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REVIEW PAPER

Emotion Recognition in Children and Adolescents with ASD and ADHD: a Systematic Review

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Abstract
Children and adolescents with autism spectrum disorder (ASD) and attention deficit and hyperactivity disorder (ADHD) show difficulties in recognizing emotions. Similarities and differences between these two clinical groups' emotion recognition (ER) have been little explored. This systematic review aims to summarize the results of comparative studies that included samples of cases with ASD and ADHD. A systematic search was conducted following PRISMA guidelines, and 24 papers were included. Behavioral, brain-based, and eye-tracking studies were considered, paying particular attention to the different methods used and to the characteristics of the study groups, such as cognitive factors, age-related differences, and comorbidities. This review provides some insight on the complex process of ER in ASD and ADHD, highlighting important directions for future research.

Keywords Emotion recognition · ASD · ADHD · Children · Adolescents · Systematic review

Autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD) are two specific neurodevelopmental conditions that may share some characteristics. The diagnostic guidelines describe social communication deficits and restricted, repetitive behaviors as being especially evident in ASD, while ADHD is characterized by inattention, hyperactivity and impulsivity (American Psychiatric Association [APA], 2013). The high frequency of ADHD symptoms in ASD (and vice versa) (Panagiotidi et al., 2017; Taurines et al., 2012) means that children may be misdiagnosed, so it is important to elucidate the factors that these two conditions share and those that are distinctive to one or the other. In this sense, social challenges are core defining symptoms of ASD, but social and interaction difficulties have been observed in ADHD as well, including a lack of reciprocity and empathy (Flavell & Miller, 1998; Panagiotidi et al., 2017) and social perception deficits (Cardillo et al., 2023).

Social cognition involves explicit and implicit processes in areas of joint attention, mentalizing, empathy, social perspective taking, social awareness, and emotion recognition (ER) (Flavell & Miller, 1998; Frith & Frith, 2008; Mundy & Newell, 2007; Preckel et al., 2018). This latter aspect refers to understanding emotional states from facial expressions, affective prosody, and body language, which are valuable sources of social information. For appropriate and adaptive interpersonal functioning, it is essential to understand other people's emotional manifestations (Demopoulos et al., 2013; Vandewouw et al., 2020). Over the past two decades, authors have tried to disentangle whether diagnoses of ASD and ADHD might encompass ER challenges, and whether there are any ER-related similarities and differences between the two conditions. To do so, researchers have applied a great variety of tasks involving different stimuli and emotions to be recognized, in addition to exploring factors related to ER (e.g., cognitive abilities, age). The present review summarizes the behavioral, brain-based, and eye-tracking findings emerging from comparative studies that investigated ER in children and adolescents with ASD, ADHD, or ASD + ADHD.

Types of Task, Stimuli, and Emotions

The great variety of methods used to assess ER commonly distinguish between labeling and matching emotions, the former referring to the ability to label emotions expressed by other people, the latter to the ability to distinguish

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one face from others showing different emotions (Yip et al., 2003). Different stimuli have been used to study ER, such as facial expressions (both static and dynamic) and auditory affective cues. Compared to static faces, dynamic cues are more natural, and from an evolutionary viewpoint, humans process other people's dynamic facial expressions more effectively than static ones, which are a simulated product of technology. Researchers who examined facial expressions in real-life conditions established that the dynamic information contained in emotional facial manifestations produced a more marked psychological and brain response (Ekman & Friesen, 2003; Kilts et al., 2003; Sato et al., 2012; Sato & Yoshikawa, 2007). Another line of research stressed the importance of affective prosody in understanding emotions (McCann & Peppé, 2003). Some authors examined affective prosody by asking participants to label the emotion conveyed by non-sense emotional words or sentences (Demopoulos et al., 2013; Löytömäki et al., 2020; Oerlemans et al., 2013). Others combined visual with vocal stimuli using socio-emotional video clips (Fine et al., 2008; Löytömäki et al., 2020; Semrud-Clikeman et al., 2010).

In the present review, we examine the type of task and stimuli, as well as the different types of emotion involved in ER tasks. Table 1 aims at summarizing the measures used by the studies included reviewing the types of emotional face recognition tasks, stimuli, and emotions assessed.

Main Findings on ER in ASD and ADHD Samples

Behavioral Findings

Compared with children with no known neurodevelopmental disorder (non-diagnosed [ND] controls), and with other clinical groups, those with ASD seem to have more difficulty in understanding and responding to expressions of emotion (see Black et al., 2017; Harms et al., 2010; Lozier et al., 2014; Uljarevic & Hamilton, 2013 for reviews). The overall picture of ER in autism is inconsistent, however, and complicated by substantial differences between studies in terms of sample size, tasks administered, and participants' attributes. Concerning the type of task, some meta-analyses (Harms et al., 2010; Uljarevic & Hamilton, 2013) found no differences in performance between emotion labeling and emotion matching tasks. This would suggest that the ER difficulties experienced by autistic participants are primary, caused by a disrupted emotion processing, and not by linguistic or perceptual challenges. Following this line, autistic participants would seem to perform less well not only in visual tasks, but also in the processing of emotional prosody (for a meta-analysis, see Leung et al., 2022), supporting a global ER deficit across modalities. Other studies support the hypothesis of a specific ER deficit in the ability to distinguish between happiness and negative emotions like fear, anger, and disgust: people with neurodevelopmental disorders seem to be less able to recognize negative emotions than positive ones (Brotman et al., 2010; Humphreys et al., 2007). Based on this hypothesis, some researchers revealed that difficulties in ASD only involved expressions associated with negative emotions (i.e., disgust, anger, sadness, and fear; Ashwin et al., 2007; Shanok et al., 2019). On the other hand, a meta-analysis (Lozier et al., 2014) found no evidence of ER challenges regarding specific emotions, and most studies reported finding individuals with ASD less accurate than controls in recognizing all six basic emotions, and especially for anger, fear, and surprise, supporting the global deficit hypothesis in autism, which postulates a general difficulty in recognizing all types of emotions in autistic individuals (for a meta-analysis, see Yeung, 2022).

Besides the well-established ER challenges in ASD, children with ADHD compared with ND participants also seem to have difficulty recognizing emotions, and especially in detecting emotional expressions of faces. There is less empirical evidence, however, and it too is mixed (see Borhani & Nejati, 2018; Romani et al., 2018 for reviews). Some studies found that participants with ADHD made mistakes with both static and dynamic emotional displays, including facial movements, tone of voice, and gestures indicating both positive and negative emotions (Ludlow et al., 2014; Pelc et al., 2006; Rapport et al., 2002). In other words, social cognitive patterns in children with ASD and ADHD may have more in common than those of children with ADHD and ND children (Demopoulos et al., 2013).

ER from affective prosody has been little investigated in ADHD, but findings point to both behavioral and neural outcomes associated with social disruption (Corbett & Glidden, 2000; Köchel et al., 2015). Unlike the case of ASD, however, the global deficit hypothesis was ruled out by more than one study on ADHD (for a meta-analysis, see Borhani & Nejati, 2018), which suggested more specific challenges in recognizing negative emotions, especially fear, followed by anger and sadness. Here again, however, the various studies on the matter show several discrepancies in how the authors defined a clear pattern of impaired ER in children with ADHD (see, for example, Corbett & Glidden, 2000; Köchel et al., 2015).

Brain-Based and Eye-Tracking Findings

While ER seems to pose significant challenges for children with autism and ADHD, questions have been raised about the different levels of their difficulties. Neuroscientific

Table 1 Summary and description of the measures used to assess ER abilities in the included studies

Study	ER measure	Reliability	Task	Stimuli	Emotions
Behavioral studies					
Berggren et al. (2016)	Frankfurt Test for Facial Affect Recognition (FEFA; Bölte et al., 2002)	Excellent internal consistency (rtt = 0.91 and 0.95) and retest reliability (rtt = 0.89 and 0.92)	Labeling	Static faces	Happiness, sadness, anger, surprise, disgust, fear, neutral
Bühler et al. (2011)	Facial Emotion Matching (FEM), developed by the neuropsychological testing system candit (developed by the neuropsychological testing system http://www.candit.com)	NR	Matching	Static faces	Joy, sadness, fear, anger, amazement, disgust
Demopoulos et al. (2013)	Diagnostic Assessment of Nonverbal Accuracy-2 (DANVA 2; Nowicki & Duke, 1994)	Reliabilities ranging from 0.69 to 0.88 and internal consistency ranging from 0.64 to 0.90	Labeling Labeling	Static faces Affective prosody	Happiness, sadness, anger, fear
Downs and Smith (2004)	Emotional understanding test (Howlin et al., 1999)	NR	Labeling	Static faces (level 1), schematic drawings (level 2)	NR
Dyck et al. (2001)	Facial Cues Test (FCT)	Cronbach $\alpha = 0.88$	Labeling	Static faces	Anger, contempt, disgust, fear, happiness, sadness, surprise, neutral
Economides et al. (2020)	Facial emotion labeling	NR	Labeling	Static faces	Happiness, anger, surprise, fear, disgust, sadness
Fine et al. (2008)	The Child and Adolescent Social Perception Measure (CASP; Magill-Evans et al., 1995)	NR	Labeling	Combined visual and vocal sources (i.e., videos of children interacting)	From basic emotions (e.g., happiness, sadness) to more complex ones (e.g., embarrassment, disappointment)
Flores-Buils and Andrés-Roqueta (2022)	Test of Emotion Comprehension (TEC)	Good test-retest reliability after 3 months of delay [$r(18) = 0.84$] and good test-retest correlation after 13 months of delay [$r(40) = 0.64$ and $r(32) = 0.54$] Cronbach $\alpha = 0.61–0.97$	Matching	Static faces	Happy, sad, angry, scared and/or well
Greco et al. (2021)	Morphing task	NR	Labeling	Dynamic morphing faces	From neutral faces to sadness, anger, surprise, happiness, disgust, and fear
Lee et al. (2018)	Penn Emotion Recognition Task (ER40; Gur et al., 2002)	NR	Labeling	Static faces	Happiness, sadness, anger, fear, neutral
Löytömäki et al. (2020)	Affective prosody recognition: emotional nonsense word task + meaningful sentences Facial affect recognition: Finnish version of the FEFA 2 test (Bölte et al., 2013) + eight photographs + eight video clips Mixed condition: matching emotion input from face and voice	Test-retest reliability $r = 0.92$ Cronbach $\alpha = 0.95$	Labeling Labeling Matching	Affective prosody Static faces + dynamic morphing faces Mixed condition	Happiness, anger, surprise, fear, disgust, sadness, neutral, ashamed
Oerlemans et al. (2013)	Facial emotion recognition (FER) Affective prosody recognition (APR)	NR	Matching Labeling	Static faces Affective prosody	Happiness, sadness, anger, fear
Semrud-Clikeman et al., 2010	The Child and Adolescent Social Perception Measure (CASP; Magill-Evans et al., 1995)	Cronbach $\alpha = 0.88$ to the CASPem Cronbach $\alpha = 0.92$ for CASPnv Test-retest reliability = 0.83–0.87	Labeling	Combined visual and vocal sources (i.e., videos of children interacting)	From basic emotions (e.g., happiness, sadness) to more complex ones (e.g., embarrassment, frustration)

