Tye *et al.* [10] for 8–13-year-old boys with ADHD.

Because of known changes in symptom severity and brain structures with age in children with ADHD [11,12], it is important to focus also on age effects when investigating functions and deficits in children with ADHD.

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Knowledge of age effects in facial emotion recognition during the childhood of individuals with ADHD is missing.

In the current study, we examined the facial emotion recognition ability with a simultaneous assessment of behavioral and neurophysiological data comparing children with and without ADHD and younger and older children, and investigating the interaction between age and ADHD. If we could detect differences in both behavioral and neurophysiological data, the current study may provide crucial new insights into the processing of facial emotion expressions in children with ADHD and a better understanding of age differences in facial emotion recognition. The findings would be relevant for a better and more objective detection and treatment of described deficit and its implicated symptoms such as severe difficulties in social interactions.

Participants and methods

Participants

Fifty-three children fulfilled the inclusion criteria, which were based on the *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. (DSM-5) criteria for ADHD [1] assessed using Barkley's Current Symptoms Scale [13]. Fifty children were included in the analyses. Because of multiple missing data, three children had to be excluded as only children with complete sets of data were included. The ADHD group included 29 children (24 males and five females; 10 with combined type, 14 with predominantly inattentive type, two with predominantly hyperactive-impulsive type, three could not be specified because of missing data; $M_{age}=12.09$ years, SD = 2.76 years; range: 7–17 years; 24 right-handed and five left-handed) and the control group included 21 children (nine males and 12 females; $M_{age}=12.08$ years, SD = 3.00 years; range: 8–17 years; 19 right-handed and two left-handed). The IQ was assessed either with the CFT 1-R [14], CFT 20-R [15], or WMT-2 [16] depending on the children's age. The children comorbidity questionnaire and the psychopathological assessment system for children and adolescents [17] were used to examine comorbid disorders of the ADHD children. Only two children showed symptoms of a developmental disorder and were included in the analyses. Without any concerns children were required to refrain from taking methylphenidate during 24 h before testing. Children with a neurological disorder, severe comorbidities, or brain traumatic injury with subsequent loss of consciousness were not included in the study. ADHD children were recruited by advertising the study in the media and by notifying psychiatrists and ADHD associations of the study. Controls were recruited from the local community by advertising the study in local media, companies, and associations.

To examine facial emotion recognition with respect to age differences, the group of children was divided into two age-dependent groups for all analyses: the younger age group included all children aged 7–11 years and the older age group included children between 11.1 and 17 years old.

The ethics committee of canton Zurich obtained the study's ethical consent. Before participation, the children and at least one parent provided written consent after the procedure had been explained to them in detail.

The present study is part of the 3-year project of Brain and Trauma Foundation, which focuses on the longitudinal investigation of biomarkers on children and adults with ADHD by measuring their brain activity by means of electroencephalogram (EEG) every 6 months.

Task procedure

Children had to undergo several tasks: among others, the emotional continuous performance task and the facial emotion matching (FEM) task.

The emotional continuous performance test (ECPT) used is a modification of the classical continuous performance task (CPT) [18]. The CPT is an attention test characterized by low critical stimuli and long duration. During the CPT, the participant had to get prepared for an action (go-trial), had to inhibit an action (no-go-trial), or simply had to ignore the stimulus. In the ECPT, different emotional stimuli were presented sequentially. The task consisted of four randomized blocks with 100 pairs of stimuli (pictures) in each block. Each stimulus was presented for 100 ms, with an interstimulus interval of 1000 ms. Trials were separated by a break of 1900 ms. The child was instructed to press the left button of a computer mouse with the finger of the dominant hand when the combination anger–anger (A–A) appeared (go-trial), not to press at the combination anger–happiness (A–H; no-go-trial), and to ignore the combinations happiness–happiness (H–H) and happiness–neutral (H–N). The duration of the task was about 22 min. During the task, the child was seated at a distance of 1.5 m in front of a computer screen in a comfortable chair (with head rest). The stimuli were presented on a 17 in. monitor using the NeuroAmp (BEE Medic). EEG signals were recorded during the tasks. AQ4

