Psychology, 2022, 13, 1622-1640
https://www.scirp.org/journal/psych
ISSN Online: 2152-7199
ISSN Print: 2152-7180

Impaired Recognition of Emotional Facial Expressions in Adults with Attention Deficit/Hyperactivity Disorder: A Review of Event Related Potential (ERP) Studies

Orrie Dan*, Ami Cohen

Department of Psychology, The Max Stern Academic College of Emek Yezreel, Emek Yezreel, Israel
Email: *orid@yvc.ac.il

How to cite this paper: Dan, O., & Cohen, A. (2022). Impaired Recognition of Emotional Facial Expressions in Adults with Attention Deficit/Hyperactivity Disorder: A Review of Event Related Potential (ERP) Studies. *Psychology*, *13*, 1622-1640.
https://doi.org/10.4236/psych.2022.1311101

Received: August 31, 2022
Accepted: October 18, 2022
Published: October 21, 2022

Abstract

Background: The link between attention deficit/hyperactivity disorder (ADHD) and impaired recognition of emotional facial expressions is well documented. The cause for this impairment is, however, unclear. Some studies suggest that it may be due to deficits in emotional processing, while others attribute it to inattention. Purpose: This review examines the temporal evolution of the response of adults with ADHD to emotional facial expressions. The process is assessed using Event Related Potential (ERP), a technique that follows the response with millisecond resolution. Method: An integrated, systematic search of relevant databases based on the Whittemore and Knafl and the PRISMA 2020 review methodologies was applied. Ten studies met all the inclusion criteria. Results: Behavioral data (such as response time) confirm that adults with ADHD have some deficits in their ability to identify emotional facial expressions when compared to healthy controls. However, their degree of impairment varies with expression type. Analysis of the time-evolution of the response, as measured by ERP, shows that the response of adults with ADHD is heightened, when compared to healthy peers, in both initial and later stages. In the intermediate window, at approximately 300 ms, adults with ADHD show muted EPR amplitudes when compared to their healthy peers. The same time-evolution of response was observed for both emotional expressions and neutral ones. Conclusions: Overall, adults with ADHD display some level of impairment in their ability to recognize emotional facial expressions that is dependent on the expression valence. The time-evolution of the responses suggests the impairment might be linked to a lapse in attention at roughly 300 ms post-stimulus.

Keywords

Attention Deficit/Hyperactivity Disorder, Event Related Potential, Emotional Facial Expressions, Adults

1. Introduction

Individuals with ADHD display deficient social competences, including difficulties in determining emotional states in others (Alperin, Gustafsson, Smith, & Karalunas, 2017; Bisch et al., 2016; Cadesky, Mota, & Schachar, 2000; Corbett & Glidden, 2000; Demirci & Erdogan, 2016; Friedman et al., 2003; Miller, Hanford, Fassbender, Duke, & Schweitzer, 2011; Pelc, Kornreich, Foisy, & Dan, 2006; Rapport, Friedman, Tzelepis, & Van Voorhis, 2002; Retz-Junginger, Giesen, Rosler, & Retz, 2016; Romani et al., 2018; Schönenberg, Schneidt, Wiedemann, & Jusyte, 2015; Singh et al., 1998; Sinzig, Morsch, & Lehmkuhl, 2008; Uekermann et al., 2010). One of the underlying factors contributing to this impairment is the reduced ability of people with ADHD to recognize emotional facial expressions (EFE) (see, for example, (Alperin et al., 2017; Bisch et al., 2016; Bora & Pantelis, 2015; Borhani & Nejati, 2018; Cadesky et al., 2000; Corbett & Glidden, 2000; Demirci & Erdogan, 2016; Feuerriegel, Churches, Hofmann, & Keage, 2015; Friedman et al., 2003; Herrmann, Biehl, Jacob, & Deckert, 2010; Miller et al., 2011; Pelc et al., 2006; Rapport et al., 2002; Retz-Junginger et al., 2016; Romani et al., 2018; Schönenberg et al., 2015; Singh et al., 1998; Sinzig et al., 2008; Uekermann et al., 2010)). Meta-analysis of related studies shows that people with ADHD require more time, and make more errors, than healthy controls in the identification of some EFE (Bora & Pantelis, 2015; Borhani & Nejati, 2018; Feuerriegel et al., 2015; Herrmann et al., 2010; Romani et al., 2018).

The underlying cause for impaired EFE recognition in individuals with ADHD is unclear. One mechanism may be related to inattention, which has been linked to errors in EFE recognition in healthy individuals (see, for example, (Lassalle & Itier, 2013)). Indeed, the response of people with ADHD to non-emotional cognitive stimuli was found to differ from that of healthy controls over periods of order 500ms or less (Barry et al., 2009), the same time frame required for identification of EFE. Therefore, the inherent inattention symptom of ADHD could be the cause for impaired EFE identification.

Alternately, deficits in EFE recognition in ADHD may be the result of an inherent impairment in emotional processing. This is supported by functional Magnetic Resonance Imaging (fMRI) studies, that find altered brain activity in regions related to emotional processing in individuals with ADHD (Rubia, 2018).

Emotions and EFE are defined on two dimensions: Valence, which refers to the degree of pleasantness, and arousal, which defines the intensity of the emotion (Barrett, 1998). Standard studies of EFE recognition utilize visual Oddball tests, where participants identify a target stimulus presented among repeated standard stimuli. These yield behavioral parameters such as reaction time (RT), valence rating and commission/omission error rates. The resulting information enables determination of the EFE valences that ADHD individuals have difficulties identifying, and the magnitude of the effect. However, behavioral measures represent the entirety cognitive and emotional processes involved in EFE recognition, and cannot probe the underlying processing.

Blood oxygenation level-dependent (BOLD) functional Magnetic Resonance Imaging (fMRI) and functional connectivity (FC) yield unique information regarding the spatial resolution of brain activity, in particular the relationships between neuroanatomy and cognitive processes (see, for example, (Ochsner, Bunge, Gross, & Gabrieli, 2002; Phan, Wager, Taylor, & Liberzon, 2002)). fMRI studies show that many brain networks participate in human emotion processing, including the amygdala, visual cortices, orbitofrontal and right frontal-parietal cortexes, basal ganglia and others (Ochsner et al., 2002; Phan et al., 2002; Phelps & LeDoux, 2005; Vuilleumier, 2005; Vuilleumier, Armony, Driver, & Dolan, 2001; Whalen et al., 1998). However, the response to EFE occurs largely within 400ms from stimulus onset (Ding, Li, Wang, & Luo, 2017; Eimer & Holmes, 2002, 2007; Eimer, Holmes, & McGlone, 2003; Hajcak, MacNamara, & Olvet, 2010; Holmes, Vuilleumier, & Eimer, 2003; Kirouac & Dore, 1983; Luo, Feng, He, Wang, & Luo, 2010; Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Junghofer, Weike, & Hamm, 2003; Vuilleumier & Pourtois, 2007; Wells, Gillespie, & Rotshtein, 2016), a time frame which fMRI's seconds-long delay (associated with its measurement of indirect metabolics) cannot access. Therefore, while fMRI is extremely effective at the identification of activity sites, it does not allow investigation of time-dependent responses.

