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N170 in attention deficit hyperactivity disorder: Systematic review

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ABSTRACT

Background: Attention deficit hyperactivity disorder (ADHD) seems to encompass impaired emotional recognition and face processing, whose underlying mechanisms are yet to be uncovered. The N170 is an event-related potential sensitive to facial expressions, being often associated with perception and attention. Thus, this work aims to summarise and meta-analyse the literature focused on N170 modulation by ADHD.

Methods: Empirical studies measuring N170 in both ADHD and healthy individuals were identified following the Preferred Reporting Items for Systematic Reviews and Meta-analysis.

Results: Fourteen studies were included in the review. Eight studies were meta-analysed and no overall significant results were found between healthy and ADHD individuals. Moderation analysis by valence revealed no differences between groups for positive and negative valence. Neutral valence yielded more negative N170 amplitudes in ADHD than in healthy individuals.

Discussion: Altogether, findings suggest that neurophysiological processing of emotional faces is generally unimpaired in ADHD individuals. Further, it may be that ambiguous faces' processing is more demanding in individuals with ADHD. Limitations of the included studies are the variability of the tasks employed and the lacking information about the specific symptoms and medication washout. Directions for future studies are discussed.

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is a prevalent neurodevelopmental disorder (Abdelnour et al., 2022), marked by behaviours of inattention, impulsiveness, and hyperactivity (Rocco et al., 2021). Both genetic and environmental factors seem to play a role in the development of ADHD (French et al., 2024; Gómez-Cano et al., 2023), with some of its traits being commonly seen in the general population (Arcos-Burgos and Acosta, 2007). Individuals diagnosed with this disorder appear to showcase, amongst others, impairments in their executive functioning (Townes et al., 2023) and adverse outcomes to their physical, mental health, and social life (French et al., 2024). For instance, they seem to have difficulties in forming and maintaining relationships, which might be due to deficits in core social processing skills (French et al., 2024; Hotte-Meunier et al., 2024).

Although various neuropsychological domains seem to be impaired in ADHD (Drechsler et al., 2020), social cognition abilities are especially relevant in understanding the challenges faced by these individuals in perception and attention to social cues (Dickstein and Castellanos, 2012; Frith, 2008; Hotte-Meunier et al., 2024). Individuals with ADHD appear to struggle in encoding and interpreting various aspects of social cognition, which impacts how they plan and respond to a social interaction, leading to difficulties in their relationships (Wiener, 2023). In particular, emotional recognition and face processing seem to be reduced in both children and adolescents (Arango-Tobón et al., 2023; Borhani and Nejati, 2018; Bozkurt et al., 2024; Graziano and Garcia, 2016; Rodrigo-Ruiz et al., 2017), as well as in adults (Beheshti et al., 2020; Dan and Cohen, 2022; Morellini et al., 2022), with ADHD (Olaya-Galindo et al., 2023). Both of these processes are fundamental in communication as they provide socially relevant information that serves as a basis to interpret the others' actions and intentions, while guiding the individual's response (Adolphs, 2002).

Despite the abovementioned findings, the underlying mechanisms for the impaired social cognition have not been fully grasped yet (e.g.,

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Dickstein and Castellanos, 2012). In fact, it is unclear if these deficits are a result of brain abnormalities in structures associated with emotional processing (i.e., the limbic network; Morellini et al., 2022), a consequence of comorbidities with other conditions, or due to alterations in the structures related to executive functioning (Romani et al., 2018). As such, studies focusing on neuronal correlates may provide useful insights into the apparent deficits of emotional face processing in ADHD individuals.

Neuronal activity can be continuously measured through an electroencephalogram (EEG), from which event-related potentials (ERP), i.e. the variance of neuron's polarity in response to an event/stimulus, can be extracted (Kappenman and Luck, 2012). The N170 is an early ERP component thought to be elicited by visual meaningful patterns, such as images, usually being associated with perceptual face processing (Eimer, 2011; Pratt, 2012; Rossion and Jacques, 2012). This component peaks at about 100–200 ms after stimulus onset, and has an occipito-temporal topography, seemingly being largest in the ventral areas of the visual cortex (Luck, 2014; Rossion and Jacques, 2012). Considering that individuals with ADHD appear to showcase altered neural activity in both the occipital and the temporal lobes (Novak et al., 2024), it seems particularly relevant to study the N170 component.

Literature tends to point in the direction of a larger N170 amplitude in response to faces than in response to any other visual stimuli, which makes this an ERP often used to perceive face processing mechanisms (Earp and Everett, 2013; Luck, 2014; Rossion and Jacques, 2012). Moreover, it seems that the N170 is sensitive to facial expressions and emotional valence (Hinojosa et al., 2015; Schindler et al., 2023). In this sense, compared to overall emotional faces, neutral faces seem to evoke lower N170 amplitudes, and angry expressions tend to have higher amplitudes, followed by fear and happiness, while no differences were found with sadness and disgust (Hinojosa et al., 2015). Furthermore, while intensity and relevancy of the emotional face seem to potentiate N170 amplitude, learned emotional associations are needed to modulate this component (Schindler et al., 2023).