Table 1 (continued)

Study	ER measure	Reliability	Task	Stimuli	Emotions
Sinzig et al. (2008)	Frankfurt Test for Facial Affect Recognition (FEFA; Bölte et al., 2002)	Excellent internal consistency (rtt = 0.91 and 0.95) and retest reliability (rtt = 0.89 and 0.92)	Labeling	Static faces	Happiness, sadness, anger, surprise, disgust, fear, neutral
Uluyagmur-Ozturk et al. (2016)	Facial emotion labeling (from Cohn-Kanade database; Kanade Cohn & Tian, 2000)	NR	Labeling	Static faces	NR
Waddington et al. (2018)	Facial Expressions Identification and Affective Prosody Tasks from the Amsterdam Neuropsychological Test (ANT; De Sonneville, 1999)	NR	Matching Labeling	Static faces Affective prosody	Happiness, sadness, anger, fear
Waddington et al. (2020)	Facial Expressions Identification and Affective Prosody Tasks from the Amsterdam Neuropsychological Test (ANT; De Sonneville, 1999)	NR	Matching Labeling	Static faces Affective prosody	Happiness, sadness, anger, fear
Brain-based and eye-tracking* studies					
Bustos-Valenzuela et al. (2022)*	Facial emotion recognition task	NR	Matching	Static faces	Anger, fear, surprise, disgust
Ozturk et al. (2018)*	Facial emotion labeling (from Cohn-Kanade database; Kanade Cohn & Tian, 2000)	NR	Labeling	Static faces	Anger, fear, happiness, neutral and sadness
Gross et al. (2012)	Facial emotion recognition (Pictures of Facial Affect, by Ekman 1976–2004, Berkeley, CA)	NR	Labeling	Static faces	Neutral, anger, disgust, fear, sadness
Safar et al. (2022)	Implicit emotional face processing task (from MacBrain Face Stimulus Set; Tottenham et al., 2009)	NR	N/A	Static faces	Happy or angry
Shephard et al. (2019)	Upright and inverted female faces displaying direct or averted gaze	NR	N/A	Static faces	NR
Tye et al. (2014)	Black-and-white face pictures	NR	N/A	Static faces	Disgust, fear, anger, joy, neutral
Vandewouw et al. (2020)	Dynamic faces (from MacBrain Face Stimulus Set; Tottenham et al., 2009)	NR	N/A	Dynamic morphing faces	From neutral to happy or angry

NR not reported, *N/A* not applicable

approaches have identified specific brain regions and networks involved in ER (Kilts et al., 2003). Social impairments associated with neurodevelopmental disorders prompted research on the brain correlates of ER in clinical groups to identify changes associated with their ER deficits. For example, research on event-related potentials (ERPs) linked to emotion processing suggested that the lateral occipitotemporal N170 is involved in the early automatic encoding of faces by comparing them with elements in memory, whereas the centro-parietal N400 is involved in examining the context and meaning of emotions. Smaller and slower N170 and N400 ERPs in autistic participants would indicate an atypical early visual processing during facial emotion detection (Black et al., 2017). Evidence from eye-tracking studies also confirmed that people with ASD process emotional faces differently than controls, for instance looking less at the eye region (for a review, see Harms et al., 2010).

As regards ADHD, a significant reduction in gamma band activity emerged, by comparison with ND participants, suggesting divergent functional trajectories during facial expression identification, especially in early stages of this process (Başar & Güntekin, 2013; Razavi et al., 2017). Going beyond the study of ERPs, neuronal oscillations synchronized across different brain regions have revealed the presence of functional networks associated with affective processing. This means that both local and global functional connectivity could be informative in studies on the atypical social cognition seen in neurodevelopmental disorders (Shephard et al., 2019). Moreover, the above mentioned specific difficulty with fear in ADHD has been linked to alterations in amygdala activity, which are thought to underlie certain particular behavioral and emotional reactions to circumstances that prompt dread in children with ADHD (Brotman et al., 2010; Posner et al., 2011). Evidence from the application of the eye-tracking confirmed less time focusing on the eyes during a facial ER task in ADHD participants as compared to controls (see, for example, Airdrie et al., 2018).

The Role of Cognitive Functioning and Age

People's ER abilities are also affected by individual characteristics, such as their cognitive skills (e.g., IQ, attentional abilities) (Bühler et al., 2011; Fine et al., 2008; Löytömäki et al., 2020). For many years, authors have debated whether the social deficit in autism is primarily affective (due to a lack of innate ability to interact emotionally with others) or cognitive (caused by meta-representational and symbolic skill impairments) (Baron-Cohen, 1988). As regards cognitive functioning, it has been suggested that the association between IQ and ER counts more in cases of ASD than in ND participants (Quintin et al., 2011; Tanaka et al., 2012), and that a higher IQ might be able to compensate for ER issues, especially in autistic individuals with a higher cognitive functioning (Harms et al., 2010; Livingston et al., 2019). Consequently, authors investigated whether a lower IQ, although within the normal range, could be associated with ER challenges (Dyck et al., 2001; Fine et al., 2008; Oerlemans et al., 2013). Attentional difficulties might also affect a child's ability to deal with social information, which is why children with ADHD could be at a disadvantage in dealing with social interactions (Semrud-Clikeman et al., 2010; Sinzig et al., 2008; Cardillo et al., 2023). In ASD too, a more limited attention to faces, and possibly a lack of joint attention, might help to explain a worse performance in ER tasks (Clifford et al., 2007). Research is needed to disentangle the aspects underpinning ER in order to guide the efforts of clinicians and educators devising tailored interventions to empower social cognition in children with neurodevelopmental disorders.

Alongside cognitive abilities, age has also been found to affect ER skills in children with both typical and atypical development. While ND children's understanding of emotions increases throughout much of childhood (Vicari et al., 2000), many studies found no correlation between age and performance in ER tasks in children with both ASD and ADHD, suggesting that they experienced no improvement, or no development of their proficiency at least, as they grew older (Borhani & Nejati, 2018; Gepner et al., 2001; Harms et al., 2010; Leung et al., 2022; Rump et al., 2009). This might mean that ER challenges are long-lasting primary features of autism, and not driven entirely by symptoms of ADHD, such as hyperactivity, which appears to ameliorate with age (Faraone et al., 2006).

Co-occurrence of ASD and ADHD, and ER as a Transdiagnostic Endophenotype

Given that difficulties with ER (and other peculiarities, like those affecting attentional and behavioral patterns) are common in both ASD and ADHD, some authors wondered whether the two conditions might be different manifestations of the same disorder (van der Meer et al., 2012). It is well known that ASD and ADHD are frequently diagnosed in comorbidity, possibly due to certain etiological and neurobiological factors (Lichtenstein et al., 2010; Polderman et al., 2014; Rommelse et al., 2011). Genetic overlapping and the resulting cognitive and brain outcomes could consequently make it hard to separate the symptoms. One of the aims of the present review is to examine similarities and differences in the way young people with ASD and ADHD identify other individuals' emotional expressions. The most useful way to examine overlaps and differences in a given ability between two disorders is to consider cases with both disorders and compare them with cases of either ASD or ADHD and with ND controls.

Another common approach to exploring the range of symptoms in ASD and ADHD focuses on endophenotypes, which could be defined as heritable vulnerabilities that enhance the risk of developing a disorder or disease (Wang et al., 2012). By creating subgroups based on endophenotypes, researchers might be able to reduce the clinical and etiological heterogeneity of their samples, particularly when their participants' conditions are caused by a complicated interplay between genes and environment—as in the case of psychiatric disorders (Almasy & Blangero, 2001). For this last category, the most often-used approach is the affected-unaffected sibling model (Oerlemans et al., 2013). Unaffected siblings have the same genetic variants and environmental risk factors as their affected siblings, and behavioral outcomes can be examined independently of any diagnosis (Sokolova et al., 2017; van Lieshout et al., 2019). Regarding shared genetic components of social cognition in ASD and ADHD, recent findings suggest that an impaired ER could be a valid endophenotype for exploring cross-disorder traits. Using factor mixture modeling, a group of researchers identified ER subtypes based on four factors (e.g., visual speed, visual accuracy, auditory speed, and auditory accuracy) and examined to what extent belonging to one subtype or another could predict the severity of ASD or ADHD problems (Waddington et al., 2018, 2020).

The Present Systematic Review

To sum up, although previous systematic reviews and meta-analyses examined ER challenges in either ASD or ADHD (Borhani & Nejati, 2018; Collin et al., 2013; Lozier et al., 2014; Romani et al., 2018; Uljarevic & Hamilton, 2013; Yeung, 2022), none to our knowledge considered studies examining both these clinical conditions. To fill this gap in the literature, the present review focuses on studies that compared ER performance in samples of children and adolescents with (and without) ASD and ADHD in an effort to reveal similarities and differences in ER between the two disorders. Studies in which cases of comorbid ASD + ADHD were compared with children diagnosed with one or other disorder are discussed too. First, we divide the results into two macro-classifications: behavioral studies and brain-based and eye-tracking studies. We consider the types of tasks' demands, stimuli used, and the emotions investigated in both behavioral, and brain-based and eye-tracking studies to see whether impairments occurred due to the task's features. Then, we examine the influence of cognitive factors (e.g., IQ, theory of mind, and attentional and inhibitory control) and age on ER. We conclude with findings on the effects of comorbid ASD + ADHD on ER and with studies that considered ER deficits as a transdiagnostic endophenotype in ASD and ADHD.