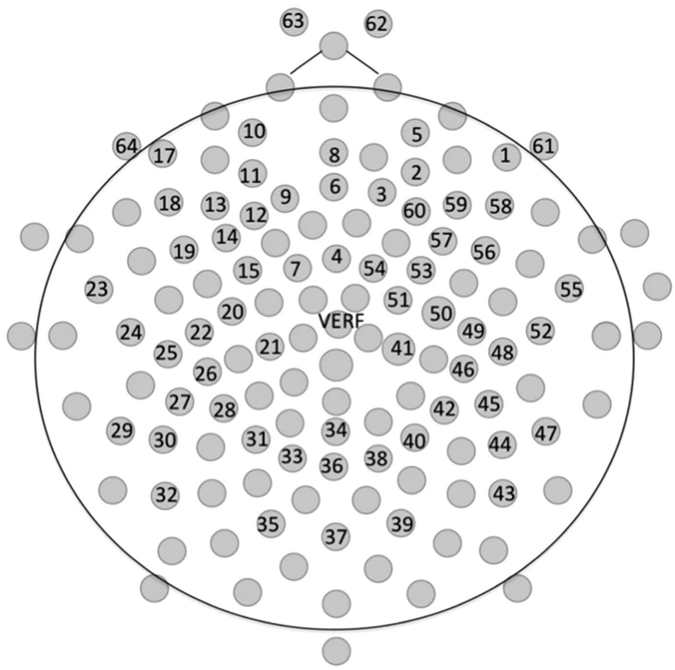
Event-related potential (ERP) enables measuring temporal brain responses within millisecond timeframes, in a non-invasive manner, as captured by an electrode array (see **Figure 1(a)**). Several ERP components were shown to be sensitive to emotional stimuli, as illustrated in **Figure 1(b)**.

P100 (80 - 145 ms post stimulus onset) is a positive-direction component usually detected at the parieto-occipital electrodes, shown to be affected significantly by facial emotions but with no integration of emotion significance or social information (Aguado et al., 2012; Ding et al., 2017; Luo et al., 2010; Utama, Takemoto, Koike, & Nakamura, 2009).

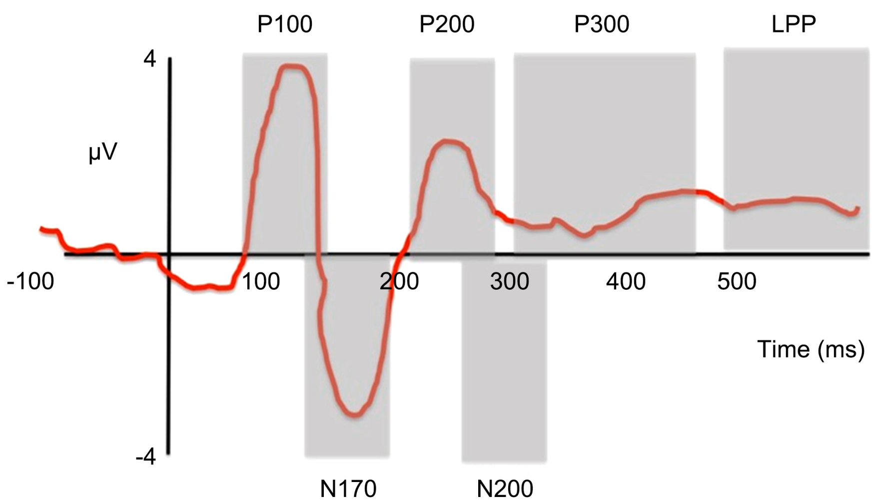
N170 (150 - 180 ms post stimulus onset) is a negative ERP component that is detected by the lateral occipitotemporal electrodes (Ding et al., 2017) and shown specifically to respond to facial stimuli (Blau, Maurer, Tottenham, & McCandliss, 2007; Holmes et al., 2003; Rossion et al., 1999). Some studies find that N170 differentiates between neutral and various emotional faces (Blau et al., 2007; Eimer & Holmes, 2002; Holmes et al., 2003; Rossion et al., 1999).

P200 (185 - 260 ms post stimulus onset) is associated with selective attention and perception of arousing stimuli (Ashley, Vuilleumier, & Swick, 2004), indexing natural selective attention such as evaluation of image features guided by perceptual processes that select affectively arousing stimuli for further processing (Dolcos & Cabeza, 2002; Schupp et al., 2004). Studies have suggested that early stimulus discrimination and selective processing of emotional pictures is reflected by increased P200 (Olofsson et al., 2008; Pourtois, Grandjean, Sander, & Vuilleumier, 2004).

N200 (265 - 300 ms post stimulus onset) is associated with face-specific arousal (intensity) levels of stimuli and with their identification and differentiation (see, for example, (Naatanen & Picton, 1986; Olofsson et al., 2008)).



(a)



(b)

Figure 1. Event Related Potential (ERP). (a) Example for electrode array; (b) A schematic of ERP output, with some of the characteristic peaks.

P300 (300 - 480 ms post stimulus onset) at the parieto-occipital electrodes indicates attention-performance related to higher order cognitive operations. Studies find differentiation in P300 between different facial expressions (Calvo & Beltran, 2013; Campanella et al., 2010; Ding et al., 2017; Schupp et al., 2003), linking P300 to top-down processing of emotional information including emotional evaluation, memory encoding and memory formation (Hajcak et al., 2010; Olofsson et al., 2008).

LPP (540 - 650 ms post stimulus onset) is typically detected at posterior-parietal sites and discriminates between discrete emotions, an indicator of emotional processing (Ding et al., 2017; Foti, Hajcak, & Dien, 2009; Foti, Weinberg, Dien, & Hajcak, 2011; Hajcak, Dunning, & Foti, 2009).

The accuracy and speed of EFE recognition increases significantly through childhood and adolescence, reaching a plateau around age 20 - 25 that is followed by a decline in the elderly (Goncalves et al., 2018; Lawrence, Campbell, & Skuse, 2015; Ruffman, Henry, Livingstone, & Phillips, 2008; Williams et al., 2009). As a result, impairment in EFE recognition cannot be clearly identifies when examining mixed-age populations. To date, however, reviews of EFE recognition in individuals with ADHD either focus on early childhood, or include a broad range of ages. For example, (Romani et al., 2018) examined individuals of ages 6 - 18, while (Bora & Pantelis, 2015) examined ages 8 - 38 years.

In this review we examine EFE recognition in adults with ADHD, comparing their responses to different expressions with those of healthy controls on both behavioral measures and the temporal evolution as given by ERP. The results allow better understanding of the underlying causes for impaired EFE recognition in adults with ADHD, and may suggest methodologies to address the issue.

2. Materials and Methods

The review methodology follows Whittemore and Knafl (Whittemore & Knafl, 2005) for integrated, systematic reviews, with additional components from PRISMA 2020 (Page et al., 2021). The stages include problem identification, search of the literature, data extraction and evaluation, data analysis and presentation of the results.

The databases searched for articles published between 1980 and 2018 include APA PsycNet, ISI Web of Science, PubMed and Scopus. Papers selected were controlled, peer reviewed studies (namely, excluding conference abstracts or papers), in English.

The systematic search on the databases was performed using a block- searching strategy that included a free text search. The blocks were created based on the aim of the study using:

(i) (“ADHD” OR “attention deficit disorder” OR “attention deficit hyperactivity disorder” OR “attention-deficit/hyperactivity disorder”)

AND (“response time” OR “reaction time” OR “error”),

AND (emotion or emotional).

(ii) (ADHD OR "attention deficit disorder" OR "attention deficit hyperactivity disorder" OR "attention-deficit/hyperactivity disorder")

AND ("event related potential" OR "event related potentials" OR "ERP"),

AND (emotion OR emotional).