N170 is also considered as an early potential, often associated with perception and attentional processes (Woodman, 2010), which may be altered in ADHD (Fuermaier et al., 2018). As such, this ERP represents both an automatic neurophysiological activity mostly associated with identification of facial information, and processing of the expression and emotion in the superior temporal cortices (Adolphs, 2002). This might offer valuable insights into the social difficulties faced in ADHD (French et al., 2024), as it helps discern whether these individuals might present atypical sociocognitive functioning or if their poor socialization could stem from hallmark symptoms such as inattention (Roberts and Trossman, 2024). Particularly, discrimination and categorization of emotions can occur rapidly after stimulus onset, which corresponds to a bottom-up aspect of processing (i.e., early encoding; Adolphs, 2002). Moreover, highly socially relevant expressions (such as negative facial expressions) seem to trigger the allocation of more attentional resources, being identified in the early stages of visual processing (Martens et al., 2010). As such, given the impaired emotional processing of individuals with ADHD (Soler-Gutiérrez et al., 2025), it might be that their difficulties have an onset in the early processing stages that constrain the subsequent socio-cognitive functioning.

However, despite being an ERP of interest in ADHD, to the best of our knowledge, there are no meta-analyses focused on N170 in this disorder. Previous qualitative reviews have touched upon this relationship, although their conclusions appear incongruent, with two reporting reduced N170 amplitude in ADHD (Feuerriegel et al., 2015; Morellini et al., 2022) and one reporting higher N170 amplitude (Dan and Cohen, 2022). Although the main target of these reviews was not the study of N170 (Dan and Cohen, 2022; Morellini et al., 2022), or the study of N170 specifically in ADHD (Feuerriegel et al., 2015), they provide valuable insights. Summarily, adults with ADHD appear to exhibit impairments in recognizing emotional facial expressions, which are highly sensitive to expression valence (Dan and Cohen, 2022). While able to compensate for this, they seem to present dysfunctions in the limbic network that limit their cognitive processing (Morellini et al., 2022). Finally, N170 and related components were identified as promising biomarkers of facial recognition dysfunction in various disorders, inrrespective of disorder-specific symptoms (Feuerriegel et al., 2015). A recent review (Roberts and Trossman, 2024), focused on the effect of the ADHD in N170, reported both a lack of evidence regarding differences in N170 amplitude between ADHD and healthy controls, and conflicting results regarding emotional expressions modulation. This review offers a relevant discussion about the potential premises that hallmark social deficits in ADHD, and emphasises the need for further investigation before targeted interventions aimed at face processing are warranted. However, the review did not include statistical power for its findings, which may limit the generalizability of their conclusions.

On account of this, the present study aims to not only systematise but also meta-analyse the literature surrounding the possible differences in N170 amplitude of individuals diagnosed with ADHD when compared to healthy controls.

2. Methods

2.1. Search strategy

The present review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020; Page et al., 2021) guidelines, and its protocol was registered in PROSPERO (CRD42023412563) on April 9th, 2023.

Records were selected from PubMed, Web of Science and EBSCOhost (PsycArticles, PsycInfo, and Psychology and Behavioral Sciences Collection) databases, by searching for titles and abstracts with: (ADHD OR Attention Deficit Hyperactivity Disorder OR Attention-Deficit Hyperactivity Disorder OR Attention Deficit/Hyperactivity Disorder OR ADD) AND (N170). Additionally, only empirical studies in the English language were screened.

2.2. Study selection

All identified studies were uploaded to Rayyan (Ouzzani et al., 2016), where LV and JOP scouted for and eliminated the existing duplicates. Thereupon, the same researchers blindly scanned the titles and abstracts for the following eligibility criteria: (a) sample with, at least, two groups of participants (children, adolescents or adults), one with ADHD and one without; (b) amplitude and/or latency of N170 reported/analysed. In a team meeting, the appraisals were revealed and disagreements were resolved by RA. The selected articles were, once again, screened for inclusion by the analyses of their full-text. Exclusion criteria are showcased in the PRISMA flow diagram (Fig. 1; Page et al., 2021).

2.3. Data extraction and quality assessment

Relevant data was extracted and compiled into a code sheet containing: (a) study information - title, publication year, and authors; (b) sample/group descriptors - size, percentage of females, mean age and respective standard deviation, and medication intake and washout; (c) task characteristics - task name, type of stimuli (e.g., emotional faces), behaviour response (i.e., active or passive); (d) ERP features - reference and region of interest, measurement technique (i.e., area, mean, or peak), and the mean and standard deviation of N170 amplitude and/or latency in the respective condition (e.g., positive faces).

A meta-analysis was performed when three or more studies comparing healthy controls and ADHD individuals were available. Effect sizes were computed from N170 means and standard deviations, sample sizes, *t*-test results, *p*-values, and the direction of effect. When crucial information was missing, a request for the needed data was sent to the authors. A lack of response led to the exclusion of the study.