Method

Search Strategy and Study Selection

This systematic review was conducted in accordance with the 2020 Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) checklist (Page et al., 2021). It was registered with PROSPERO (International Prospective Register of Systematic Reviews; registration No. CRD42021270510). A systematic search of the PubMed, Web of Science, ScienceDirect, and Scopus databases was conducted by two of the authors (RL, GC), who screened titles and abstracts, setting no time constraints on the published articles to consider. Combinations of the same search terms—"autism," "ASD," "ADHD," "emotion recognition," "emotion understanding," "emotion identification," "emotion attribution," "emotion differentiation," "cognitive empathy," "neurodevelopmental disorders," "children," and "adolescents"—were used in all the databases. As permitted by each database, the terms were explored mainly in titles, abstracts and keywords, and (if possible) in the full text of the articles. Reference lists were also searched manually to identify studies of potential interest that might have been overlooked. Articles were included in the review if: (1) the study compared groups with ASD (without intellectual disability [ID]), ADHD, or comorbid ASD + ADHD; (2) experimental ER tasks were used; and (3) the study sample included children and adolescents.

First, we eliminated duplicates from our total set of studies to consider. Then, we excluded papers in which ASD and ADHD groups were not considered from a comparative perspective. Then, we omitted studies for which a full text was unavailable, or was not written in English, single-case reports, comments, letters, protocol papers, reviews, and qualitative studies. After reading the full texts of the remaining eligible studies, we opted to include research papers based on the methods used to assess ER abilities. We excluded studies that used self-report or parent/teacher-report questionnaires to assess the child's ability to understand others' emotions, only considering those that used experimental tasks designed to assess ER abilities. Studies that adopted the "Reading the Mind with the Eyes" test (RMET) (Baron-Cohen et al., 1997) were also disregarded because Baron-Cohen (2001) conceived it as a test of "how well participants can put themselves into the mind of the other person and tune in to their mental state," so it is usually described as a theory of mind test rather than an emotion recognition test (Baron-Cohen, 2001; Chander et al., 2020). At this point in our data processing, we excluded two further studies because the samples' characteristics did not meet our inclusion criteria (Buitelaar et al., 1999; Löytömäki et al., 2022).

Data Extraction

Data were extracted independently by two of the authors, then compared to find and solve any discrepancies. The data extracted included the sample's demographic details (i.e., sample size, gender, and age), IQ assessments, and comorbidities; our inclusion and exclusion criteria (e.g., neurological and genetic conditions); the measures used to assess ER; and the results. Between-group effect sizes were calculated for the study outcomes for which means and standard deviations were available (effect sizes had already been included in some studies).

Methodological Quality Assessment

Each study was assessed for risk of bias using the Quality Assessment of Case-Controlled Studies of the National Heart Lung and Blood Institute (National Institutes of Health [NIH], 2014). This tool helps reviewers to focus on key concepts when judging the internal validity of case-control studies: the lower the quality rating of the study, the greater the risk of bias. An exhaustive description of the quality assessment process is provided in the Supplementary materials section.

Results

Search Results

The PRISMA flow diagram is shown in Figure 1. The literature search was carried out in November 2022. In all, 364 publications were identified in four databases (PubMed, Web of Science, ScienceDirect, and Scopus), and 97 duplicates were removed. Of the 267 records screened for eligibility, 211 were excluded because they did not concern children and adolescents with a clinical diagnosis of ASD, ADHD, or ASD + ADHD. The remaining 56 reports were further assessed, but 34 were excluded because they did not satisfy our inclusion criteria (see Fig. 1 for details). Twenty-two publications met our inclusion criteria, and another two papers were identified from their reference lists, so 24 studies were ultimately included in this review.

Characteristics of the Studies

Tables 2 and 3 list the characteristics of the studies reviewed, which were all published before September 2022, and concerned participants from 4.5 to 22 years old. The samples usually included both sexes (16 samples), while seven papers only concerned boys, and one did not specify the participants' sex (Bustos-Valenzuela et al., 2022). The studies came from 13 countries (the USA, Italy, Spain, Sweden, Germany, Australia, Greece, Finland, Turkey, Canada, the UK, the Netherlands, and Korea). The clinical groups had been recruited at psychiatric clinics for children and adolescents, pediatric clinics, special consultation services, or academic medical and day-care centers. The ND control groups had been recruited at schools and through advertisements in the local media. The data analyzed in the studies had been collected over the course of 21 years (2001–2022), so successive versions of disease classifications (International Classification of Diseases and Related Health Problems, ICD; Diagnostic and Statistical Manual of Mental Disorders, DSM) had been used to diagnose cases of ASD and ADHD. Similarly, different versions of the Wechsler Intelligence scales had been administered to assess IQ. The number of studies published in this particular field increased in the second decade of the period considered: only four studies were published before 2010, as opposed to 20 between 2011 and 2022. Twenty-two studies were published in peer-reviewed journals, while two were presented at international conferences, the 2020 IEEE International Conference on Machine Learning and Applications (Economides et al., 2020) and the 15th IEEE International Conference on Machine Learning and Applications (Uluyagmur-Ozturk et al., 2016).

Quality of the Studies

The methodological quality assessment (see Table S1 in the Supplementary materials) was used to test the studies' internal validity. Three studies included in the review received a "Poor" overall quality rating, while the quality of 11 studies was rated as "Fair," and for 10 it was "Good."

Overview of the Studies

Findings will be divided (and explained) into two main categories: behavioral studies and brain-based and eye-tracking studies.

Seventeen behavioral studies (Berggren et al., 2016; Bühler et al., 2011; Demopoulos et al., 2013; Downs & Smith, 2004; Dyck et al., 2001; Economides et al., 2020; Fine et al., 2008; Flores-Buils & Andrés-Roqueta, 2022; Greco et al., 2021; Lee et al., 2018; Löytömäki et al., 2020; Oerlemans et al., 2013; Semrud-Clikeman et al., 2010; Sinzig et al., 2008; Uluyagmur-Ozturk et al., 2016; Waddington et al., 2018, 2020) were included in the review, in which performance in ER tasks was compared between the study groups. Two of these studies classified participants' diagnoses based on a subtyping approach, measuring speed and accuracy in auditory and visual ER tasks (Waddington et al., 2018), and machine learning methods that focused on correct answers and response times (Uluyagmur-Ozturk et al., 2016). One study instead investigated the genetic components of ADHD and ASD by examining the cross-disorder trait of ER difficulty (Waddington et al., 2020).

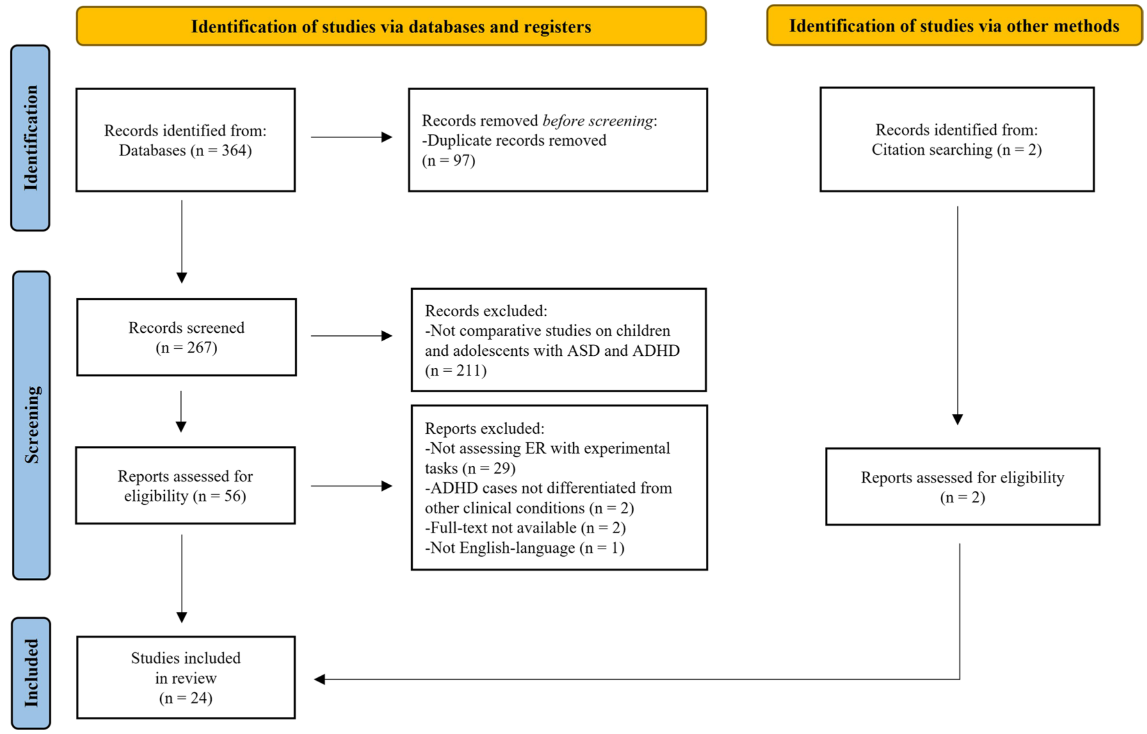

Fig. 1 The PRISMA flow diagram of the systematic review search strategy

Among brain-based studies, three studies used electroencephalography (EEG) (Gross et al., 2012; Shephard et al., 2019; Tye et al., 2014), one functional magnetic resonance imaging (fMRI) (Vandewouw et al., 2020), and one magnetoencephalography (MEG) (Safar et al., 2022) to assess neural activity in response to emotional faces in children with and without ASD and ADHD. Among eye-tracking studies, one applied the eye-tracker to measure gaze fixation and cognitive vergence responses to the eye regions on the faces used as stimuli (Bustos-Valenzuela et al., 2022), and one performed a multimodal classification with the noisy eye tracker in order to detect the diagnosis of the participants (Ozturk et al., 2018).

Within each section (behavioral, and brain-based and eye-tracking studies), the demands of the tasks, the stimuli used, and the emotions considered will be summarized, along with the main results obtained. Three of the studies that used brain-based (Gross et al., 2012) and eye-tracking (Bustos-Valenzuela et al., 2022; Ozturk et al., 2018) techniques also reported behavioral findings (accuracy and/or RTs) which will be included as well in the "Behavioral Studies" section. Finally, nine behavioral, brain-based, and eye-tracking studies considered the role of cognitive functioning on ER, 3 age-related differences in ER, 6 ER as a transdiagnostic endophenotype, and 7 the role of comorbidities; thus, findings will be described altogether at the end of the "Results" section.