It should be noted that using search criteria such as "adult" vs. "child" was not effective, since most studies did not clearly specify the study population age group in their searchable abstracts. Also, including criteria such as "facial expression" eliminated some relevant papers. Therefore, the search used more general criteria and the results were individually screened by the author for relevance.

Search results were collated and duplicates removed. Then the publications were examined individually based on their titles and abstracts, and irrelevant studies excluded (in particular, ones whose focus was on children or adolescents). The final step involved assessment of the full text of the remaining papers to ensure relevance.

3. Results

3.1. Study Selection and Characteristics

Search (i) yielded 94 papers. Of these, 8 were reviews, 3 conference papers or abstracts, and 2 corrections. Of the remaining 81 papers, 74 focused on topics not related to this review (e.g. effects of medication) and/or on children and adolescents. 7 papers were relevant to this study. Search (ii) yielded a total of 60 unique papers. Of these, 8 were reviews, 2 were meeting abstracts and 1 an editorial. Of the remaining, 34 focused on topics not relevant to this review (e.g. emotional control), and 9 studied EFE using ERP in children or adolescents. This left 5 papers on EFE recognition in adults with ADHD using ERP. 2 of these overlapped with the results of search (i). The process is summarized in Figure 2.

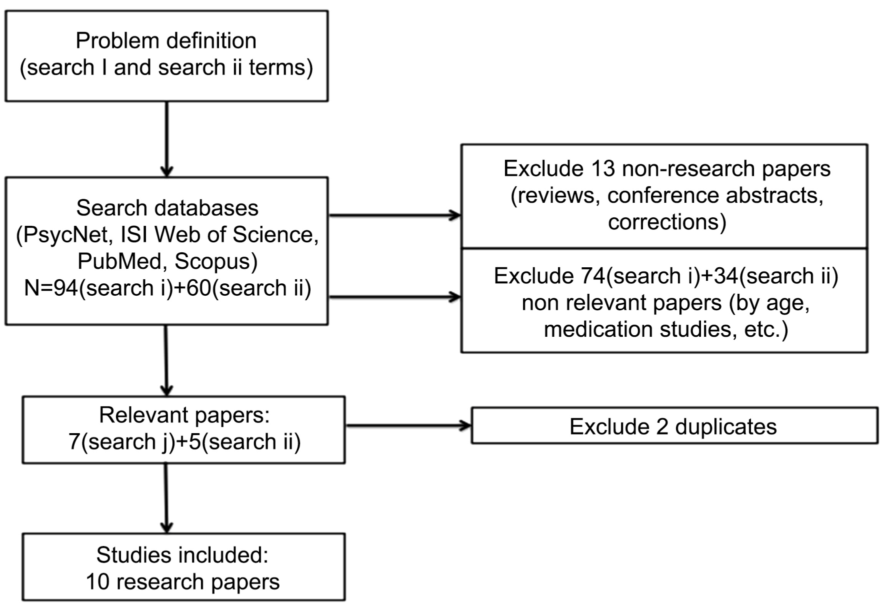


Figure 2. Paper selection flow diagram.

The ten papers that satisfied the search criteria are listed in Table 1.

3.2. Reaction Time and Error Rate

A number of studies examined the reaction time and error rates associated with recognition of emotional facial expressions in adults with ADHD, in comparison to a matched control group (study data is summarized in Table 1). The effect is highly sensitive to the expression valence:

Neutral: Most tests use a neutral facial expression as the "non-target" cue, so that the process examines whether an individual can distinguish an emotional expression when compared to the neutral one. When using neutral expressions as the target expression, Rapport et al. (Rapport et al., 2002) and Schultz et al (Schulz et al., 2014) did not observe significant differences in neutral expression recognition between ADHD and controls. In contrast, both Baran-Tatar (Baran Tatar et al., 2015) and Bisch et al. (Bisch et al., 2016) found that adults with

Table 1. Demographic and study design data.

Authors	ADHD participants, M:F	ADHD subtype	Control participants, M:F	Age average	ADHD medication status
Baran-Tatar et al. (Baran Tatar, Yargic, Oflaz, & Buyukgok, 2015)	40 29:11	NS*	40 29:11	26	Tested while using MPH
Bisch et al. (Bisch et al., 2016)	23 16/7	NS	31 21/10	28	Medication-free for 24 hrs prior
Herrmann et al. (Herrmann et al., 2009)	32 17:15	NS	33 17:15	33	Medication-free For 72 hours prior
Ibáñez et al.	10 9:1	NS	10 9:1	33	Medication-free on day of test
Markovska-Simoska et al. (Markovska-Simoska & Pop-Jordanova, 2010)	50 21:29	I, HI, C	50 24:26	30 - 34	Medication-free for 48 hrs prior
Miller et al. (Miller et al., 2011)	33 NS	C and I	18 NS	34	Medication-free for 24 hrs prior
Rapport et al. (Rapport et al., 2002)	28 16:12	C and HI	28 15:13	33 - 36	NS
Raz and Dan (Raz & Dan, 2015a)	21 5:15	C	19 4:15	25	Medication-free for 24 hrs prior
Raz and Dan (Raz & Dan, 2015b)	21 5:15	C	19 4:15	25	Medication-free for 24 hrs prior
Shishakova et al. (Shushakova, Ohrmann, & Pedersen, 2018)	39 21:18	C and I	40 22:18	31	Medication-free for 24 hrs prior

*NS indicates "not specified", namely, where the article did not specify relevant details.

ADHD made more neutral expressions recognition errors than the controls. Interestingly, the neutral-expression recognition errors made by the ADHD participants seem to be independent of medication status: The subjects tested by Baran-Tatar et al. (Baran Tatar et al., 2015) performed the test while under the influence of MPH, while the Bisch et al. (Bisch et al., 2016) ones were medication-free for a period of 24 hrs.

Happy: RT results are contradictory: Markovska-Simoska et al. (Markovska-Simoska & Pop-Jordanova, 2010) and Schultz et al. (Schulz et al., 2014) did not observe significant differences between the ADHD and controls, while Raz and Dan (Raz & Dan, 2015a, 2015b) find that the RT was much slower for the ADHD group. It should be noted that happy EFE is the only expression that is clearly pleasant, and is therefore studied most frequently. Overall, accuracy in recognition rates of happy EFE was the highest in both controls and ADHD subjects. Rapport et al. (Rapport et al., 2002) found that the ADHD group was less accurate than the control group in identification of happy EFE, although the difference between the means was within the SD of the two distributions (85.7 ± 19.6 in ADHD, vs. 95.8 ± 9.8). Similar results were found (Baran Tatar et al., 2015) for the ADHD under MPH conditions, and for medication-free ADHD subjects (Bisch et al., 2016). Miller et al. (Miller et al., 2011) did not observe significant differences in recognition of happy EFE between controls and either ADHD-C or ADHD-I. The similarity between the two groups held even when distinguishing omission and commission errors: Both Markovska-Simoska et al. (Markovska-Simoska & Pop-Jordanova, 2010) and Raz and Dan (Raz & Dan, 2015a) did not find any significant differences in either commission or omission errors between the two groups.

Sad: RT was similar for sad EFE identification in ADHD and control groups (Markovska-Simoska & Pop-Jordanova, 2010; Schulz et al., 2014). Rapport et al. (Rapport et al., 2002) did not find significant difference in recognition errors sad EFE between the ADHD and control groups. Similarly, while Miller et al. (Miller et al., 2011) did not observe differences between ADHD-C and the control. However, individuals with ADHD-I made more errors (Miller et al., 2011). Comparing omission and commission errors, Markovska-Simoska et al. (Markovska-Simoska & Pop-Jordanova, 2010) showed that the number of omission errors similar between the ADHD and control group for sad EFE, but the number of commission errors was twice as high in the ADHD group as the control, while Schultz (Schulz et al., 2014) found only minor differences.