To assess the quality of the included studies, a checklist for reporting

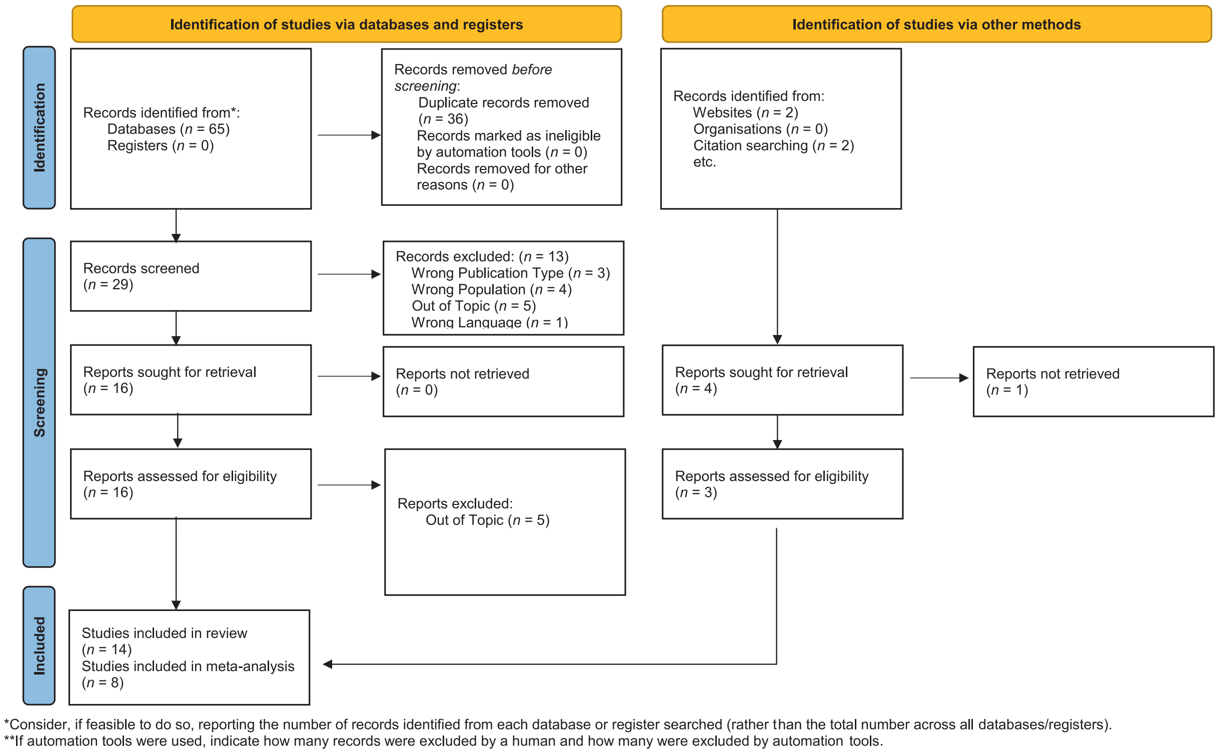

Fig. 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources.

EEG and MEG research (Keil et al., 2014) was used. As some of the items from this checklist are not relevant to the research topic, only the points that follow were taken into account: hypotheses, participants, recording characteristics and instruments, stimulus and timing parameters, description of data preprocessing steps, measurement procedures, statistical analyses, and figures (minus the last item). A dichotomous scale (0 = absent; 1 = present) was used to score each item, and the total quality was determined by summing all markings. Therefore, methodological quality could range from 0 to 29 and was greater the higher its value. The checklist was filled in by BB and LV, who were blind to the other's scoring. The markings for each item were, thereafter, compared and diverging scores were checked against the original article, with RA giving the final verdict.

2.4. Analytical strategy and meta-analytic methods

For data analysis, ProMeta software version 3.0 (Internovi, Italy) was used, while Hedges' g (Hedges, 1981) served to estimate the pooled effect sizes for N170 amplitude. Effects size values were classified as small ($g \geq |0.20|$), medium ($g \geq |0.50|$), and large ($g \geq |0.80|$) (Cohen, 1988). Forest plots were generated to summarise the data, which includes values for Hedges' g, 95 % confidence intervals, and sample size.

Q statistic (Cochran, 1954) was used to assess the variability between studies (i.e., heterogeneity), as described by I^2 statistic (Higgins et al., 2011) and a significance level of 0.1 (Egger et al., 1997). Thus, heterogeneity was categorised as being low ($I^2 < 25$ %), medium (25 % $< I^2 \leq 50$ %), or high ($I^2 \geq 50$ %), with random effects models being used in the last two. To assess publication bias, Eggers's test of intercept bias was employed.

Moderation analysis by condition was set to be performed when heterogeneity was found to be statistically significant. No correction for multiple comparisons was made to the p-values. Due to a lack of available studies, the condition's emotions were grouped into negative, positive or neutral valence.

3. Results

3.1. Search results

An initial search identified 65 records, 36 of which were discarded for being duplicates (see Fig. 1). The remaining 29 studies were screened by title and abstract. The decision for inclusion or exclusion by their title and abstract had an almost perfect agreement between researchers (k = 0.85; Landis and Koch, 1977). Sixteen studies were screened by full-text. A manual search identified three other eligible studies. After eligibility analysis, data was extracted from 14 records.