In the FEM task from the Candit neuropsychological test battery, pictures of different human facial emotion expressions extracted from Ekman and Friesen [19] were presented on a portable computer screen in front of the participant. Six pictures (model pictures) showing the emotions happiness, anger, fear, disgust, sadness, surprise, and a neutral face of the same individual were displayed permanently on the edge of the screen. In the center of the screen, stimuli of different human facial emotion expressions were presented sequentially. These stimuli consisted of 24 pictures with the same emotions as displayed in the model pictures. The child was asked to choose one of the model pictures showing an equal emotion as the one presented in the center of the screen. By tapping on one of the model pictures, the next stimulus was presented. Trial duration was therefore dependent on the child's speed of performance.

During the task, the participant was seated in a chair at a table in a quiet room. The task was presented on a AQ5 10.1 in. tablet (Windows 8.1) that was placed on the table in front of the participant.

Three variables [reaction time (ms), the number of commission errors (false-positive reactions), and the number of omission errors (false-negative reactions)] were recorded for the ECPT and four variables [reaction time (ms) and accuracy (% of the number of right answers from all answer possibilities in response to one emotion) for each emotion (happy and angry)] for the FEM task. The seven variables were taken together in the analysis as variables for the behavioral performance.

Electroencephalogram recording and data

A NeuroAmp ×23 with a PC-controlled 19-channel electroencephalographic system was used to record the EEG. The input signals, referenced to the linked earlobes, were sampled at a rate of 250 Hz and filtered between 0.5 and 50 Hz. For all electrodes, there was impedance below 5 kΩ. Before data processing, the linked earlobe reference montage was changed to a common average reference montage. Using an electrode cap with tin electrodes (Electro-cap International Inc.), the electrodes were placed according to the International 10–20 system. Artifact correction was carried out as described previously elsewhere [20].

The EEGLAB Matlab Toolbox [21] and self-programmed EEGLAB plugin were used for ERP analysis. The N170 and N250 were measured after the second stimulus onset of the A–A condition of the ECPT at the electrode-channels left temporal (T5) and right temporal (T6) because the largest N170 can be measured at bilateral occipito-temporal areas of the scalp, normally at the posterior electrode-channels left temporal (T5) and right temporal (T6) [22] as well as the N250 [23]. To measure the latency and amplitude of the raw ERP waves, a variation of the fractional area approach was used as described previously elsewhere [24]. The predefined latency windows were defined after the second stimulus onset of the A–A condition at T5 and T6 for the N250 from 232 to 280 ms with the peak at 256 ms and for the N170 from 148 to 294 ms with the peak at 176 ms.

The amplitudes and latencies of the N170 and N250 at T5 and T6 were used in the analysis as variables for the neurophysiological performance.

Statistical analyses

To quantify the performance measurements of the children, the means were calculated for each variable individually for all children. The Software Statistical Package for Social Science (BM SPSS Statistics for Macintosh, version 22.0) was used for the data analyses.

Three multivariate analyses of covariances (MANCOVAs) were carried out to test the main effects and interactions of the experiment groups (children with ADHD vs. children without ADHD) and the age groups (younger vs. older children) in terms of behavioral and neurophysiological performance. IQ and sex were controlled for behavioral and neurophysiological variables. Univariate analyses of variance (ANOVAs) were carried out post-hoc to identify differences, which were indicated by the MANCOVAs.

Results

Attention deficit hyperactivity disorder symptoms

On the basis of the ADHD questionnaire, children with ADHD showed significantly more current inattentive symptoms [$F_{(42, 1)} = 72.62$, $P < 0.001$, $r = 0.634$] current hyperactive/impulsive symptoms [$F_{(42, 1)} = 11.11$, $P = 0.002$, $r = 0.209$], and current total ADHD symptoms [$F_{(42, 1)} = 50.42$, $P < 0.001$, $r = 0.546$] compared with children without ADHD.

Facial emotion recognition ability

Behavioral performance

The MANCOVA in terms of behavioral performance showed neither a significant main effect of experiment group (children with and without ADHD) nor a significant interaction effect of experiment group by age group. Instead, a significant main effect could be found for age group (younger and older children) [$F_{(6, 35)} = 5.31$, $P = 0.001$, $r = 0.477$].