Behavioral Studies

Types of Experimental Task and Stimuli

Among behavioral studies, although the most used stimuli were static faces such as photos (Berggren et al., 2016; Bühler et al., 2011; Demopoulos et al., 2013; Downs & Smith, 2004; Dyck et al., 2001; Economides et al., 2020; Flores-Buils & Andrés-Roqueta, 2022; Lee et al., 2018; Löytömäki et al., 2020; Oerlemans et al., 2013; Sinzig et al., 2008; Uluyagmur-Ozturk et al., 2016; Waddington et al., 2018, 2020), also dynamic morphing faces (Greco et al., 2021; Löytömäki et al., 2020), affective prosody (Demopoulos et al., 2013; Löytömäki et al., 2020; Oerlemans et al., 2013; Waddington et al., 2018, 2020), and combined visual and vocal sources (i.e., videos of social interactions) (Fine et al., 2008; Semrud-Clikeman et al., 2010) were used to assess ER.

As regards tasks' demands, participants were asked to label emotions (or chose from options) they were shown in 12 of the studies reviewed (Berggren et al., 2016;

Table 2 Characteristics and findings of the behavioral studies reviewed ($n = 17$)

Study	Groups (N)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	IQ	Comorbidities			
Berggren et al. (2016)°°	ASD = 35 ADHD = 32 ND = 32	ASD = 11.6 (1.8) ADHD = 11.1 (2.1) ND = 11.7 (1.8) Age range: 8.6–15.9	ASD = 103.8 (11.9) ADHD = 101.7 (12.9) ND = 102.9 (8.5) WISC-IV	For the ASD group: 11 had ADHD, 9 had behavioral disorders, 3 had tic disorders/Tourette, and all had phobias or sleep disorders	Neurological disorders, severe mental disorders, genetic syndromes, and intellectual disability (IQ < 70)	Cross-sectional	Accuracy *Global scores* ASD < ND in face test ($p = 0.009$, $d = 0.74$) *Specific scores* ASD < ND in neutral (face, $d = 0.27$) and happiness (face, $d = 01.18$; eyes, $d = 1.04$) ($p < 0.0001$) RTs *Global scores* ASD > ND ($p = 0.01$, $d = 0.74$), ASD > ADHD ($p = 0.01$, $d = 0.58$) in face test *Specific scores* ASD > ND in all emotions of face test (except for happiness) ($p = 0.01$, $0.55 < d < 0.89$)
Bühler et al. (2011)°°	ASD = 86 ADHD = 84 ASD + ADHD = 52	ASD = 10 (8) ADHD = 9 (7) ASD + ADHD = 10 (1) Age range: 4.5–22	ASD = 105.4 (16.7) ADHD = 97.9 (22) ASD + ADHD = 99 (18.9) WISC ASD > ASD + ADHD > ADHD ($p = 0.04$)	None ADHD = patients who had been diagnosed with a hyperkinetic disorder (F90.0) or a conduct disorder (F90.1)	Comorbidities	Cross-sectional	Accuracy No differences between groups ($p = 0.06$) Errors ASD > ADHD on mouth errors ($p = 0.01$) but not on eye errors ($p = 0.106$) Children under 10 years old: ASD > ADHD total errors ($p = 0.037$, $d = 0.33$) RTs No differences between groups ($p = 0.22$)
Demopoulos et al. (2013)	ASD = 137 ADHD = 436	ASD = 10.39 ± 3.49 ADHD = 10.58 ± 3.11 Age range: 6–17	ASD = 88.33 ± 18.86 ADHD = 98.20 ± 14.79 WISC IV, WAIS-III ASD < ADHD ($p < 0.001$)	NR	NR	Cross-sectional	Accuracy ASD < ADHD in both facial ($p < 0.01$, $d = 0.50$) and vocal ($p < 0.05$, $d = 0.49$) affect tests, with IQ as covariate Both groups performed below the normative sample for both tests ($p < 0.001$, $0.18 < d < 0.86$)
Downs and Smith (2004)	ASD = 10 ADHD = 16 ND = 10	ASD = 7.10 (1.1) ADHD = 8.3 (1) ND = 7.7 (1.2) Age range: 5.8–9.9	ASD = 106 (7.63) ADHD = 103.38 (12–40) ND = 108.90 (12.22) WISC-III, WPPSI-R	ADHD participants also had oppositional defiant disorder (ODD) in comorbidity	ASD children who did not take part to the treatment or with Asperger's disorder	Cross-sectional	Accuracy Level 1: ASD < ADHD, ND ($p < 0.01$, $d = 0.85$) Level 2: no differences between ASD, ADHD, and ND ($d = 0.23$)
Dyck et al. (2001)* °°	ASD = 28 ADHD = 35 ND = 36	M (DS) = 12.09 (2.20)	NR WISC III ND > ADHD > ASD	For ASD group: mental retardation, oppositional defiant disorder. For ADHD: Tourette, conduct disorder	Not speaking English, comorbid disorders, and psychological disorders for ND	Cross-sectional	Accuracy ASD = ADHD < ND ($p < 0.001$, $0.17 < d < 0.58$)

Table 2 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	IQ	Comorbidities			
Economides et al. (2020)*	ASD = 8 ADHD = 13 ND = 33	Clinical group (ASD, ADHD) = 8.16 (1.85) ND = 8.21 (1.82) Age range: 6–11.9	NR	32% of participants had a comorbid disorder (not specified)	NR	Cross-sectional	Accuracy *Global scores* ASD, ADHD < ND but no differences emerged between ASD and ADHD *Specific scores* Clinical < ND on disgust ($p = 0.000$) and happiness ($p = 0.019$) on stimuli with children (but not adults) Clinical < ND on sadness on stimuli with adults (but not children) ($p = 0.003$) Clinical: disgust on male stimuli < female stimuli ($p = 0.0016$); sadness on female stimuli < male stimuli ($p = 0.001$); disgust and surprise on stimuli with male children < stimuli with male adults ($p = 0.001$, $p < 0.029$)
Fine et al. (2008)°°	ASD = 37 ADHD = 30 ND = 19	ASD = 128.14 (29.11) ADHD = 124.47 (23.75) ND = 119.58 (13.34)* Age range: 6–15 *In months	ASD = 104.16 (12.26) ADHD = 107.87 (13.77) ND = 116.47 (13.34)	20 of the children in the ASD group also had a secondary diagnosis of ADHD	Participants whose diagnosis was not unanimous, or with a history of seizure disorder, progressive neurological problems, traumatic brain injury, or any other serious medical condition	Cross-sectional	Accuracy CASPec (emotion cues): ASD < ND ($p < 0.001$, $d = 1.48$), ADHD < ND ($p = 0.002$, $d = 1.14$) CASPnv (non-verbal cues): ASD < ND ($p = 0.030$, $d = 0.97$) No differences between ASD and ADHD groups in either the CASPec ($p = 0.27$, $d = 0.55$) or the CASPnv ($p = 1$, $d = 0.25$)
Flores-Buils and Andrés-Roqueta (2022)*	ASD = 36 ADHD = 20 ND = 73	ASD = 106.78 (25.41) ADHD = 117.05 (22.88) ND = 110.45 (24.42)* Age range: 5–12 *In months	NR	Two children of the ASD group showed an ADHD condition in their reports, and a child presented ADHD and DLD	NR	Cross-sectional	Accuracy ASD < ADHD, ND

Table 2 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	IQ	Comorbidities			
Greco et al. (2021)	ASD = 20 ADHD = 21 ND = 21	ASD = 9.33 ADHD = 10.12 ND = 10.12 Age range: 7–12	FSIQ ≥ 85	No	First language was not Italian, other medical or psychiatric disorders, visual or auditory impairment or neurodevelopmental	Cross-sectional	Overall *Accuracy* No differences between ASD and ADHD. ND better than both *RTs* ASD > ADHD, ND Errors *Human faces* ASD > ND in disgust ($\chi^2 = 7.612$; $p = 0.022$) ADHD > ASD, ND in surprise ($\chi2 = 6.025$; $p = 0.049$) *Cartoon faces* ADHD > ASD, ND ($\chi^2 = 6.620$; $p = 0.037$) ADHD had the highest percentage of errors with disgust ($\chi^2 = 9.371$; $p = 0.009$) RTs *Human faces* ND < ASD, ADHD (F happiness, M disgust) ND, ADHD < ASD (M/F surprise, M anger, M happiness) ND < ASD (F fear) ND < ADHD (M anger) *Cartoon faces* ND, ADHD < ASD ND < ASD (F surprise, M sadness) Note: M = male faces, F = female faces
Lee et al. (2018)	ASD = 8 ADHD = 15	ASD = 8.00 (0.93) ADHD = 8.40 (0.91) Age range: 7–10	ASD = 82.38 (20.98) ADHD = 88.07 (12.50) WISC-IV	Unspecified comorbidities	Change in dose or type of medication during training period, less than 12 of the total 24 sessions, IQ < 70	Social skills training on emotion recognition	Before the training: Accuracy No differences between ADHD and ASD (ER40 $d = 0.33$) RTs No differences between ADHD and ASD (ER40 $d = 0.36$)
Löytömäki et al. (2020)* °°	ASD = 20 ADHD = 17 ND = 106	ASD = 8.25 (1.21) ADHD = 8.06 (1.30) ND = 8.02 (1.42) Age range: 6–10	NR (only inclusion criteria verbal-IQ > 85)	20 participants had comorbid diagnoses (ASD = 9, ADHD = 8, DLD = 3, such as SLD, ADHD + ASD) 7 participants also had subsidiary diagnoses, such as a motor function disorder or Tourette's syndrome	Any psychiatric diagnoses, such as depression	Cross-sectional	Accuracy No differences between ASD and ADHD in all emotion recognition tasks (FEFA2 $d = 0.17$, photos $d = 0.45$, video $d = 0.03$, prosody $d = 0.39$) ASD < ND in FEFA2 ($p = 0.002$, $d = 0.84$) and photos ($p = 0.031$, $d = 0.64$) ADHD < ND in affective prosody recognition (non-sense words) ($p = 0.017$, $d = 0.72$)