3.2. Methodological quality assessment

Studies included in the present review scored an average of 18 in Keil et al.' (2014) checklist, with the lowest total being 13 and the highest being 23. The modal value was 23 (n = 3).

3.3. Study characteristics

A total of 1183 participants were included in the reviewed studies, of which 400 were ADHD participants (29 % females) and 783 were part of the control group (44 % female) (see Table 1). Studies included adult samples (n = 6), children (n = 4), or both children and adolescents (n = 4). The participants' ages ranged from four years-old to about 37 years.

The most applied tasks were the oddball, the dual valence task, and the emotion processing task (n = 2 for each). The remaining tasks were included in only one study each: expression of emotion, face processing, visuo-spatial attention cueing, emotional go/no-go, emotion recognition, modified S1-S2 paradigm, passive face-viewing, and emotional continuous performance. In addition, most of the tasks (n = 13) required an active response from the participant and one study included a passive viewing task.

All tasks used face stimuli, mainly with a neutral or angry expression (n = 10 for both), followed by happiness (n = 8), fear (n = 5), and disgust (n = 3). These emotions were classified into a positive valence (i.e.,

Table 1
Characteristics of the included studies.

Authors (year)	Quality	Population	n (% females)	Age M ± SD	Medication washout	Task	N170 Time window	Region [Reference]	Condition	Results	
										Amplitude	Latency
Aydin et al. (2023)	23	Adults	*n* ADHD = 93 (43 %) n CONT = 407 (56 %)	ADHD: 22.2 ± 1.0 CONT: 22.5 ± 1.0	NA	Expression of emotion task	129–277 ms	P7 & P8 [Average]	Anger, Disgust, Fear, Neutral	ADHD = CONT	ADHD = CONT
Raz and Dan (2015b)	23	Adults	*n* ADHD = 21 (76 %) *n* CONT = 19 (79 %)	ADHD: 25.4 ± 2.1 CONT: 24.7 ± 2.7	NA	Oddball	145–205 ms	Frontal & Posterior (occipital-parietal) [Average]	Anger, Neutral	ADHD = CONT	
Raz and Dan (2015a)*	23	Adults	*n* ADHD = 17 (82 %) *n* CONT = 20 (70 %)	ADHD: 24.1 ± 1.7 CONT: 24.5 ± 2.9	Sporadic	Oddball	155–200 ms	Posterior-parietal, Occipital [Average]	Anger, Happiness, Neutral	ADHD = CONT	
Tye et al. (2013)	22	Children	*n* ADHD = 18 (0 %) *n* CONT = 26 (0 %)	ADHD: 10.5 ± 1.9 ADHD: 10.6 ± 1.8	48 h	Emotion Processing task	150–290 ms	P7, P8, Pz [Linked Mastoids]	Neutral [Upright, Inverted; Direct, Averted gaze]	ADHD = CONT	ADHD = CONT
Thoma et al. (2020)*	21	Adults	*n* ADHD = 18 (61 %) *n* CONT = 25 (56 %)	ADHD: 37.1 ± 10.2 ADHD: 35.0 ± 11.0	No washout	Face processing task	150–200 ms	P7, P8, PO7, PO8 [Average]	Anger, Happiness, Neutral [Upright, Inverted]	ADHD = CONT	ADHD = CONT
Groom et al. (2017)	19	Children and Adolescents	*n* ADHD = 12 (47 %) *n* CONT = 20 (20 %)	ADHD: 11.9 ± 2.4 CONT: 12.6 ± 1.9	No medication	Visuo-spatial attention cueing task	150–200 ms	O1 & 02 [Average]	Neutral [Direct, Averted gaze]	ADHD = CONT	
Tye et al. (2014)	19	Children	*n* ADHD = 18 (0 %) *n* CONT = 26 (0 %)	ADHD: 10.5 ± 1.9 CONT: 10.6 ± 1.8	48 h	Emotion processing task	150–290 ms	P7 & P8 [Linked Mastoids]	Anger, Disgust, Fear, Happiness, Neutral	ADHD = CONT	ADHD = CONT
Ibáñez et al., 2014*	17	Adults	*n* ADHD = 16 (7 %) *n* CONT = 41 (37 %)	ADHD: 34.6 ± 11.1 CONT: 38.3 ± 11.4	Day of experiment	Dual Valence Task	140–190 ms	T6 & T7 [Average]	Anger, Happiness	Happiness minus Anger: ADHD < CONT	
Ibáñez et al., 2011*	17	Adults	*n* ADHD = 10 (10 %) *n* CONT = 10 (10 %)	ADHD: 33.1 ± 3.6 CONT: 33.0 ± 3.8	Day of experiment	Dual valence task	160–210 ms	T8 [Average] T7 [Average]	Anger Happiness Anger, Happiness	ADHD = CONT ADHD < CONT ADHD = CONT	
Alperin et al. (2017)*	16	Children and Adolescents	*n* ADHD = 49 (14 %) *n* CONT = 60 (37 %)	ADHD: 13.7 ± 1.5 CONT: 13.9 ± 1.1	24 h–48 h	Emotional Go/No-go task	150–250 ms	P7 & P8 [Average]	Fear, Happiness, Neutral	ADHD = CONT	