Angry: Although unpleasant EFE include sad, fearful and angry, the latter is often used as a model expression. Angry EFE identification required longer times in the ADHD group than in controls (Markovska-Simoska & Pop-Jordanova, 2010; Raz & Dan, 2015a, 2015b). Rapport et al. (Rapport et al., 2002), Baran-Tatar (Baran Tatar et al., 2015) and Bisch et al. (Bisch et al., 2016) found that the ADHD group made significantly more errors in the recognition of angry expressions than the control. In contrast, Miller et al. (Miller et al., 2011) found that both ADHD-C and ADHD-I performed similarly to the control only for angry expression recognition. Markovska-Simoska et al. (Markovska-Simoska & Pop-Jordanova, 2010) did not find differences in the number of omission errors made, but the ADHD group showed 1/3 as many commission errors as the control. In contrast, Raz and Dan (Raz & Dan, 2015b) observed three-times as many omission errors in the ADHD group when compared to controls.

3.3. Event Related Potential (ERP)

The time evolution of emotion processing can be divided into three steps that are associated with the different ERP components (Luo et al., 2010): An initial, automatic, overall processing step that occurs on timescales of order 100 ms, followed by an intermediate stage that distinguishes between emotional and neutral facial expressions on time scales of 150 - 250 ms. Last is the stage at which the specific emotional facial expression is determined, over times of 300 ms or more. Here we review findings according to these three time steps (study data summarized in **Table 1**):

3.3.1. Initial Response Stage: 100 - 150 ms Post Stimulus

P100 (also referred to as P1) is a positive-direction component that peaks about 100 - 130 ms after stimulus onset. It is usually detected at the parieto-occipital electrodes (PO, see **Figure 1(a)**). P100 was shown to be significantly sensitive to facial emotions (Aguado et al., 2012; Ding et al., 2017; Luo et al., 2010; Utama et al., 2009).

Raz and Dan (Raz & Dan, 2015a) found that the P100 amplitude in the posterior-parietal and occipital electrodes of participants with ADHD was much larger, for all types of expression, than that of the control group. The response for pleasant (happy) was larger than for unpleasant (angry) valence expressions in both groups, although in the controls the differences between the expressions were not statistically significant. In the ADHD group, the response to neutral face stimuli in the occipital channels was similar to the response to the angry EFE, while in the control it matched the response to happy EFE (Raz & Dan, 2015a). In the Oz electrode, Herrmann et al. (Herrmann et al., 2009) found no significant differences in the response neutral, pleasant, or unpleasant EFE in both ADHD and control groups, or between the two subject groups.

3.3.2. Intermediate Stage: 150 - 250 ms Post Stimulus

Studies indicate that early lateralized processing, as reflected by the ERP signature of N170, encodes for emotional features holistically. N170 is a negative ERP component that is detected by the lateral occipitotemporal electrodes and peaks at (approximately) 170 ms after stimulus onset (Ding et al., 2017) and responds to face, rather than non-face, stimuli (Blau et al., 2007; Holmes et al., 2003; Rossion et al., 1999).

As expected, both healthy controls and adults with ADHD were found to exhibit a significant N170 response to neutral or emotional facial expressions (Raz

& Dan, 2015a, 2015b). In both groups, the amplitude of the N170 was smaller for the neutral stimulus when compared to an emotional one. However, for each expression valence (neutral, pleasant-happy, unpleasant-angry) the amplitude was significantly larger in the ADHD group (Raz & Dan, 2015a, 2015b).

Comparing the different valence EFE, adults with ADHD did not show significant differences in N170 to the pleasant and unpleasant stimuli in both hemispheres, while the N170 response of the controls in the right hemisphere was larger for happy EFE when compared to angry (Ibanez et al., 2011). The response in the occipital and posterior-parietal channels was higher in the ADHD group to angry EFE than happy, while the healthy controls displayed the opposite (Raz & Dan, 2015a).

3.3.3. Later Stages: 300 ms or More Post Stimulus

Early posterior negativity (EPN), over the occipito-temporal sites, has a peak at 210 - 350 ms after the application of a stimulus. The amplitude and hemisphere of EPN in response to EFE was found to depend on the expression (Aguado et al., 2012; Ding et al., 2017), suggesting that EPN response that occurs after N170 can discriminate between emotions. The amplitude of EPN after pleasant EFE stimuli (happy expression) was reduced in ADHD adults when compared to the healthy control subjects (Herrmann et al., 2009; Williams et al., 2008). However, it was similar in both groups after unpleasant stimuli (Herrmann et al., 2009; Raz & Dan, 2015a).

P300 has a peak latency of 300 - 400 ms, typically characterized by a positive deflection at the parieto-occipital electrodes. The ERP response of adults with ADHD and controls to neutral and to happy EFE was found to be similar at this time point, but their response to angry EFE was different (Raz & Dan, 2015a).

The response to stimuli varies not only with time, but also with electrode location. Therefore, a useful method to present such data is by topographical maps that display the value of the voltage measured in the different electrodes at a specific time point. **Figure 2** compares the topographical maps of the P300 response to neutral and to angry EFE between control and ADHD adults (Raz & Dan, 2015b). The response to the neutral expression is indeed similar for both groups, with voltage values that are near zero for all electrodes. In contrast, the response to the angry EFE is quite different: The control group shows very negative values at the anterior prefrontal electrodes, and very positive values at the parietal and occipital midline. In contrast, the ADHD group shows a nearly uniform and near zero distribution that resembles the response to neutral expressions.

Examining the difference in P300 peak potential between an emotional EFE (either angry or happy) and a neutral expression as a function of individual RT revealed a significant negative correlation with RT for the ADHD adults, that was more pronounced for the unpleasant EFE. No such correlation was found in the control group (Raz & Dan, 2015a). This suggests that poorer discrimination between neutral and emotional stimuli (as given by a smaller P300 amplitude difference) is associated with slower response time. LPP (also referred to as LPC) is typically detected at parietal sites similar to P300: A positive-going component of ERP that peaks at approximately 300 ms and may persist for long periods of time up to several seconds (Ding et al., 2017; Foti et al., 2011; Hajcak et al., 2009). The response of LPP to emotion stimuli differs significantly from the early parietal activities (Foti et al., 2009) and can discriminate between different EFE (Calvo & Beltran, 2013; Recio, Schacht, & Sommer, 2014). Shushakova et al. (Shushakova et al., 2018) found the centroparietal LPP response was lower for neutral expressions when compared to the unpleasant EFE for stimulant-medicated ADHD, stimulant free ADHD, and controls. In the case of neutral expressions, the LPP for the control and medicated ADHD subjects was not significantly different, while the medication-free group's values were much higher. In the case of unpleasant valence EFE, the responses of the two ADHD groups were similar (Shushakova et al., 2018). These results indicate that long-term ADHD medication can affect responses to EFE even when the subjects are not under their direct influence.