Table 2 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	IQ	Comorbidities			
Oerlemans et al. (2013)°°	Facial emotion recognition (FER): ASD + ADHD = 43 ASD = 47 Siblings ASD = 79 ND = 139 Affective prosody recognition (APR): ASD + ADHD = 30 ASD = 36 Siblings ASD = 49 ND = 72	FER: ASD + ADHD = 10.5 (2) ASD = 10.7 (2.1) Siblings ASD = 9.7 (2) ND = 9.2 (1.9) APR: ASD + ADHD = 11.5 (1.5) ASD = 11.6 (1.2) Siblings ASD = 10.9 (1.3) ND = 10.7 (1.1) Age range: 6–13 ASD + ADHD = ASD > siblings ASD = ND	FER ASD + ADHD = 103.3 (13.3) ASD = 103.1 (14.1) Siblings ASD = 106.4 (12.5) ND = 107.4 (11.7) APR ASD + ADHD = 101.7 (11.9) ASD = 103.4 (14.7) Siblings ASD = 106.2 (12.3) ND = 106.1 (11.3) WISC III	NR	IQ ≤ 60, a diagnosis of epilepsy, brain disorders or known genetic disorders, such as Down's syndrome or Fragile X syndrome	Cross-sectional with two different samples for FER and APR	Group differences between ASD, siblings of ASD and ND FER**:** Errors *Global score* ASD > ND ($p = 0.015$, $d = 3.94$) *Specific scores* ASD, siblings ASD > ND on happiness ($p = 0.034$, $p = 0.007$) RTs *Specific scores* ASD > ND on happiness ($p = 0.01$), sadness ($p = 0.017$), anger ($p = 0.024$), fear ($p = 0.006$) APR**:** Errors *Specific scores* ASD > ND on sadness ($p = 0.023$) ASD > siblings ASD on anger ($p = 0.022$) RTs *Specific scores* ASD > ND on all emotions ($p < 0.004$) siblings ASD > ND on fear ($p = 0.01$) Group differences between ASD, ASD + ADHD and ND FER**:** Errors *Global scores* ASD + ADHD > ND ($p = 0.004$) *Specific scores* ASD + ADHD > ND on happiness ($p = 0.012$) RTs *Global scores* ASD, ASD + ADHD > ND ($p = 0.005$; $p = 0.027$) *Specific scores* ASD + ADHD > ND on happiness ($p = 0.003$) and fear ($p = 0.004$) ASD > ND on anger ($p = 0.021$) and fear ($p = 0.042$) APR**:** Errors *Specific scores* ASD + ADHD > ND on sadness ($p = 0.012$) ASD + ADHD > ASD on happiness ($p = 0.039$) RTs *Specific scores* ASD + ADHD > ND on all emotions ($p < 0.016$) ASD > ND on all emotions ($p < 0.042$)

Table 2 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	IQ	Comorbidities			
Semrud-Clikeman et al. (2010)* °°	ASD = 52 ADHD-c = 76 ADHD-pi = 77 ND = 113	ND = 10.4 (25.1) ASD = 10.3 (28.8) ADHD-C = 10.0 (24.4) ADHD-PI = 10.8 (25.4)* Age range: 9.1–16.5 *SD in months	Verbal IQ: ASD = 107.3 (17.6) ADHD-c = 110 (16.6) ADHD-pi = 106.1 (11.7) ND = 111.9 (14.3) WASI	27 ASD also had ADHD (14 ADHD-C, 13 ADHD-PI)	Participants whose diagnosis was not unanimous, reading disability, seizure disorder, serious medical condition, progressive neurological problems, and severe mood disorders	Cross-sectional	Accuracy CASPec: ASD < ADHD ($p = 0.001$, $d = 0.79$) CASPnv: no differences between ASD and ADHD ($d = 0.54$), only ASD, ADHD < ND ($p = 0.015$)
Sinzig et al. (2008)°°	ASD + ADHD = 21 ASD = 19 ADHD = 30 ND = 29	ASD + ADHD = 11.6 (3.7) ASD = 13.6 (3.4) ADHD = 12.7 (3.1) ND = 12.8 (2.9) Age range: 6.1–18.9	ASD + ADHD = 102 (13.1) ASD = 111 (19.1) ADHD = 100 (14.9) ND = 109 (12.9)	NR	Medical causes of autism, including Fragile X syndrome and tuberous sclerosis, those with other neurological disorders	Cross-sectional	Accuracy *Global scores* ADHD < ND in recognition of pairs of both faces ($p = 0.04$) and eyes ($p = 0.009$) ADHD + ASD < ND in eyes test ($p = 0.009$) *Specific scores* ASD + ADHD < ASD for joy (eyes; $p = 0.02$, $d = 1.09$) and surprise (faces; $p = 0.04$, $d = 0.82$) ASD + ADHD < ND for joy (eyes; $p = 0.01$, $d = 1.83$) and surprise (faces; $p = 0.002$, $d = 1.12$) ADHD < ND in joy (eyes; $p = 0.04$, $d = 0.70$)
Uluyagmur-Ozturk et al. (2016)	ASD = 18 ADHD = 30 ND = 13	ASD = 10.5 ADHD = 9.46 ND = 9.22 Age range: around 10	NR	NR	NR	Classification on machine learning methods	Authors could differentiate ASD from ADHD with 90% accuracy by using Adaboost algorithm on RTs
Waddington et al. (2018)	ASD = 85 ADHD = 74 ASD + ADHD = 60 Siblings = 177 ND = 156	ASD = 12.32 (2.48) ADHD = 12.67 (1.71) ASD + ADHD = 12.14 (2.79) Siblings ASD + ADHD = 11.77 (2.79) Siblings ADHD = 12.81 (1.63) ND = 13.11 (2.35) Age range: 7–18	ASD = 101.51 (14.67) ADHD = 99.49 (14.13) ASD + ADHD = 102.36 (13.15) Siblings ASD + ADHD = 105.73 (12.63) Siblings ADHD = 99.61 (14.42) ND = 105.15 (12.42)	NR	IQ < 70, a diagnosis of epilepsy, brain disorders, known genetic disorders (e.g., Down syndrome or Fragile X syndrome), with an additional criterion of a clinical diagnosis of autistic disorder or Asperger's disorder	Emotion recognition subtyping approach with participants from two cohorts (the NeuroIMAGE and the BOA studies)	A four-class ER subtyping: (1) Average visual, impulsive auditory (2) Average-strong visual and auditory (48.98% of ASD and ADHD, 15.26% of ND) (3) Impulsive/imprecise visual, average auditory (4) Weak visual and auditory (66.07% of ASD and ADHD, 10.09% of ND)

Table 2 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	IQ	Comorbidities			
Waddington et al. (2020)	ASD = 89 ASD + ADHD = 64 Siblings of ASD + ADHD = 122 ADHD = 111 Siblings of ADHD = 69 ND = 220	ASD = 12.32 (2.48) ADHD = 12.67 (1.71) ASD + ADHD = 12.14 (2.79) Siblings ASD + ADHD = 11.77 (2.79) Siblings ADHD = 12.81 (1.63) ND = 13.11 (2.35) Age range: 7–18	M (DS) = 100–103	NR	IQ < 70, diagnosis of epilepsy, and known genetic syndromes (e.g., Down syndrome or Fragile X syndrome), a clinical diagnosis of ASD based on DSM-IV criteria	Emotion recognition subtyping approach with participants from two cohorts (the NeuroIMAGE and the BOA studies)	Higher ASD-PRS (polygenic risk score) associated with faster visual emotion recognition *Categorical analysis* ASD-PRS = reduced in class 3 compared to other classes ($p = 0.021$) *Dimensional analysis* ADHD-PRS = reduced the probability of being assigned to class 1 or 3 ($p = 0.028$ and $p = 0.044$, respectively)

ASD autism spectrum disorder, *ADHD* attention deficit and hyperactivity disorder, *ND* non-diagnosed group, *NR* not reported, *ER* emotion recognition, *IQ* intelligence quotient, *WISC* Wechsler Intelligence Scale for Children, *WAIS* Wechsler Adult Intelligence Scale, *WPPSI* Wechsler Preschool and Primary Scale of Intelligence, *WASI* Wechsler Abbreviated Scale of Intelligence, *RTs* reaction times, *d* Cohen's *d*

*Studies with other clinical groups not discussed in the review. For information about other groups, please see the corresponding article

°°Studies that considered the effect of cognitive variables on emotion recognition abilities (please see sections on "The role of cognitive functioning and age")

Table 3 Characteristics and findings of the brain-based and eye-tracking studies reviewed ($n = 7$)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	**IQ**	**Comorbidities**			
Bustos-Valenzuela et al. (2022)	ASD = 18 ADHD = 27 ASD + ADHD = 15 ND = 31	Age range: 8–18	IQ > 70	NR	Depressive episodes, bipolar disorder, schizophrenia, and conduct disorder	Cross-sectional with eye-tracker	**Accuracy** ND > ADHD, ASD + ADHD **Eye-tracker** *Gaze fixation duration and cognitive vergence to eyes* ADHD, ADHD + ASD < ND, ASD
Gross et al. (2012)	ASD = 10 ADHD = 9 ND = 11	ASD = 14.1 (2.7) ADHD = 14.2 (3.9) ND = 14.8 (4.5) Age range: 9–21	ASD = 94.2 (18.1) ADHD = 98.6 (9.2) WISC, WASI	Mood disorders (ASD = 2, ADHD = 1), anxiety (ASD = 2, ADHD = 1)	A history of seizure disorder, significant hearing or visual impairment, a brain abnormality conclusively confirmed on imaging studies or an identified genetic disorder	Cross-sectional with EEG using data alignment	Abnormal regional gamma activation patterns in ASD *P7, P8*: ASD had lower induced gamma power during ER compared to control task *P3, P4, P7, P8*: ADHD had higher induced gamma power during ER compared to control task ND showed small differences between the two tasks

Table 3 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	**IQ**	**Comorbidities**			
Ozturk et al. (2018)	ASD + ADHD = 12 ADHD = 12 ND = 10	ASD + ADHD = 10.5 (1.35) ADHD = 9.20 (1.08) ND = 9.37 (1.34)	IQ > 70	NR	IQ < 70, not fluent in speech, not able to read and write, visual acuity problems	Multimodal classification on noisy eye tracker and application log data	**Accuracy** *Specific scores* ASD + ADHD, ADHD < ND on fear (p = 0.028, d > 0.70) **RTs** *Specific scores* ADHD, ND < ASD + ADHD on fear (p < 0.001), on happiness (p = 0.005), on sadness (p = 0.004); ADHD < ND < ASD + ADHD on anger (p < 0.001); ND < ADHD < ASD + ADHD on neutral (p < 0.001) **Pupil diameter** ADHD < ND on all emotions (p < 0.05), ADHD < ASD + ADHD < ND on anger (p < 0.0001)
Safar et al. (2022)°°	ASD = 100 ADHD = 71 ND = 87	ASD = 12.22 (3.20) ADHD = 11.55 (2.57) ND = 11.28 (3.50) Age range: 5–19	ASD = 100.12 (16.55) ADHD = 102.92 (13.21) ND = 112.10 (12.72)	NR	ND not included if born premature or diagnosed with learning, language, neurological, or developmental disabilities	Cross-sectional with MEG	**Functional connectivity** *Beta band* ASD < ND ADHD < ND ASD < ADHD *Gamma band* ADHD happy > angry (p < 0.001) ND happy > angry (p < 0.033) ASD angry > happy (p < 0.001)