A subsequent univariate ANOVA (see Table 1, Supplemental digital content 1, *http://links.lww.com/WNR/A432*, which shows the mean values of the behavioral performance), showed significant effects of the age group on the mean reaction time of the ECPT [$F_{(1, 40)} = 19.64$, $P < 0.001$, $r = 0.329$], with the younger age group showing a longer reaction time ($M = 537$ ms) than the older age group ($M = 430$ ms). Moreover, a main effect was found in the FEM task in the accuracy of the emotion anger [$F_{(1, 40)} = 5.11$, $P = 0.029$, $r = 0.113$], where the younger age group ($M = 43.42\%$) was less accurate than the older age group ($M = 65.74\%$).

No statistically significant effects of the age group were found in the accuracy of the ECPT, the accuracy of the emotion happiness, and the mean reaction time in the emotion happiness and the emotion anger.

Neurophysiological performance

In terms of the neurophysiological performance, the MANCOVA yielded similar results as reported for the behavioral performance. A significant main effect was found for age group [$F_{(8, 36)} = 4.24$, $P = 0.001$, $r = 0.485$]. Again, there was neither a significant main effect of experiment group nor a significant interaction of experiment group by age group.

The following univariate ANOVA (see Fig. 2, Supplemental digital content 2, *http://links.lww.com/WNR/A433*, which shows the comparison of the mean latencies) showed significant effects of the age group on the latency of the right hemispheric N170 [$F_{(1, 43)}=32.12$, $P<0.001$, $r=0.428$], by showing a greater latency for the younger age group ($M=184$ ms) compared with the older age group ($M=160$ ms), on the latency of the left hemispheric N170 [$F_{(1, 43)}=9.85$, $P=0.003$, $r=0.186$], with the younger age group showing a greater latency ($M=180$ ms) than the older age group ($M=166$ ms), and on the latency of the right hemispheric N250 [$F_{(1, 43)}=4.78$, $P=0.034$, $r=0.100$], where the younger age group had a greater latency ($M=261$ ms) in comparison with the older age group ($M=255$ ms).

No significant main effects of the age group were found for the latency of the left hemispheric N250 and for the mean amplitudes of right and left hemispheric N170 and N250.

The ERPs are shown in Fig. 1.

Discussion

In the current study, both behavioral and neurophysiological performances of facial emotion recognition were compared between children with and without ADHD and between younger and older children.

Facial emotion recognition in children with attention deficit hyperactivity disorder

Surprisingly and contrary to our expectations, in this study, the behavioral performance tasks as well as the neurophysiological measurements could not differentiate the ADHD group from the group without ADHD in different tasks targeting children's ability of facial emotion recognition.

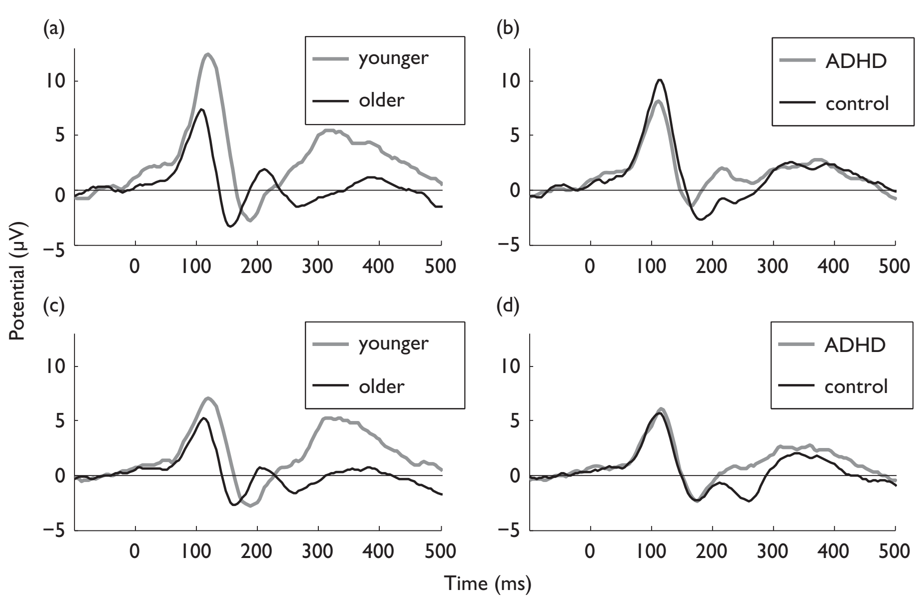
The present results thus implicate no substantial deficits in the behavioral and neurophysiological performance of facial emotion recognition in children with ADHD. The contradicting results presented in this study compared with previous studies [5,6,9] may be explained by differences in the task designs used to assess the facial emotion recognition performance and in the various electrode positions used to examine the N170.