(*continued on next page*)

Table 1 (*continued*)

Authors (year)	Quality	Population	n (% females)	Age M ± SD	Medication washout	Task	N170 Time window	Region [Reference]	Condition	Results	
										Amplitude	Latency
Zhao et al. (2020)	16	Children	*n* ADHD = 29 (21 %) *n* CONT = 29 (38 %)	ADHD: 33.1 ± 3.6 CONT: 33.0 ± 3.8	No medication	Modified S1-S2 paradigm	175–225 ms	P7, P8, PO7, PO8 [NA]	Neutral [Consistent, Inconsistent]	ADHD = CONT	ADHD = CONT
Williams et al. (2008)*	14	Children and Adolescents	*n* ADHD = 51 (0 %) *n* CONT = 51 (0 %)	ADHD: 13.8 ± 2.3 CONT: 13.1 ± 2.4	74 h	Emotion Recognition Task	150–220 ms	O1, O2 [NA]	Anger, Fear, Neutral Disgust, Happiness	ADHD > CONT ADHD = CONT	ADHD = CONT ADHD = CONT
Flegenheimer et al. (2017)*	13	Children	*n* ADHD = 19 (26 %) *n* CONT = 28 (36 %)	ADHD: 6.5 ± 0.8 CONT: NA	48 h	Passive Face-Viewing Task	125–300 ms	TP8 [Mastoids] O2 [Mastoids] TP8 & O2 [Mastoids]	Fear Fear Anger, Happiness, Sadness, Surprise	Fear minus Neutral: ADHD < CONT Fear minus Neutral: ADHD = CONT Emotion minus Neutral: ADHD = CONT	
Rinke et al. (2017)*	13	Children and Adolescents	*n* ADHD = 29 (17 %) *n* CONT = 21 (57 %)	ADHD: 12.1 ± 2.8 CONT: 12.1 ± 3.0	24 h	Emotional Continuous Performance Task	148–294 ms	T5, T6 [Average]	Anger [anger-anger condition]	ADHD = CONT	ADHD = CONT

Note. ADHD = attention deficit hyperactivity disorder; CONT = control group; NA = Non-Available.
* articles included in the meta-analysis.

happiness; $n = 8$), a neutral valence ($n = 10$), or a negative valence (i.e., anger, fear, and disgust; $n = 10$).

The N170 amplitude was measured at parietal ($n = 7$), occipital ($n = 4$), temporal ($n = 3$), and frontal ($n = 1$) sites, or at their junctions, namely, occipital-parietal ($n = 3$) and temporoparietal ($n = 1$). The time-windows ranged from 125 to 300 ms across studies. Only four studies found significant differences between ADHD and healthy controls, namely in T6 and T7 in a happiness minus anger condition (Ibáñez et al., 2014), in T8 in happiness (Ibáñez et al., 2011), in O1 and O2 in anger, fear and neutral conditions (Williams et al., 2008), and in TP8 fear minus neutral condition (Flegenheimer et al., 2017).

3.4. Meta-analysis

Data was requested for eight studies (Groom et al., 2017; Ibáñez et al., 2014; Raz and Dan, 2015a; Raz and Dan, 2015b; Rinke et al., 2017; Tye et al., 2013; Tye et al., 2014; Zhao et al., 2020), but none of the authors responded. Three of these provided the information required for effect size calculation and were, thus, included in the meta-analysis (Raz and Dan, 2015a; Rinke et al., 2017; Ibáñez et al., 2014). As such, eight studies were included in the meta-analysis due to data availability (e.g., *p*-values and amplitude means) (Alperin et al., 2017; Flegenheimer et al., 2017; Ibáñez et al., 2011; Ibáñez et al., 2014; Raz and Dan, 2015a; Rinke et al., 2017; Thoma et al., 2020; Williams et al., 2008). These studies included 209 participants with ADHD and 256 controls. The overall analysis (Table 2) showed no significant differences between both groups ($g = -0.04$, 95 % CI [−0.38, 0.31], $p = .822$, Fig. 2), however heterogeneity across studies was statistically significant (Q (8) $= 33.68$, $p < .001$, $I^2 = 79$ %). No publication bias was found in the analysis ($b = 3.39$, $p = .203$, Fig. 3).

A moderation analysis by emotional valence was performed, namely negative ($n = 5$), positive ($n = 5$), and neutral ($n = 3$) (Fig. 4). None of the conditions showed significant variance between studies ($p > .086$, Table 2) and no publication bias was found ($p > .203$; Fig. 5). In addition, only the neutral condition showed significant differences between studies ($g = -0.39$, 95 % CI [−0.60, −0.18], $p < .001$), revealing more negative amplitudes for the N170 component in participants with ADHD.

4. Discussion

The present work sought to summarise the literature involving N170 amplitude in ADHD and in healthy individuals. Underage samples were predominantly studied, while the employed tasks varied across the included studies. In most of them, participants were required to actively respond to a specific face stimulus, which portrayed positive, negative, or neutral valence emotions. In turn, the N170 was mainly measured in the parietal region.