4. Discussion

Individuals with ADHD often exhibit impairment in social competences related to emotion processing and regulation (Alperin et al., 2017; Bisch et al., 2016; Demirci & Erdogan, 2016; Miller et al., 2011; Pelc et al., 2006; Rapport et al., 2002; Retz-Junginger et al., 2016; Romani et al., 2018; Schönenberg et al., 2015; Singh et al., 1998; Sinzig et al., 2008; Uekermann et al., 2010). Specifically, they display difficulties in determining emotional state in others (see, for example, (Cadesky et al., 2000; Corbett & Glidden, 2000; Pelc et al., 2006; Rapport et al., 2002; Sinzig et al., 2008)). Although ADHD symptoms and competencies in EFE recognition are age-dependent, to date no review focused specifically on EFE recognition in adults with ADHD.

The behavioral findings of the papers reviewed here suggest that impaired recognition of EFE in adults with ADHD is linked to inattention. Adults with ADHD typically require longer RT to recognize EFE, and display larger RT variability and more recognition errors when compared to healthy controls (Markovska-Simoska & Pop-Jordanova, 2010; Miller et al., 2011; Rapport et al., 2002; Raz & Dan, 2015a, 2015b; Schulz et al., 2014). This is consistent with the general finding that individuals with ADHD display significant intra-individual variability in RT on a range of computerized tasks (Tamm et al., 2012), which is thought to reflect lapses in sustained attention.

The link between recognition of EFE and attention lapses in adults with ADHD, rather than deficits in emotional processing, is also consistent with the difficulties in identification of neutral expressions-namely, expressions that do not elicit an emotional reaction (Baran Tatar et al., 2015; Bisch et al., 2016). However, it should be noted that in these tests, target neutral expressions were interspaced with emotional ones, so that some emotional processing component might still play a role in identification.

RT and error rates represent the entire, complex process of EFE recognition. They encompass multiple steps such as the identification of features, cognitive processing, emotional processing, and even neurological control of hand motions. Decoupling these requires a methodology that provides temporal information within millisecond resolution, namely, ERP.

ERP is highly effective for following the evolution, with time, of responses to stimuli. The voltage difference in a particular electrode, at a specific time, between ADHD and control subjects is an indicator of differences in activity. Occurring approximately 100ms post stimulus, the P100 amplitude in healthy controls distinguishes between different valence EFE (see, for example, (Eimer & Holmes, 2002, 2007; Holmes et al., 2003; Olofsson et al., 2008)). Therefore, although it is unlikely that over this short period there is integration of emotion significance or social information (Ding et al., 2017), P100 suggests that partial information can be extracted rapidly before completing the differentiation of expressions (see, for example, (Eimer & Holmes, 2002)). Slightly later in the temporal evolution of EFE processing, N170 is effective for determination of emotion neural processing, although it may not provide information regarding modulatory factors (see, for example, (Leppanen, Kauppinen, Peltola, & Hietanen, 2007)).

The response of adults with ADHD to EFE in the initial stages shows larger amplitudes in both P100 and N170 when compared to healthy adults (Raz & Dan, 2015a, 2015b). This could suggest that adults with ADHD have an increased sensitivity, initially, to facial stimuli. Significantly, the larger response is not caused by emotional content, occurring for pleasant, unpleasant or neutral expression stimuli, although it is modulated by valence: The P100 amplitude of the response to happy EFE was higher for happy when compared to angry EFE, while the N170 was higher for the angry expression. It is interesting to note that the latter is consistent with meta-analysis of the N170 response in healthy adults, that found that the amplitude to anger EFE is higher than to happy EFE at that time point (Hinojosa, Mercado, & Carretie, 2015).

After ~170 ms, sensitivity in the reaction to different EFE develop in the control group: The response to happy, when compared to angry EFE was significantly larger in the right hemisphere (Ibanez et al., 2011) and in the posterior-parietal channels (Raz & Dan, 2015a). Interestingly, however, in both occipital and posterior-parietal channels the differences between angry and neutral expressions was not statistically significant (Raz & Dan, 2015a). In contrast, the ADHD group showed higher amplitude to angry EFE than to happy (Raz & Dan, 2015a). Furthermore, there were no significant differences in their response to happy vs. neutral expressions (Raz & Dan, 2015a). This observation is consistent with other studies that report diminished emotional reaction to pleasant stimuli in ADHD adults (Conzelmann et al., 2009), and may be correlated with mental states and executive functioning in ADHD (Lennox, Jacob, Calder, Lupson, & Bullmore, 2004).

The enhanced response of controls to happy EFE, when compared to that of the adults with ADHD, persists into the 200-300 ms post stimulus timeframe; The EPN difference between neutral and pleasant EFE was reduced in the ADHD group, when compared to the healthy controls (Herrmann et al., 2009; Williams et al., 2008). However, it was similar in both groups after unpleasant stimuli (Herrmann et al., 2009; Raz & Dan, 2015a).

The association of P300 with top-down processing of emotional information, namely, emotional evaluation, memory encoding and memory formation (Hajcak et al., 2010; Olofsson et al., 2008), suggests that it can be used to investigate processing of emotions, and in particular the relationship between emotion and attention. By this stage (300 ms post stimulus), the heightened response of the control group to happy EFE is reduced and becomes similar to that of the ADHD group (Raz & Dan, 2015a). However, while the P300 of the ADHD to angry EFE is now reduced, and similar to the response to happy EFE, the control group's response to angry EFE becomes much more significant (Raz & Dan, 2015a, 2015b), as illustrated in **Figure 2**. Interestingly, at longer timescales, LPP indicates that the response of (unmedicated) ADHD subjects to either neutral or negative EFE is more significant than that of the control (Shushakova et al., 2018).

These ERP results can be summarized as follows: Generally, the initial response (up to approximately 200ms post stimulus) and later response (after ~350 ms) of adults with ADHD to either neutral or emotional facial expressions is heightened when compared to that of their healthy control group. In the intermediate window, however, at approximately 300ms, the ADHD group shows muted EPR amplitudes when compared to the controls. A similar attenuation in the P300 amplitudes was also found in ADHD adults when presented with complex, non-emotional visual stimuli (Grane et al., 2016).

These findings suggest that recognition errors in adults with ADHD are associated with inattention, rather than an inherent impairment in emotional processing: Studies using continuous performance tasks based on non-emotional cues also find that adults with ADHD make more errors than healthy control for tasks whose RT is of order 250 - 300 ms, even when matched for IQ and education (see, for example, (Marchetta, Hurks, De Sonneville, Krabbendam, & Jolles, 2008; Tucha et al., 2017)). The attenuation in P300 is consistent with the loss of attention at this time window, since such tasks do not evoke an emotional response. Taken together, these results suggest that that individuals with ADHD experience inattention within 300 ms from stimulus onset that impacts their ability to recognize EFE.

This review focused on studies of adults, controlling for medication status. Future studies should consider issues such as the ADHD subgroup or the role of gender, since those may contribute significantly to variability in the response. Generally, more detailed characterization of the ERP components in response to the different EFE in ADHD populations would enable better understanding of the components affecting EFE recognition.