Age effects in facial emotion recognition

The expected age effect was shown both in the behavioral performance and in the neurophysiological performance.

Older children showed better recognition accuracy of the emotion anger than the younger children and were faster in their responses. The longer reaction times of the younger children compared with the older children are in line with the general assumption of increased speed processing in adolescents compared with younger children [25]. This indicates that there exists an age-dependent difference in the process of facial emotion recognition between younger children and adolescents.

Fig. 1



The averaged waveforms showing the N170 and N250 (a) from the younger and older age group at T6, (b) from the attention deficit hyperactivity disorder (ADHD) and control group at T6, (c) from the younger and older age group at T5, and (d) from the ADHD and control group at T5. Zero millisecond indicates the second stimulus onset of the A–A condition of the emotional continuous performance test.

The age effect found in the neurophysiological data could be traced back to the right hemispheric latency of the N170 and N250 and to the left hemispheric latency of the N170. The younger children showed longer latencies than the older children, indicating a neural delay in decoding of facial emotion expressions in younger children compared with older children [8]. Thus, age-dependent differences in the process speed of facial emotion recognition were detected on the neurophysiological level, indicated in divergent latencies, as well as on the behavioral level, observed in the different reaction times.

Age-dependent facial emotion recognition ability in children with attention deficit hyperactivity disorder

The absence of an interaction effect between age group and experiment group indicates that both experimental groups showed the same pattern of age group-dependent differences in the performance of facial emotion recognition. Thus, it seems that the pattern of age group-dependent differences in the performance of a neuropsychological function is comparable in children with and without ADHD. This is contradictory to the general assumption of a delayed maturation in children with ADHD [12] and suggests that the delayed maturation is not present in all neurophysiological functions of children with ADHD and that facial emotion recognition could be one of them.

Conclusion

In the current study, no deficit in facial emotion recognition was found for children with ADHD even with neurophysiological parameters. Thus, a facial emotion recognition deficit seems to be secondary in children with ADHD and it might occur only with specific emotions or ADHD subtypes. A difference in facial emotion recognition was found between younger and older children. Therefore, the information processing of facial emotion recognition seems to be above all an age-dependent function, which is reflected in a later recognition of facial emotions in the right hemisphere of younger children. Further research is needed on facial emotion recognition in other age groups and with other kinds of emotions.

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A.B., A.M., G.C., L.R., and S.L. contributed toward the study conception and design. A.B., A.M., G.C., L.R., and S.L. headed the acquisition of data. A.M., G.C., L.J., L.R., and S.L. have been involved in drafting or revising the manuscript. L.R. and G.C. made substantial contributions toward the analysis of data. All authors read and approved the final manuscript.

Conflicts of interest

There are no conflicts of interest.