Our meta-analytical results revealed no overall differences between individuals with ADHD and healthy controls in N170 amplitudes. Although incongruent with some of the previous reviews, which reported differences between both groups (Dan and Cohen, 2022; Feuerriegel et al., 2015; Morellini et al., 2022), this finding is congruent with the conclusions from a prior review (Roberts and Trossman, 2024). Also, the six studies that were not included in the meta-analysis due to the lack of statistical information all reported no overall differences between ADHD and healthy controls, further highlighting this result (congruently with Roberts and Trossman, 2024). One possible explanation for the differing results could be that the observed deficits in emotional recognition and face processing of individuals with ADHD (e.g., Arango-Tobón et al., 2023; Morellini et al., 2022) may not necessarily be due to alterations in sociocognitive functioning, but to an interplay of other factors. A previous review found an influence of age, characteristics of ADHD (e.g., more or less impulsive), and of comorbidities in the ability of facial emotion recognition (Olaya-Galindo et al., 2023), while another found no evidence of age, hemispheric lateralization, nor cognitive load

Table 2
Statistics for overall and moderator effect.

	Heterogeneity statistics					Confidence Interval - 95 %			Publication Bias	
	Q	p-value	I^2	k	Hedges' g	Lower limit	Upper limit	p-value	b	p-value
Overall	33.68	.000	79.21	8	−0.04	−0.38	0.31	.822	3.39	.203
Moderation by valence										
Negative	8.16	.086	50.95	5	−0.23	−0.50	0.04	.093	1.23	.667
Neutral	1.29	.525	0	**3**	**−0.39**	**−0.60**	**−0.18**	**.000**	4.09	.203
Positive	6.96	.138	42.54	5	−0.09	−0.36	0.18	.514	1.43	.611

modulation in differencing N170 amplitudes of ADHD individuals from controls (Roberts and Trossman, 2024). In the present work, however, moderation analyses with these factors could not be performed due to a lack of information. Taking this into account, it may be that social difficulties are a consequence of poor interactions and inadequate learning of emotional associations caused by other ADHD traits. For one, inattention, which is a hallmark symptom of ADHD, might negatively impact socialization with peers and pose a challenge in the formation and maintenance of relationships (Neprily et al., 2025). Given this, seeing as adults with ADHD seem to be able to compensate for their impairments in emotional face processing (Morellini et al., 2022) future research could explore both the differences between age groups but also the developmental trajectories of face-processing mechanisms in these individuals.

Regarding the modality of the tasks (i.e., passive or active), active tasks seem to induce lower N170 amplitudes, which may be attributed to possible competing processes dampening this ERP (Schindler and Bublatzky, 2020). Considering that only one out of the fourteen included studies employed a passive task, if a moderation analysis by modality could have been run, differences between healthy controls and ADHD individuals could arise. Incidentally, the disparity in the employed tasks also prevented us from conducting a moderation analysis. Thus, whether the tasks themselves impact N170 modulation is still undetermined. Regarding emotional valence, results of the moderation analysis revealed that individuals with ADHD and healthy controls do not differ in N170 amplitude for both positive and negative stimuli. This finding does not align with prior literature reporting dulled recognition of these types of emotions by individuals with ADHD (Bozkurt et al., 2024; Romani et al., 2018). In their review, Roberts and Trossman (2024) found differing results in respect to N170 amplitude modulation by threat-related emotional stimuli. As such, these authors indicate that there might be atypical neuronal processing of emotional faces, but that the direction of the differential response has undetermined origins. Still, it should not be overlooked that other variables could be influencing these results, as mentioned (Olaya-Galindo et al., 2023). Nevertheless, significant differences were found regarding N170 amplitude in response to neutral valence stimuli, with ADHD individuals showing a more negative N170.

Bearing in mind that emotional expressions tend to elicit higher N170 amplitudes than neutral expressions (Hinojosa et al., 2015), it is interesting that differences were only found for the latter. For a start, the face is thought to express various social-visual cues, which are used to infer about the person's intentions and harmfulness level (Albohn et al., 2019; Oosterhof and Todorov, 2008). As such, it appears as though no true neutral expression exists, granted that information seems to constantly be extracted from different facial cues to ascertain these

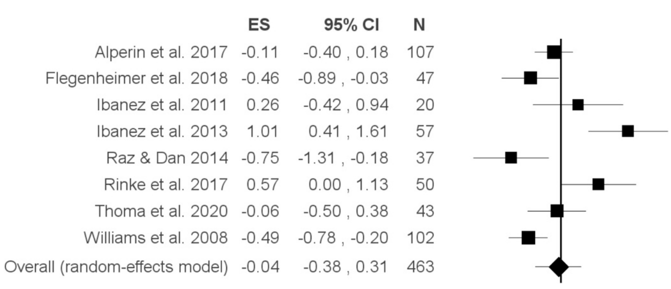

Fig. 2. Forest plot for N170 amplitude in ADHD individuals versus healthy controls. Negative effect sizes indicate a more negative amplitude in the ADHD group.