Table 3 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	**IQ**	**Comorbidities**			
Shephard et al. (2019)	ASD = 18 ADHD = 15 ASD + ADHD = 28 ND = 24	ASD = 140.32 (20.40) ADHD = 125.78 (22.92) ASD + ADHD = 126.31 (20.27) ND = 126.69 (21.47)* Age range: 8–13 *In months	ASD = 115.68 (15.73) ADHD = 104.11 (14.23) ADHD + ASD = 109.72 (13.41) ND = 120.04 (13.42) WASI ADHD, ASD + ADHD < ND (p = 0.002)	NR	IQ < 70, visual acuity problems, neurological or neurodevelopmental conditions other than ASD, ADHD, and ODD	Cross-sectional with EEG	Significant effects of ASD (p = 0.04) and ADHD (p = 0.03) on large-scale networks in the alpha range in the time-range of the P1 (early visual processing) = hypoconnectivity in ASD, hyperconnectivity in ADHD Children with ASD + ADHD showed both ASD-like hypoconnectivity and ADHD-like hyperconnectivity
Tye et al. (2014)	ASD = 19 ADHD = 18 ASD + ADHD = 29 ND = 26	ASD = 11.69 (1.70) ADHD = 10.48 (1.91) ASD + ADHD = 10.53 (1.69) ND = 10.56 (1.79) Age range: 8–13	ASD = 115.68 (15.73) ADHD = 104.11 (14.23) ASD + ADHD = 109.72 (13.41) ND = 120 (13.42) WASI ND > ADHD, ASD + ADHD	NR	English not as the main language, specific medical disorders, history of traumatic brain injury, a diagnosis of epilepsy and other comorbid psychiatric disorders not including ODD	Cross-sectional with EEG	Abnormalities in emotional face processing in ASD and ADHD *Early N170* (automatic processing) altered in ASD and ASD + ADHD *Late N400* (contextual/affective meaning, extended network) altered in ADHD and ASD + ADHD

Table 3 (continued)

Study	Groups (*N*)	Participants' characteristics			Exclusion criteria	Research design	Results
		Age	**IQ**	**Comorbidities**			
Vandewouw et al. (2020)*	ASD = 87 ADHD = 44 ND = 49	ASD = 12.97 (3.34) ADHD = 11.06 (2.32) ND = 11.00 (3.59) Age range: 5–19	NR	In the ASD group, some participants had ADHD, anxiety, intellectual disability, and learning disorder In the ADHD group, some participants had anxiety, intellectual disability, learning disorder, disruptive behavior disorder, and obsessive-compulsive disorder	57 excluded because of excessive motion during fMRI	Cross-sectional with fMRI	Shared atypical visual information processing in ASD and ADHD *Occipital and temporal regions*: ASD and ADHD differentiated less between dynamic faces and control condition. ND had greater decreases in activation to faces rather than control condition compared to clinical groups in occipital areas *Left superior frontal gyrus*: Altered activation highlights increasing difficulties of ASD and ADHD with age.

ASD autism spectrum disorder, *ADHD* attention deficit and hyperactivity disorder, *ND* non-diagnosed group, *NR* not reported, *ER* emotion recognition, *IQ* intelligence quotient, *WISC* Wechsler Intelligence Scale for Children, *WAIS* Wechsler Adult Intelligence Scale, *WPPSI* Wechsler Preschool and Primary Scale of Intelligence, *WASI* Wechsler Abbreviated Scale of Intelligence, *RTs* reaction times, *d* Cohen's *d*

*Studies with other clinical groups not discussed in the review. For information about other groups, please see the corresponding article

°°Studies that considered the effect of cognitive variables on emotion recognition abilities (please see sections on "The role of cognitive functioning and age")

Demopoulos et al., 2013; Downs & Smith, 2004; Dyck et al., 2001; Economides et al., 2020; Fine et al., 2008; Greco et al., 2021; Lee et al., 2018; Löytömäki et al., 2020; Semrud-Clikeman et al., 2010; Sinzig et al., 2008; Uluyagmur-Ozturk et al., 2016), while 5 studies adopted matching paradigms, asking respondents to compare one face with others showing different emotions or to match a target emotion to the correct face (Bühler et al., 2011; Flores-Buils & Andrés-Roqueta, 2022; Oerlemans et al., 2013; Waddington et al., 2018, 2020).

Among behavioral findings, overall differences between the ASD and ADHD groups' performance were not statistically significant (Bühler et al., 2011; Dyck et al., 2001; Economides et al., 2020; Fine et al., 2008; Greco et al., 2021; Lee et al., 2018; Löytömäki et al., 2020), but both clinical groups performed worse than ND participants, when the control group was present. The most common statistically significant differences between the groups emerged for ASD and ND, with ASD < ND (Berggren et al., 2016; Dyck et al., 2001; Economides et al., 2020; Fine et al., 2008; Greco et al., 2021; Löytömäki et al., 2020), and for ADHD and ND, with ADHD < ND (Bustos-Valenzuela et al., 2022; Dyck et al., 2001; Economides et al., 2020; Greco et al., 2021; Löytömäki et al., 2020; Ozturk et al., 2018; Sinzig et al., 2008). It was only in 4 studies that the ASD sample fared significantly worse than the ADHD sample (Demopoulos et al., 2013; Downs & Smith, 2004; Flores-Buils & Andrés-Roqueta, 2022; Semrud-Clikeman et al., 2010). As well as being less accurate, participants in clinical groups needed more time to identify emotions than ND groups, especially in the case of ASD (Berggren et al., 2016; Greco et al., 2021; Oerlemans et al., 2013; Ozturk et al., 2018).

Two studies that used the same task (FEFA; Bölte et al., 2002) identified specific differences between the clinical groups and ND for ER from whole faces and from the eyes. Their findings were mixed, however: in one, the ASD group performed worse than the ND group, particularly when processing faces (both for accuracy and RTs) (Berggren et al., 2016); in the other, the ADHD group's performance was worse than the ND group's for both faces and eyes (Sinzig et al., 2008). In this latter study, the ASD + ADHD group fared less well in the ER task for eyes than the other groups, but—in terms of total score—it was more difficult for all participants to recognize emotions from the eyes region. When Bühler et al. (2011) examined the influence of the mouth region on ER in children with ASD and ADHD, they found that the former made more mistakes than the latter when only shown a mouth, but the two groups' performance was similar when only eyes were displayed.

Only two behavioral studies explored ER using dynamic stimuli (i.e., a "morphing task," an image processing technique used for the metamorphosis from one image to another), identifying a worse performance in the clinical groups than in controls (Greco et al., 2021; Löytömäki et al., 2020).

As concerns affective prosody in ER, ASD and ADHD groups both performed below the normative sample (Demopoulos et al., 2013) or worse than controls (Löytömäki et al., 2020). In one of these studies in which the ND group was not included, the ADHD group performed significantly better than the ASD group (Demopoulos et al., 2013). Oerlemans et al. (2013) concluded that affective prosody skills are impaired in children with ASD, especially when considering RTs, and their difficulties would be exacerbated by a comorbid ADHD.

When showing social-interaction videos to assess ER, two studies found ND children better able to identify emotions than children with ADHD or ASD, while no significant differences emerged between the two clinical groups (Fine et al., 2008). Participants with ASD also had more difficulty recognizing nonverbal prompts than ND controls. Another study found that a group with ASD performed significantly less well on ER than a group with ADHD when asked to identify emotions in a video (Semrud-Clikeman et al., 2010).

Types of Emotion

Seven studies in which behavioral findings were reported examined the ability of children with ASD and ADHD to recognize different emotions (Berggren et al., 2016; Economides et al., 2020; Greco et al., 2021; Lee et al., 2018; Oerlemans et al., 2013; Ozturk et al., 2018; Sinzig et al., 2008). While almost all the studies included in this review only considered basic emotions, four studies also included complex emotions (i.e., frustration, embarrassment, contempt, disappointment, and shame), though the authors did not distinguish between them in their analyses (Dyck et al., 2001; Fine et al., 2008; Löytömäki et al., 2020; Semrud-Clikeman et al., 2010).

As regards the challenge posed by specific emotions, Berggren et al. (2016) found that ASD group performed less well than ND group, but not than ADHD, in identifying happiness (in terms of both accuracy and response times) in face and eyes tests. Significant differences for joy and surprise emerged between ND groups and those with ADHD or ASD + ADHD, both clinical groups being more impaired (Greco et al., 2021; Sinzig et al., 2008). Regarding affective prosody, children with ASD seemed less able to recognize happiness than ND children, and their difficulty was exacerbated by ADHD in comorbidity (Oerlemans et al., 2013).

Compared with ND groups, ASD and ASD + ADHD groups have proved less able to recognize negative emotions (anger, fear, sadness, and disgust) when processing faces (Greco et al., 2021; Oerlemans et al., 2013; Ozturk et al., 2018). Sadness was also less well detected by children with ASD and ASD + ADHD when affective prosody was investigated. ASD groups had slower response times than the other groups too, for all emotions investigated, when shown whole faces (Berggren et al., 2016; Greco et al., 2021; Ozturk et al., 2018).

That said, two behavioral studies found no significant differences between ASD and ADHD groups in terms of their ability to recognize specific emotions (Economides et al., 2020; Lee et al., 2018).

Brain-Based and Eye-Tacking Studies

Types of Experimental Task and Stimuli

Although also in brain-based and eye-tracking studies the most used stimuli were static faces (Bustos-Valenzuela et al., 2022; Ozturk et al., 2018; Gross et al., 2012; Shephard et al., 2019; Tye et al., 2014; Safar et al., 2022), dynamic morphing faces were used to assess ER in one study (Vandewouw et al., 2020). As regards brain-based studies included in the present review, participants were not asked to produce a behavioral response that demanded ER abilities but only neural responses to emotions were assessed (Safar et al., 2022; Shephard et al., 2019; Tye et al., 2014; Vandewouw et al., 2020), except for one study in which children were asked to label the correct emotion displayed by faces (Gross et al., 2018). As for eye-tracking studies, Bustos-Valenzuela et al. (2022) asked participants to detect the target emotion written on the screen between different faces (matching paradigm), whereas Ozturk et al. (2018) instructed children to label the facial emotions.