References

1 American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. Arlington, VA: American Psychiatric Press; 2013.
2 Biederman J. Attention-deficit/hyperactivity disorder: a selective overview. *Biol Psychiatry* 2005; **57**:1215–1220.
3 Nixon E. The social competence of children with attention deficit hyperactivity disorder: a review of the literature. *Child Adolesc Ment Health* 2001; **6**:172–180.
4 Thomas LA, Bellis MD, Graham R, LaBar KS. Development of emotional facial recognition in late childhood and adolescence. *Dev Sci* 2007; **10**:547–558.
5 Demirci E, Erdogan A. Is emotion recognition the only problem in ADHD? effects of pharmacotherapy on face and emotion recognition in children with ADHD. *Atten Deficit Hyperact Disord* 2016. 1–8.
6 Pelc K, Kornreich C, Foisy ML, Dan B. Recognition of emotional facial expressions in attention-deficit hyperactivity disorder. *Pediatr Neurol* 2006; **35**:93–97.
7 Blau VC, Maurer U, Tottenham N, McCandliss BD. The face-specific N170 component is modulated by emotional facial expression. *Behav Brain Funct* 2007; **3**:7.
8 Wynn JK, Jahshan C, Altshuler LL, Glahn DC, Green MF. Event-related potential examination of facial affect processing in bipolar disorder and schizophrenia. *Psychol Med* 2013; **43**:109–117.
9 Williams LM, Hermens DF, Palmer D, Kohn M, Clarke S, Keage H, *et al.* Misinterpreting emotional expressions in attention-deficit/hyperactivity disorder: evidence for a neural marker and stimulant effects. *Biol Psychiatry* 2008; **63**:917–926.
10 Tye C, Battaglia M, Bertoletti E, Ashwood KL, Azadi B, Asherson P, *et al.* Altered neurophysiological responses to emotional faces discriminate children with ASD, ADHD and ASD + ADHD. *Biol Psychol* 2014; **103**:125–134.
11 Biederman J, Mick E, Faraone SV. Age-dependent decline of symptoms of attention deficit hyperactivity disorder: impact of remission definition and symptom type. *Am J Psychiatry* 2000; **157**:816–818.
12 Shaw P, Gogtay N, Rapoport J. Childhood psychiatric disorders as anomalies in neurodevelopmental trajectories. *Hum Brain Mapp* 2010; **31**:917–925.
13 Barkley R, Murphy K. *Attention-deficit hyperactivity disorder: a clinical workbook*, 3rd ed. New York, NY: Guilford Press; 2006.
14 Weiß RH, Osterland J. *CFT 1-R Grundintelligenztest Skala 1 – Revision*. Göttingen: Hogrefe; 2013. AQ6
15 Weiß RH. *Grundintelligenztest Skala 2 – Revision – (CFT 20-R)*. Göttingen: Hogrefe; 2006.
16 Formann AK, Waldherr K, Piswanger K. *Wiener Matrizen-Test 2 Manual*. Göttingen: Beltz Test GmbH; 2011.
17 Döpfner M, Berner W, Flechtner H, Lehmkuhl G, Steinhausen H-C. *Psychopathologisches Befund-System für Kinder und Jugendliche (CASCAP-D)*. Göttingen: Hogrefe; 1999.
18 Rosvold HE, Mirsky AF, Sarason I, Bransome ED Jr, Beck LH. A continuous performance test of brain damage. *J Consult Psychol* 1956; **20**:343–350.
19 Ekman P, Friesen WV. *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologists Press; 1976.
20 Müller A, Candrian G, Dall'Acqua P, Kompatsiari K, Baschera G-M, *et al.* Altered cognitive processes in the acute phase of mTBI: an analysis of independent components of event-related potentials. *Neuroreport* 2015; **26**:952–957.
21 Makeig S, Westerfield W, Enghoff S, Jung T-P, Townsend J, Courchesne E, *et al.* Dynamic brain sources of visual evoked responses. *Science* 2002; **295**:690–694.
22 Rossion B, Jacques C. Does physical interstimulus variance account for early electrophysiological face sensitive responses in the human brain? Ten lessons on the N170. *Neuroimage* 2008; **39**:1959–1979.
23 Williams LM, Kemp AH, Felmingham K, Liddell BJ, Palmer DM, Bryant RA. Neural biases to covert and overt signals of fear: dissociation by trait anxiety and depression. *J Cogn Neurosci* 2007; **19**:1595–1608.
24 Kompatsiari K, Candrian G, Mueller A. Test–retest reliability of ERP components: a short-term replication of a visual Go/NoGo task in ADHD subjects. *Neurosci Lett* 2016; **617**:166–172.
25 Kail R. Developmental change in speed of processing during childhood and adolescence. *Psychol Bull* 1991; **109**:490–501.

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