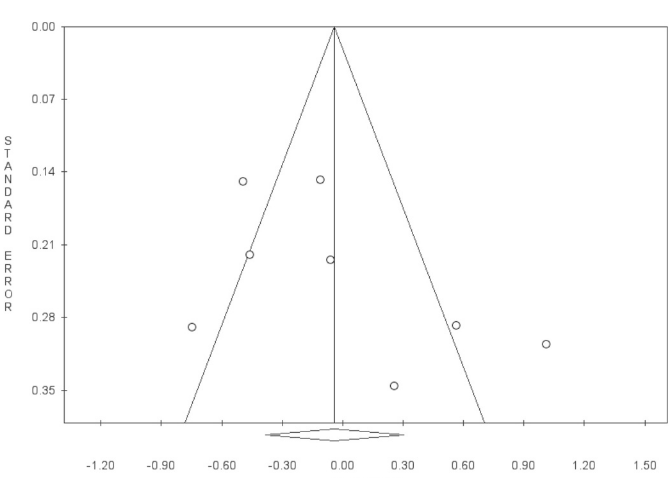

Fig. 3. Funnel plots showing the relation between the precision and effect size of each study.

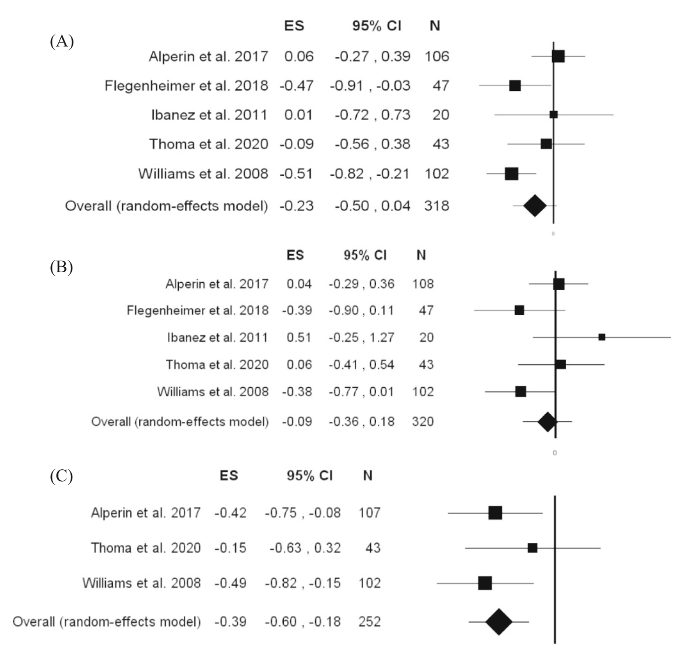

Fig. 4. Forest plots for N170 amplitude in ADHD individuals versus healthy controls, divided by valence: (A) negative, (B) positive, and (C) neutral. Negative effect sizes indicate a more negative amplitude in the ADHD group.

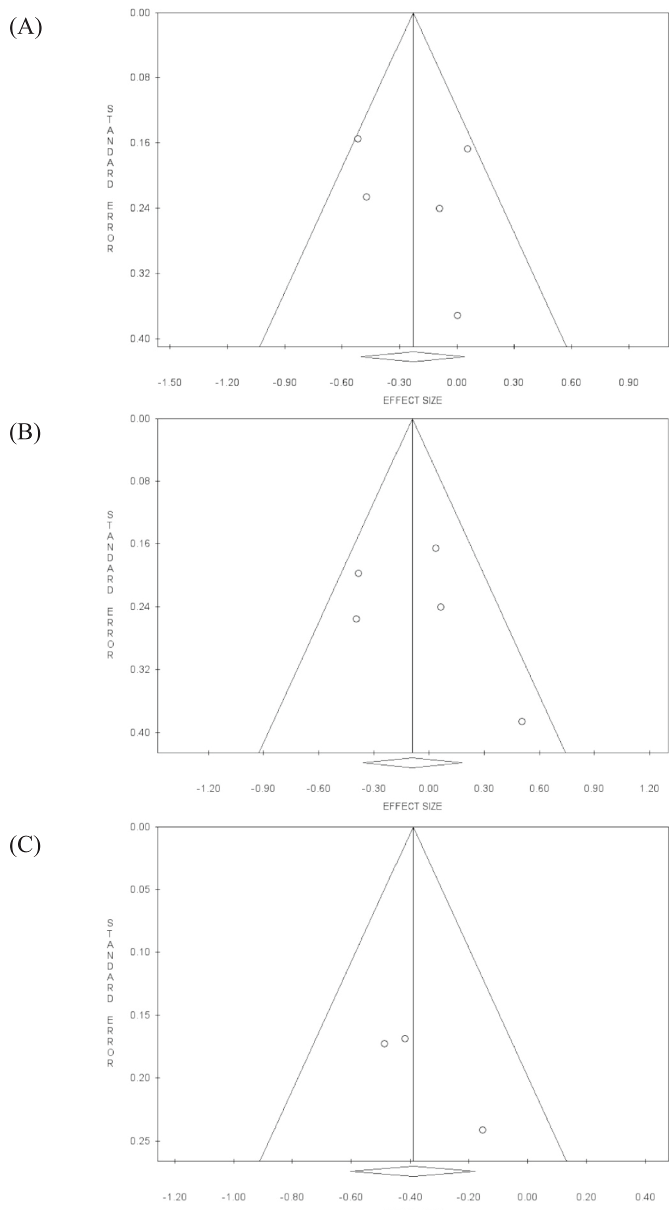

Fig. 5. Funnel plots showing the relation between the precision and effect size of each study, divided by valence: (A) negative, (B) positive, and (C) neutral.