Concerning results from EEG data, Shephard et al. (2019) found a significant hypoconnectivity in networks that support all cognitive domains (in all conditions: during resting-state, attentional control, and face processing tasks) in children with ASD (alone or +ADHD) compared with children without autism (ADHD or ND). In particular, during the social cognition task, children with ASD exhibited a hypoconnected network involving long-range left-hemisphere and bilateral fronto-central connections in the alpha range during the P1 time-range associated with early visual/attentional processing of faces. On the other hand, children with ADHD showed a significant hyperconnectivity in large-scale networks in the alpha range during the early visual processing (P1 time-range) of the face-processing social cognition task. Another proposed distinction between ASD and ADHD in terms of electrophysiological functioning concerned the temporal stage of emotion processing (Tye et al., 2014). While children with ASD exhibited alterations at the encoding stage (with a reduced lateral occipito-temporal N170 amplitude), those with ADHD revealed irregularities at the contextual processing stage (with a reduced modulation of centro-parietal N400 amplitude). On the other hand, Gross et al. (2012) reported abnormal regional gamma activation in ASD: the power of induced gamma in the parietal and parieto-occipital cortices was higher in ADHD and lower in ASD, a finding that might lie behind a better performance in the ADHD group than in the ASD group.

As regards fMRI acquisition, a study using a morphing task suggested that atypical visual information processing in the occipital and temporal regions might contribute to ER difficulties in children with ASD and ADHD (Vandewouw et al., 2020). The ND group had a more markedly weaker activation to faces (especially angry ones) than to other objects (flowers) than the clinical groups. The processing was similar in the ASD and ADHD groups, whether the stimuli were faces or flowers, and it was associated with alterations in medial and lateral occipital activity.

Furthermore, another neuroimaging study which used the extreme resolution of MEG to explore patterns of functional connectivity (Safar et al., 2022) showed that ASD and ADHD groups had a significantly reduced functional connectivity in the beta band than controls. In the gamma band, there was a pattern of connectivity in a network known to be involved in emotion processing (orbital frontal and limbic regions), as expected for the ND group. The connectivity was stronger for happy than for angry faces in the ADHD and ND groups, while the opposite was true in the ASD group.

Findings from eye-tracking studies revealed that, compared with ND and ASD groups, children with ADHD and ADHD + ASD showed a shorter gaze fixation and weaker cognitive vergence responses to stimuli showing the eye regions of a face (Bustos-Valenzuela et al., 2022). Also another study (Ozturk et al., 2018) revealed the importance of eye-tracking studies by presenting a classification framework for ASD and ADHD diagnoses, in which the pupil diameter and eye gaze had a higher classification power than behavioral accuracy and RTs.

Type of Emotions

Among brain-based and eye-tracking findings, three of them examined the different brain and gaze activation when contrasting emotions, finding some differences between the groups (Ozturk et al., 2018; Safar et al., 2022; Vandewouw et al., 2020).

Safar et al. (2022) reported a weaker network connectivity in the gamma band for happy faces and a stronger connectivity for anger in cases of ASD, as opposed to ND and ADHD groups, indicating that functional connectivity network strength in each group was modulated by the valence of the faces. Another study found significant differences between ASD, ADHD, and ASD + ADHD groups in terms of brain activation when seeing specific emotions (Vandewouw et al., 2020). Significant differences were found in an area connecting the right inferior occipital, inferior and middle temporal gyri, in which ASD children demonstrated enhanced activation to angry compared to happy faces than the other groups. Then, in happy versus angry faces, a significant group-by-age interaction was found (see paragraph "Age-related differences in ER"). However, data-driven clustering methods (Safar et al., 2022) showed a significant increase in the mean network strength in the theta and beta frequency bands when seeing happy faces, in a subgroup composed mainly by ASD and ADHD participants, compared to ND dominant subgroup. In contrast, for angry faces, significant differences between the subgroups in mean network strength were found in alpha and gamma, where the ASD-ADHD dominant subgroup showed an increase compared to baseline, and the ND dominant subgroup showing a decrease.

That said, when applying eye-tracking procedures, a distinguishing factor between ADHD and ASD was the reduced average pupil diameters of the participants with ADHD compared to the ASD and ND groups while looking at angry faces (Ozturk et al., 2018).

The Role of Cognitive Functioning and Age

Some studies included in this review took into account the role of IQ (Dyck et al., 2001; Fine et al., 2008; Oerlemans et al., 2013), theory of mind (Dyck et al., 2001; Löytömäki et al., 2020), linguistic factors, and working memory (Löytömäki et al., 2020), and attentional and inhibitory control (Berggren et al., 2016; Bühler et al., 2011; Fine et al., 2008; Safar et al., 2022; Semrud-Clikeman et al., 2010; Sinzig et al., 2008) when comparing children with ASD and ADHD on ER.

Dyck et al. (2001) first suggested that ER abilities could discriminate between cases of ASD with ID, ASD (Asperger's syndrome), ADHD, and other disorders, but—if intelligence was covaried—then both ER and IQ were needed to distinguish ASD from the other disorders. When IQ was covaried, however, no significant differences emerged between the ASD and ADHD groups in terms of ER. Another study (Oerlemans et al., 2013) found significant effects of IQ: on the visual recognition of certain emotions in all participants—in terms of accuracy (for sadness, fear) and response times (for happiness, anger); and also on the auditory recognition of sadness, anger, and fear.

Unsurprisingly, another factor found linked to ER is the ability to mentalize (theory of mind; ToM). This association between ER and ToM seemed robust ($r = 0.78$) (Dyck et al., 2001), with ToM being able to significantly predict children's delay in facial ER (Löytömäki et al., 2020). Expressive vocabulary was another predictor of ER in the same study: children who scored 1 SD below their age level were slower in the ER matching task than children with age-appropriate language skills. The combined impairment in expressive vocabulary and either auditory or visual working memory predicted the degree of delay in a task that involved matching facial expressions with tones of voice.

Finally, three studies found that the severity of attentional symptoms related to the ability to interpret emotional stimuli in both ASD and ADHD (Semrud-Clikeman et al., 2010; Safar et al., 2022; Sinzig et al., 2008). Fine et al. (2008) revealed that, taken together, IQ and attention accounted for about 52% of the variance in an ER task (CASP), but inattention alone already contributed significantly to this variance. While ASD and ADHD groups' ER accuracy and response times correlated negatively with their attentional distractibility, this was not the case for ND children (Berggren et al., 2016). However, among studies that investigated the link between attentional skills and emotion recognition, Safar et al. (2022) performed brain-behavior correlations between measures of network strength for the main effect of group in the beta band and self-reported attention problems, finding a strong negative correlation across all groups (ADHD, ASD, and ND). Commission errors in a task testing inhibitory control (Go/No go) and ER errors in an eye test were also able to discriminate between groups of children, with some differences relating to their age: 71% of younger children with ASD, and 73% of those with ADHD were classified correctly, as opposed to 63% of older children with ASD, and 54% of those with ADHD (Bühler et al., 2011).

Age-related differences in ER ability in children with ASD and ADHD were considered in three of the studies reviewed (Bühler et al., 2011; Oerlemans et al., 2013; Vandewouw et al., 2020).

Bühler et al. (2011) reported that, while children with ASD had difficulty understanding facial emotions from an early age (from 4.5 years old), those with ADHD seemed to develop this kind of social difficulty only later on (≥10 years). Following up on this, Oerlemans et al. (2013) found that age had a strong effect on speed of facial and vocal ER, with older children performing both faster and better than younger ones, regardless of whether they had been diagnosed with ASD or ADHD, and that ADHD symptoms in children with ASD could interfere with their ER ability.

At a neural level, the only age-related changes were seen with the happy/angry faces in the left superior frontal gyrus. While activation of this region decreased with age in ND children, it increased in those with ASD and showed no age-related effects in ADHD. This area was more activated with happiness in adolescents with ASD and with anger in ND controls (Vandewouw et al., 2020).

Effect of Comorbidities on ER

Seven studies considered how comorbidity, in cases of ASD + ADHD, affected children's ER skills (Bühler et al., 2011; Bustos-Valenzuela et al., 2022; Oerlemans et al., 2013;

Ozturk et al., 2018; Shephard et al., 2019; Sinzig et al., 2008; Tye et al., 2014).

Among behavioral findings, one study found no significant difference between the groups with ASD, ADHD, and ASD + ADHD performances on the ER task (Bühler et al., 2011), whereas others found differences when comorbidities were present. Two stated that children with ASD were better at recognizing both faces and eye-pairs than children with ADHD or ASD + ADHD, although participants with pure autism scored lower (but not significantly so) than a ND group (Bustos-Valenzuela et al., 2022; Sinzig et al., 2008); another one revealed that participants with ASD made more errors in recognizing happiness when also ADHD was diagnosed, whereas in general children with ASD + ADHD scored always lower than ND (Oerlemans et al., 2013).

Among brain-based studies, some findings on the neural correlates of ER in ASD and ADHD (and ASD + ADHD) indicate that these disorders can be separated. As mentioned earlier, children with ASD exhibit alterations at the encoding stage, and those with ADHD have neural irregularities when assessing emotional context. In cases of comorbid ASD + ADHD, deficits at both stages of face processing would point to compound effects of the two disorders (Tye et al., 2014). In Shephard's work (2019), children diagnosed with comorbidity also revealed both ASD-like and ADHD-like hyperconnectivity.

Among eye-tracking studies, children with ADHD and ADHD + ASD had a shorter gaze and lower cognitive vergence to the eye regions of the face stimuli than those with ASD or ND children (Bustos-Valenzuela et al., 2022). Like accuracy, reaction times could also discriminate between groups of children with ADHD from those with ASD + ADHD, but in a different way: children with ASD + ADHD took longer to recognize emotions than those with ADHD or ND controls (Ozturk et al., 2018).

ER as a Transdiagnostic Endophenotype

Some studies investigated the role of genetics in ER, and whether difficulties in ER might be a viable endophenotype in ASD and ADHD (Oerlemans et al., 2013; Ozturk et al., 2018; Safar et al., 2022; Uluyagmur-Ozturk et al., 2016; Waddington et al., 2018, 2020).

The first issue was addressed in a study that compared performance on ER in children with ASD with that of their siblings to investigate the impact of genetics on ER. It emerged that unaffected siblings seemed to perform at an intermediate level on speed measures, somewhat worse than ND controls and better than children with ASD, especially for negative emotions (Oerlemans et al., 2013).