5. Conclusion

The papers reviewed here find, overall, that adults with ADHD have some impairment in their ability to recognize emotional facial expressions. This is manifested in slower RT, larger RT variability, and a higher error rate. However, the effect is highly sensitive to the expression valence. Examining the time-evolution of response using ERP suggests that this impairment might be associated with a lapse in attention at roughly 300 ms post-stimulus.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Aguado, L., Valdes-Conroy, B., Rodriguez, S., Roman, F. J., Dieguez-Risco, T., & Fernandez-Cahill, M. (2012). Modulation of Early Perceptual Processing by Emotional Expression and Acquired Valence of Faces an ERP Study. *Journal of Psychophysiology, 26,* 29-41. https://doi.org/10.1027/0269-8803/a000065

Alperin, B. R., Gustafsson, H., Smith, C., & Karalunas, S. L. (2017). The Relationship between Early and Late Event-Related Potentials and Temperament in Adolescents with and without ADHD. *PLOS ONE, 12,* e0180627. https://doi.org/10.1371/journal.pone.0180627

Ashley, V., Vuilleumier, P., & Swick, D. (2004). Time Course and Specificity of Event-Related Potentials to Emotional Expressions. *NeuroReport, 15,* 211-216. https://doi.org/10.1097/00001756-200401190-00041

Baran Tatar, Z., Yargic, I., Oflaz, S., & Buyukgok, D. (2015). The Relationship between Emotion Recognition and the Symptoms of Attention Deficit and Impulsivity in Adult Patients with Attention Deficit Hyperactivity Disorder. *Turk Psikiyatri Dergisi, 26,* 172-180.

Barrett, L. F. (1998). Discrete Emotions or Dimensions? The Role of Valence Focus and Arousal Focus. *Cognition & Emotion, 12,* 579-599. https://doi.org/10.1080/026999398379574

Barry, R. J., Clarke, A. R., McCarthy, R., Selikowitz, M., Brown, C. R., & Heaven, P. C. L. (2009). Event-Related Potentials in Adults with Attention-Deficit/Hyperactivity Disorder: An Investigation Using an Inter-Modal Auditory/visual Oddball Task. *International Journal of Psychophysiology, 71,* 124-131. https://doi.org/10.1016/j.ijpsycho.2008.09.009

Bisch, J., Kreifelts, B., Bretscher, J., Wildgruber, D., Fallgatter, A., & Ethofer, T. (2016). Emotion Perception in Adult Attention-Deficit Hyperactivity Disorder. *J Neural Transm (Vienna), 123,* 961-970. https://doi.org/10.1007/s00702-016-1513-x

Blau, V. C., Maurer, U., Tottenham, N., & McCandliss, B. D. (2007). The Face-Specific N170 Component Is Modulated by Emotional Facial Expression. *Behavioral and Brain Functions, 3,* Article No. 7. https://doi.org/10.1186/1744-9081-3-7

Bora, E., & Pantelis, C. (2015). Meta-Analysis of Social Cognition in Attention-Deficit/Hyperactivity Disorder (ADHD): Comparison with Healthy Controls and Autistic Spectrum Disorder. *Psychological Medicine, 46,* 699-716.

https://doi.org/10.1017/S0033291715002573

Borhani, K., & Nejati, V. (2018). Emotional Face Recognition in Individuals Withattention-Deficit/Hyperactivity Disorder: A Review Article. *Developmental Neuropsychology, 43,* 256-277. https://doi.org/10.1080/87565641.2018.1440295

Cadesky, E. B., Mota, V. L., & Schachar, R. J. (2000). Beyond Words: How Do Children with ADHD And/or Conduct Problems Process Nonverbal Information About Affect? *Journal of the American Academy of Child and Adolescent Psychiatry, 39,* 1160-1167. https://doi.org/10.1097/00004583-200009000-00016

Calvo, M. G., & Beltran, D. (2013). Recognition Advantage of Happy Faces: Tracing the Neurocognitive Processes. *Neuropsychologia, 51,* 2051-2060. https://doi.org/10.1016/j.neuropsychologia.2013.07.010

Campanella, S., Bruyer, R., Froidbise, S., Rossignol, M., Joassin, F., Kornreich, C. et al. (2010). Is Two Better Than One? A Cross-Modal Oddball Paradigm Reveals Greater Sensitivity of the p300 to Emotional Face-Voice Associations. *Clinical Neurophysiology, 121,* 1855-1862. https://doi.org/10.1016/j.clinph.2010.04.004

Conzelmann, A., Mucha, R. F., Jacob, C. P., Weyers, P., Romanos, J., Gerdes, A. B. M. et al. (2009). Abnormal Affective Responsiveness in Attention-Deficit/Hyperactivity Disorder: Subtype Differences. *Biological Psychiatry, 65,* 578-585. https://doi.org/10.1016/j.biopsych.2008.10.038

Corbett, B., & Glidden, H. (2000). Processing Affective Stimuli in Children with Attention-Deficit Hyperactivity Disorder. *Child Neuropsychology, 6,* 144-155. https://doi.org/10.1076/chin.6.2.144.7056

Demirci, E., & Erdogan, A. (2016). Is Emotion Recognition the Only Problem in ADHD? Effects of Pharmacotherapy on Face and Emotion Recognition in Children with ADHD. *ADHD Attention Deficit and Hyperactivity Disorders, 8,* 197-204. https://doi.org/10.1007/s12402-016-0201-x

Ding, R., Li, P., Wang, W., & Luo, W. B. (2017). Emotion Processing by ERP Combined with Development and Plasticity. *Neural Plasticity, 2017,* Article ID: 5282670. https://doi.org/10.1155/2017/5282670

Dolcos, F., & Cabeza, R. (2002). Event-Related Potentials of Emotional Memory: Encoding Pleasant, Unpleasant, and Neutral Pictures. *Cognitive, Affective, & Behavioral Neuroscience, 2,* 252-263. https://doi.org/10.3758/CABN.2.3.252

Eimer, M., & Holmes, A. (2002). An ERP Study on the Time Course of Emotional Face Processing. *Neuroreport, 13,* 427-431. https://doi.org/10.1097/00001756-200203250-00013

Eimer, M., & Holmes, A. (2007). Event-Related Brain Potential Correlates of Emotional Face Processing. *Neuropsychologia, 45,* 15-31. https://doi.org/10.1016/j.neuropsychologia.2006.04.022

Eimer, M., Holmes, A., & McGlone, F. P. (2003). The Role of Spatial Attention in the Processing of Facial Expression: An ERP Study of Rapid Brain Responses to Six Basic Emotions. *Cognitive Affective & Behavioral Neuroscience, 3,* 97-110. https://doi.org/10.3758/CABN.3.2.97

Feuerriegel, D., Churches, O., Hofmann, J., & Keage, H. A. D. (2015). The N170 and Face Perception in Psychiatric and Neurological Disorders: A Systematic Review. *Clinical Neurophysiology, 126,* 1141-1158. https://doi.org/10.1016/j.clinph.2014.09.015

Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating Neural Responses to Emotional Pictures: Evidence from Temporal-Spatial PCA. *Psychophysiology, 46,* 521-530. https://doi.org/10.1111/j.1469-8986.2009.00796.x

Foti, D., Weinberg, A., Dien, J., & Hajcak, G. (2011). Event-Related Potential Activity in the Basal Ganglia Differentiates Rewards From Nonrewards: Temporospatial Principal Components Analysis and Source Localization of the Feedback Negativity. *Human Brain Mapping, 32,* 2207-2216. https://doi.org/10.1002/hbm.21182

Friedman, S. R., Rapport, L. J., Lumley, M., Tzelepis, A., VanVoorhis, A., Stettner, L., & Kakaati, L. (2003). Aspects of Social and Emotional Competence in Adult Attention-Deficit/Hyperactivity Disorder. *Neuropsychology, 17,* 50-58. https://doi.org/10.1037/0894-4105.17.1.50

Goncalves, A. R., Fernandes, C., Pasion, R., Ferreira-Santos, F., Barbosa, F., & Marques-Teixeira, J. (2018). Effects of Age on the Identification of Emotions in Facial Expressions: A Meta-Analysis. *Peerj, 6,* e5278. https://doi.org/10.7717/peerj.5278