social signals (Albohn et al., 2019). However, neutral faces seem to have less distinguishable features/cues for reading, leading to the need for longer visual inspection of these expressions (Sawada et al., 2022). Thus, given that perception and attention to social cues seem to be impaired in ADHD (Dickstein and Castellanos, 2012; Frith, 2008), these individuals could require more processing to try and identify the social signals in the neutral facial expression. In this way, the more negative N170 amplitude in ADHD may reflect compensatory allocation of attention to the neutral face, stemming from their increased difficulty in recognizing these expressions (Olaya-Galindo et al., 2023). It would, then, be interesting to explore if the latency of the N170 component is delayed in ADHD recognition of faces, considering that these individuals may need more time to process the sensorio-visual information. In order to prove that N170 alterations are related to difficulties in the processing of facial expressions of emotion and not influenced by previous brain processes such as simply visual face perception, it would also be important to analyse the P100 component (Torrence and Troup, 2017).

Given the findings of this meta-analysis, it appears as though N170 is not a reliable index of ADHD deficits in interpersonal relationships, namely regarding face recognition and emotional processing. As noted by Roberts and Trossman (2024), there is not enough evidence to support either an intrinsic impairment in social cognition nor a deficitary social context and emotional association learning in ADHD. In this way, the difficulties faced by these individuals in establishing and maintaining relationships may have a multifaceted origin, where biological and contextual factors could play a role in the severity of their social skills problems. Although the N170 component only seems to capture differences when neutral faces are used as stimuli, other ERPs have been found to be better indexes for ADHD-related impairments. For example, the Early Posterior Negativity is a component which is sensitive to perceptual emotional stimuli (Hajcak et al., 2012) and has been shown to be reduced in individuals with ADHD (respectively, Herrmann et al., 2009; Sarraf-Razavi et al., 2018). Additionally, Late Positive Potential is an ERP that represents affective processing of stimuli and is mostly sensitive to relevant biological imperatives (Hajcak et al., 2012), which has also been shown to be altered in ADHD (Kennedy and Montreuil, 2021; Köchel et al., 2012). These ERPs have consistently shown to be modulated by emotional expressions (Schindler and Bublatzky, 2020) and have a later onset (respectively, 200–300 ms and after 300 ms; Hajcak et al., 2012) than N170. For this reason, these components discriminate between emotions (Dan and Cohen, 2022) and display higher sensitivity to attentional resources allocation (Schindler and Bublatzky, 2020). Given that inattention is a trait associated with ADHD (Rocco et al., 2021) that seems to modulate these components (Schneidt et al., 2018), it seems appropriate for future studies to focus on their role in social functioning deficits in these individuals.

4.1. Limitations and future directions

The present review and meta-analysis contains some limitations that shall be addressed. First, the diversity in tasks employed prevented a moderation analysis from being conducted, casting doubt upon the effects of this heterogeneity in the null-findings. Second, not enough information was available about the pharmacological treatment of the participants (i.e., type of medication, dosage), nor the washout time periods. Thus, granted that medications in ADHD intend to "normalise" brain activity, it is possible that results are influenced by this uncontrolled variable. Further, a lack of studies measuring specific facial expressions lead to the combination of different emotions into three categories (i.e., valence). Hence, the current results may not truly reflect N170 amplitude differences between healthy and ADHD individuals, when observing distinct emotions. Finally, studies reporting the N170 latency were scarce, thus differences between groups were not possible to be analysed.

Heeding the above limitations, future studies should focus on employing standard passive recognition tasks, increasing the comparability and accuracy of their results. Medication usage by the participants should, also, be properly assessed and controlled for. Additionally, more research regarding the latency of N170 ERP would be advantageous for understanding ADHD deficits in facial emotion processing.

4.2. Conclusion

The present study is the first, to our knowledge, to meta-analyse the literature focused on N170 in healthy and ADHD individuals. Analyses only revealed a more negative N170 amplitude in ADHD individuals' response to neutral faces. This unexpected result suggests that ambiguous faces may demand higher processing for emotion recognition. Moreover, null-findings in the remaining analyses point towards generally normal neural processing of emotional expressions in ADHD. Thus, other factors may influence and give rise to the denoted difficulty in the perception of social cues by individuals with ADHD. In fact, delving into N170 latency research may prove fruitful in determining differences in reaction time between ADHD and healthy individuals.

CRediT authorship contribution statement

Beatriz C.R. Barroso: Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Luísa Vieira:** Methodology, Data curation, Conceptualization. **Joana O. Pinto:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Rita Almeida:** Writing – review & editing, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that there are no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpsycho.2025.112585.

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