Grane, V. A., Brunner, J. F., Endestad, T., Aasen, I. E. S., Kropotov, J., Knight, R. T., & Solbakk, A.-K. (2016). ERP Correlates of Proactive and Reactive Cognitive Control in Treatment-Naïve Adult ADHD. *PLOS ONE, 11,* e0159833. https://doi.org/10.1371/journal.pone.0159833

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and Controlled Attention to Emotion: Time-Course of the Late Positive Potential. *Clinical Neurophysiology, 120,* 505-510. https://doi.org/10.1016/j.clinph.2008.11.028

Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-Related Potentials, Emotion, and Emotion Regulation: An Integrative Review. *Developmental Neuropsychology, 35,* 129-155. https://doi.org/10.1080/87565640903526504

Herrmann, M. J., Biehl, S. C., Jacob, C., & Deckert, J. (2010). Neurobiological and Psychophysiological Correlates of Emotional Dysregulation in ADHD Patients. *ADHD Attention Deficit and Hyperactivity Disorders, 2,* 233-239. https://doi.org/10.1007/s12402-010-0047-6

Herrmann, M. J., Schreppel, T., Biehl, S. C., Jacob, C., Heine, M., Boreatti-Hümmer, A. et al. (2009). Emotional Deficits in Adult ADHD Patients: An ERP Study. *Social Cognitive and Affective Neuroscience, 4,* 340-345. https://doi.org/10.1093/scan/nsp033

Hinojosa, J. A., Mercado, F., & Carretie, L. (2015). N170 Sensitivity to Facial Expression: A Meta-Analysis. *Neuroscience and Biobehavioral Reviews, 55,* 498-509. https://doi.org/10.1016/j.neubiorev.2015.06.002

Holmes, A., Vuilleumier, P., & Eimer, M. (2003). The Processing of Emotional Facial Expression Is Gated by Spatial Attention: Evidence From Event-Related Brain Potentials. *Cognitive Brain Research, 16,* 174-184. https://doi.org/10.1016/S0926-6410(02)00268-9

Ibanez, A., Petroni, A., Urquina, H., Torrente, F., Torralva, T., Hurtado, E. et al. (2011). Cortical Deficits of Emotional Face Processing in Adults with ADHD: Its Relation to Social Cognition and Executive Function. *Social Neuroscience, 6,* 464-481. https://doi.org/10.1080/17470919.2011.620769

Kirouac, G., & Dore, F. Y. (1983). Accuracy and Latency o Judgment of Facial Expressions of Emotions. *Perceptual and Motor Skills, 57,* 683-686. https://doi.org/10.2466/pms.1983.57.3.683

Lassalle, A., & Itier, R. J. (2013). Fearful, Surprised, Happy, and Angry Facial Expressions Modulate Gaze-Oriented Attention: Behavioral and ERP Evidence. *Social Neuroscience, 8,* 583-600. https://doi.org/10.1080/17470919.2013.835750

Lawrence, K., Campbell, R., & Skuse, D. (2015). Age, Gender, and Puberty Influence the Development of Facial Emotion Recognition. *Frontiers in Psychology, 6,* Article No. 761. https://doi.org/10.3389/fpsyg.2015.00761

Lennox, B. R., Jacob, R., Calder, A. J., Lupson, V., & Bullmore, E. T. (2004). Behavioural and Neurocognitive Responses to Sad Facial Affect Are Attenuated in Patients with

Mania. *Psychological Medicine, 34,* 795-802.
https://doi.org/10.1017/S0033291704002557

Leppanen, J. M., Kauppinen, P., Peltola, M. J., & Hietanen, J. K. (2007). Differential Electrocortical Responses to Increasing Intensities of Fearful and Happy Emotional Expressions. *Brain Research, 1166,* 103-109. https://doi.org/10.1016/j.brainres.2007.06.060

Luo, W. B., Feng, W. F., He, W. Q., Wang, N. Y., & Luo, Y. J. (2010). Three Stages of Facial Expression Processing: ERP Study with Rapid Serial Visual Presentation. *Neuroimage, 49,* 1857-1867. https://doi.org/10.1016/j.neuroimage.2009.09.018

Marchetta, N. D. J., Hurks, P. P. M., De Sonneville, L. M. J., Krabbendam, L., & Jolles, J. (2008). Sustained and Focused Attention Deficits in Adult ADHD. *Journal of Attention Disorders, 11,* 664-676. https://doi.org/10.1177/1087054707305108

Markovska-Simoska, S., & Pop-Jordanova, N. (2010). Face and Emotion Recognition by ADHD and Normal Adults. *Acta Neuropsychologica, 8,* 99-122.

Miller, M., Hanford, R. B., Fassbender, C., Duke, M., & Schweitzer, J. B. (2011). Affect Recognition in Adults with ADHD. *Journal of Attention Disorders, 15,* 452-460.
https://doi.org/10.1177/1087054710368636

Naatanen, R., & Picton, T. W. (1986). N2 and Automatic versus Controlled Processes. *Electroencephalography and Clinical Neurophysiology. Supplement, 38,* 169-186.

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. E. (2002). Rethinking Feelings: An fMRI Study of the Cognitive Regulation of Emotion. *Journal of Cognitive Neuroscience, 14,* 1215-1229. https://doi.org/10.1162/089892902760807212

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective Picture Processing: An Integrative Review of ERP Findings. *Biological Psychology, 77,* 247-265.
https://doi.org/10.1016/j.biopsycho.2007.11.006

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D. et al. (2021). The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ, 372,* Article No. N71. https://doi.org/10.1136/bmj.n71

Pelc, K., Kornreich, C., Foisy, M. L., & Dan, B. (2006). Recognition of Emotional Facial Expressions in Attention-Deficit Hyperactivity Disorder. *Pediatric Neurology, 35,* 93-97.
https://doi.org/10.1016/j.pediatrneurol.2006.01.014

Phan, K. L., Wager, T., Taylor, S. F., & Liberzon, I. (2002). Functional Neuroanatomy of Emotion: A Meta-Analysis of Emotion Activation Studies in PET and fMRI. *Neuroimage, 16,* 331-348. https://doi.org/10.1006/nimg.2002.1087

Phelps, E. A., & LeDoux, J. E. (2005). Contributions of the Amygdala to Emotion Processing: From Animal Models to Human Behavior. *Neuron, 48,* 175-187.
https://doi.org/10.1016/j.neuron.2005.09.025

Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological Correlates of Rapid Spatial Orienting Towards Fearful Faces. *Cerebral Cortex, 14,* 619-633.
https://doi.org/10.1093/cercor/bhh023

Rapport, L. J., Friedman, S. L., Tzelepis, A., & Van Voorhis, A. (2002). Experienced Emotion and Affect Recognition in Adult Attention-Deficit Hyperactivity Disorder. *Neuropsychology, 16,* 102-110. https://doi.org/10.1037/0894-4105.16.1.102

Raz, S., & Dan, O. (2015a). Altered Event-Related Potentials in Adults with ADHD During Emotional Faces Processing. *Clinical Neurophysiology, 126,* 514-523.
https://doi.org/10.1016/j.clinph.2014.06.023

Raz, S., & Dan, O. (2015b). Behavioral and Neural Correlates of Facial versus Nonfacial Stimuli Processing in Adults with ADHD: An ERP Study. *Neuropsychology, 29,* 726-738.
https://doi.org/10.1037/neu0000176

Recio, G., Schacht, A., & Sommer, W. (2014). Recognizing Dynamic Facial Expressions of Emotion: Specificity and Intensity Effects in Event-Related Brain Potentials. *Biological Psychology, 96,* 111-125. https://doi.org/10.1016/j.biopsycho.2013.12.003

Retz-Junginger, P., Giesen, L., Rosler, M., & Retz, W. (2016). Deficits in Facial Expression Recognition in Adult Attention-Deficit Hyperactivity Disorder. *Psychiatrische Praxis, 43,* 219-221. https://doi.org/10.1055/s-0034-1387570

Romani, M., Vigliante, M., Faedda, N., Rossetti, S., Pezzuti, L., Guidetti, V., & Cardona, F. (2018). Face Memory and Face Recognition in Children and Adolescents with Attention Deficit Hyperactivity Disorder: A Systematic Review. *Neuroscience and Biobehavioral Reviews, 89,* 1-12. https://doi.org/10.1016/j.neubiorev.2018.03.026

Rossion, B., Campanella, S., Gomez, C. M., Delinte, A., Debatisse, D., Liard, L. et al. (1999). Task Modulation of Brain Activity Related to Familiar and Unfamiliar Face Processing: An ERP Study. *Clinical Neurophysiology, 110,* 449-462. https://doi.org/10.1016/S1388-2457(98)00037-6

Rubia, K. (2018). Cognitive Neuroscience of Attention Deficit Hyperactivity Disorder (ADHD) and Its Clinical Translation. *Frontiers in Human Neuroscience, 12,* Article No. 100. https://doi.org/10.3389/fnhum.2018.00100

Ruffman, T., Henry, J. D., Livingstone, V., & Phillips, L. H. (2008). A Meta-Analytic Review of Emotion Recognition and Aging: Implications for Neuropsychological Models of Aging. *Neuroscience & Biobehavioral Reviews, 32,* 863-881. https://doi.org/10.1016/j.neubiorev.2008.01.001

Schönenberg, M., Schneidt, A., Wiedemann, E., & Jusyte, A. (2015). Processing of Dynamic Affective Information in Adults with ADHD. *Journal of Attention Disorders, 23,* 32-39. https://doi.org/10.1177/1087054715577992

Schulz, K. P., Bédard, A.-C. V., Fan, J., Clerkin, S. M., Dima, D., Newcorn, J. H., & Halperin, J. M. (2014). Emotional Bias of Cognitive Control in Adults with Childhood Attention-Deficit/hyperactivity Disorder. *NeuroImage: Clinical, 5,* 1-9. https://doi.org/10.1016/j.nicl.2014.05.016

Schupp, H. T., Junghofer, M., Weike, A. I., & Hamm, A. O. (2003). Attention and Emotion: An ERP Analysis of Facilitated Emotional Stimulus Processing. *NeuroReport, 14,* 1107-1110. https://doi.org/10.1097/00001756-200306110-00002

Schupp, H. T., Ohman, A., Junghofer, M., Weike, A. I., Stockburger, J., & Hamm, A. O. (2004). The Facilitated Processing of Threatening Faces: An ERP Analysis. *Emotion, 4,* 189-200. https://doi.org/10.1037/1528-3542.4.2.189

Shushakova, A., Ohrmann, P., & Pedersen, A. (2018). Exploring Deficient Emotion Regulation in Adult ADHD: Electrophysiological Evidence. *European Archives of Psychiatry and Clinical Neuroscience, 268,* 359-371. https://doi.org/10.1007/s00406-017-0826-6

Singh, S. D., Ellis, C. R., Winton, A. S. W., Singh, N. N., Leung, J. P., & Oswald, D. P. (1998). Recognition of Facial Expressions of Emotion by Children with Attention-Deficit Hyperactivity Disorder. *Behavior Modification, 22,* 128-142. https://doi.org/10.1177/01454455980222002

Sinzig, J., Morsch, D., & Lehmkuhl, G. (2008). Do Hyperactivity, Impulsivity and Inattention Have an Impact on the Ability of Facial Affect Recognition in Children with Autism and ADHD? *European Child & Adolescent Psychiatry, 17,* 63-72. https://doi.org/10.1007/s00787-007-0637-9

Tamm, L., Narad, M. E., Antonini, T. N., O'Brien, K. M., Hawk Jr., L. W., & Epstein, J. N. (2012). Reaction Time Variability in ADHD: A Review. *Neurotherapeutics, 9,* 500-508. https://doi.org/10.1007/s13311-012-0138-5

Tucha, L., Fuermaier, A. B. M., Koerts, J., Buggenthin, R., Aschenbrenner, S., Weisbrod, M. et al. (2017). Sustained Attention in Adult ADHD: Time-on-Task Effects of Various Measures of Attention. *Journal of Neural Transmission, 124,* S39-S53. https://doi.org/10.1007/s00702-015-1426-0

Uekermann, J., Kraemer, M., Abdel-Hamid, M., Schimmelmann, B. G., Hebebrand, J., Daum, I. et al. (2010). Social Cognition in Attention-Deficit Hyperactivity Disorder (ADHD). *Neuroscience and Biobehavioral Reviews, 34,* 734-743. https://doi.org/10.1016/j.neubiorev.2009.10.009

Utama, N. P., Takemoto, A., Koike, Y., & Nakamura, K. (2009). Phased Processing of Facial Emotion: An ERP Study. *Neuroscience Research, 64,* 30-40. https://doi.org/10.1016/j.neures.2009.01.009

Vuilleumier, P. (2005). How Brains Beware: Neural Mechanisms of Emotional Attention. *Trends in Cognitive Sciences, 9,* 585-594. https://doi.org/10.1016/j.tics.2005.10.011

Vuilleumier, P., & Pourtois, G. (2007). Distributed and Interactive Brain Mechanisms during Emotion Face Perception: Evidence from Functional Neuroimaging. *Neuropsychologia, 45,* 174-194. https://doi.org/10.1016/j.neuropsychologia.2006.06.003

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of Attention and Emotion on Face Processing in the Human Brain: An Event-Related fMRI Study. *Neuron, 30,* 829-841. https://doi.org/10.1016/S0896-6273(01)00328-2

Wells, L. J., Gillespie, S. M., & Rotshtein, P. (2016). Identification of Emotional Facial Expressions: Effects of Expression, Intensity, and Sex on Eye Gaze. *PLOS ONE, 11,* e0168307. https://doi.org/10.1371/journal.pone.0168307

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. B., & Jenike, M. A. (1998). Masked Presentations of Emotional Facial Expressions Modulate Amygdala Activity without Explicit Knowledge. *Journal of Neuroscience, 18,* 411-418. https://doi.org/10.1523/JNEUROSCI.18-01-00411.1998

Whittemore, R., & Knafl, K. (2005). The Integrative Review: Updated Methodology. *Journal of Advanced Nursing, 52,* 546-553. https://doi.org/10.1111/j.1365-2648.2005.03621.x

Williams, L. M., Hermens, D. F., Palmer, D., Kohn, M., Clarke, S., Keage, H. et al. (2008). Misinterpreting Emotional Expressions in Attention-Deficit/Hyperactivity Disorder: Evidence for a Neural Marker and Stimulant Effects. *Biological Psychiatry, 63,* 917-926. https://doi.org/10.1016/j.biopsych.2007.11.022

Williams, L. M., Mathersul, D., Palmer, D. M., Gur, R. C., Gur, R. E., & Gordon, E. (2009). Explicit Identification and Implicit Recognition of Facial Emotions: I. Age Effects in Males and Females across 10 Decades. *Journal of Clinical and Experimental Neuropsychology, 31,* 257-277. https://doi.org/10.1080/13803390802255635