Following this line of investigation, some researchers used machine learning methods to see whether a diagnosis of ASD and ADHD could be predicted from performance in a facial ER tasks (Uluyagmur-Ozturk et al., 2016). A complex feature selection algorithm was used to select the most informative elements in the dataset. The authors were able to distinguish participants with ADHD from those with ASD on response time data with 90% accuracy, and with 80% when both accuracy and reaction times were considered. As regards classification methods based on eye tracker fixation data during an ER task, it has been confirmed that pupil diameter and fixation time could be important features for distinguishing between cases of ASD or ADHD and ND children, and especially between the latter two (Ozturk et al., 2018). Another data-driven classification has been proposed by Safar et al. (2022) that divided the sample into two subgroups (ASD-ADHD dominant, and ND dominant) based on eight measures of network connectivity strength, highlighting differences between subgroups in mean network connectivity strength for happy and for angry faces compared to baseline.

Waddington et al. (2018, 2020) tried to identify different indirect causative chains from genetics via ER to ADHD and ASD by dividing ER abilities into four classes. In a first study, they concluded that the weakest-performing class (with difficulties in both visual and auditory ER) included the largest percentage of cases of ASD and ADHD (66%) and the smallest percentage of ND children (10%). The frequency of errors was much the same in ASD, ADHD, and ASD + ADHD, with 17%, 24%, and 25% of patients, respectively, in the weakest-performing class. In a second study, the authors combined their ER endophenotypes with the polygenic risk score for ASD and ADHD, which assesses an individual's genetic variants of a given disease to estimate their risk of developing it. Counterintuitively, the "impulsive visual and average auditory" ER class coincided with a lower polygenic risk score for ASD, and a high genetic risk of ADHD was associated with the "average-to-strong visual and auditory" ER class.

Discussion

The goal of this review was to shed further light on differences and similarities between children and adolescents with ASD or ADHD regarding their ER abilities, considering the features of behavioral, brain-based, and eye-tracking studies used to measure this construct (tasks' demands, stimuli, emotions), as well as participants' cognitive abilities, age-related differences, comorbidity for ASD + ADHD, and diminished ER as a transdiagnostic endophenotype. The validity of the present review might be enhanced by our having included two conference papers (Economides et al., 2020; Uluyagmur-Ozturk et al., 2016) drawn from the "gray literature," which is often under cited but may contain important findings. We also evaluated the risk of bias using a quality assessment tool that was applied to each study, in order to estimate the methodological quality and the studies' internal validity (reported in the Supplementary materials). In discussing our results, we pay particular attention to the quality of the studies reviewed and to the predictive value of their findings.

Behavioral Findings

Types of Task and Stimuli

There was clearly a great variety in the tasks and stimuli used to examine ER in comparative studies on children and adolescents with ASD and ADHD (or both). Although some authors have suggested that emotion matching tasks might be easier than emotion labeling tasks (because the former does not require a verbal response), we cannot confirm as much due to the paucity of studies that used the discrimination paradigm. Both types of task might be valid tools for measuring ER, however, as they showed a positive correlation, which would suggest some degree of shared processing (Palermo et al., 2013). Most studies found no significant differences in ER task performance, in terms of accuracy and reaction times, between ASD and ADHD groups, though both almost always performed less well than ND controls (Bühler et al., 2011; Dyck et al., 2001; Economides et al., 2020; Fine et al., 2008; Greco et al., 2021; Lee et al., 2018; Löytömäki et al., 2020). Difficulties emerging in both ASD and ADHD were often more pronounced for reaction times, which were identified as a factor capable of distinguishing between the clinical groups and ND controls, especially for ASD (Berggren et al., 2016; Greco et al., 2021; Oerlemans et al., 2013; Ozturk et al., 2018). Though most findings suggest no differences in ER ability between ASD and ADHD, some evidence based on behavioral findings might support a worse ER performance in children with ASD than in those with ADHD (Demopoulos et al., 2013; Downs & Smith, 2004; Flores-Buils & Andrés-Roqueta, 2022; Semrud-Clikeman et al., 2010). By considering the characteristics of the tools, we can hopefully draw some assumptions on the underlying mechanisms of the challenges with ER in youth with different neurodevelopmental disorders.

As regards the types of stimuli used, some authors explored visual and vocal expressions of emotion as they are both part of everyday life, contributing equally (and often together) to human communication processes. Concerning visual stimuli, a distinction can be drawn between static (i.e., photos) and dynamic (i.e., videos, morphing tasks) materials used to investigate ER abilities. Dynamic facial expressions seemed to be more realistic, better representing what we encounter in our everyday social interactions, when further information can be gleaned from the social context (Kilts et al., 2003). Though a comparison between static and dynamic stimuli might be useful when investigating ER in people with ASD and ADHD, the number of published studies that used dynamic cues (Greco et al., 2021; Löytömäki et al., 2020; Vandewouw et al., 2020) is still limited, and their findings are inconsistent.

The behavioral findings of studies regarding affective prosody and combined visual-vocal stimuli (videos of social interactions) suggest that children with ADHD might find ER less difficult than those with ASD (Demopoulos et al., 2013; Semrud-Clikeman et al., 2010). Children with ASD were proved less able than ADHD or ND groups to detect nonverbal cues in a social interaction when the intonation of the voices was normal but the words spoken were filtered to make them unintelligible (Semrud-Clikeman et al., 2010). They also struggled more with the appropriate labeling of emotions displayed in videos (Fine et al., 2008; Semrud-Clikeman et al., 2010). The quality of these studies was fair, and the effect sizes varied from medium to large for between-group differences. The authors tried to explain why children with ASD should have more difficulty with acoustic emotional cues: receptive social skills based on the recognition of affect from vocal information are needed to produce an appropriate response. A large proportion of the participants with ASD had a previous or ongoing language disorder, however, so it may be that the gap in performance between the ADHD and ASD groups is an artifact of language abilities rather than a matter of social cognitive processes (Demopoulos et al., 2013). An alternative explanation might be that difficulties with combined visual and vocal stimuli in a video might underlie the ER weakening that is a fundamental characteristic affecting social experience in ASD, rather than a specific deficit affecting face perception (Humphreys et al., 2007). Here again, however, study findings were not consistent. For instance, one study found that children with ADHD also had more difficulty than ND controls when trying to identify emotions conveyed by non-sense words (Löytömäki et al., 2020). These mixed results were partially confirmed by further investigations, after Demopoulos et al. (2013) acknowledged that children with ASD performed slightly less well than those with ADHD on a variety of social skills, but the performance of those with ADHD was also substandard. Such small differences may indicate that children with ADHD have ASD-like social peculiarities (Greene et al., 1996), or that their performance can be hindered by their typically impulsive and inattentive behavior (Demopoulos et al., 2013).

Types of Emotions

One question unanswered by the body of research on ER is whether any difficulties experienced in ASD and ADHD are general or specific to certain emotions (Uljarevic & Hamilton, 2013). The widely held opinion that children with neurodevelopmental conditions can recognize happiness, but not other emotions, might be cast in doubt by many of the results included in this review both from behavioral and brain-based studies. As regards behavioral findings, compared with ND controls, and sometimes with cases of ADHD too, children and adolescents with ASD and with ASD + ADHD were also slower and/or less accurate to detect all emotions (Berggren et al., 2016; Greco et al., 2021; Oerlemans et al., 2013; Ozturk et al., 2018; Sinzig et al., 2008), including happiness which is usually the most easily recognizable emotion.

Brain-Based and Eye-Tracking Studies

The studies addressing neural responses in ER were at low risk of bias, given their reliable design.

Some researchers tried to identify the neurobiological mechanisms involved in ER for people with ASD or ADHD, or both, and envisaged distinct neurocognitive processes in each disorder. An atypical functional connectivity has been suggested as an important neurobiological factor in both ASD and ADHD (Barry et al., 2002; Courchesne & Pierce, 2005). Previous literature had suggested that ASD is characterized by a reduced connectivity in integrative neural circuitry leading to difficulties in higher-order cognitive skills, such as social cognition and attention control (Just et al., 2004). Findings from Shephard et al. (2019) indicate that the two conditions can be dissociated based on oscillatory neural networks, with a task-independent hypoconnectivity (during all proposed task conditions) involving long-range left-hemisphere and bilateral frontal-central connections in the alpha range in children with ASD, and a task-related hyperconnectivity (during social cognition tasks) in large-scale networks in the alpha range in children with ADHD. This would mean that reduced functional integration of large-scale networks may underlie deficits in higher-order cognitive function in ASD, whereas attentional engagement towards faces in the early stages of visual processing is particularly disrupted in ADHD, due partly to this hyperconnectivity (Shephard et al., 2019). Abnormal ERP responses (i.e., N170, N400) and different regional gamma activation patterns (a lack of coactivation of EEG activity in gamma band in ASD) also seem to distinguish between ASD and ADHD (Gross et al., 2012; Tye et al., 2014). The neurobiological mechanisms underlying neural abnormalities in ASD and ADHD are still unclear, however. Findings from a MEG study (Safar et al., 2022) revealed a main effect of group: ASD and ADHD demonstrated significantly reduced functional connectivity compared to controls, with ADHD showing the higher reduction in a left hemisphere predominant network involving frontal, subcortical, and temporal connections.

Studies on functional connectivity were able to establish that ASD and ADHD children also shared similarities in underpinning neural mechanisms (Safar et al., 2022; Vandewouw et al., 2020). A general reduction in functional connectivity in a predominant network involving the frontal, subcortical, and temporal connections has been seen in both clinical groups (Safar et al., 2022). In another study, ASD and ADHD groups also showed a similar level of activation when processing dynamic stimuli with shared alterations in medial and lateral occipital activity, regardless of whether they were faces or flowers, while ND children had a greater decrease in activation for faces (especially those expressing anger) than for objects, suggesting a more idiosyncratic processing of emotional cues (Vandewouw et al., 2020). Despite the discussion describing the differences between ASD and ADHD, the brain-based data are clear that both groups share more similarities as neurodevelopmental disorders than they differ as distinct diagnoses.

Differently, findings from eye-tracking studies included in the present review could possibly highlight some differences between ASD and ADHD concerning eye movements and pupil diameter linked to ER. Children with ADHD demonstrated weaker vergence responses to the eyes, perhaps underlying the inability to pay attention to these cues for emotion detection, whereas children with ASD have no attention deficit in regards of facial ER (Bustos-Valenzuela et al., 2022). Ozturk et al. (2018) affirmed that pupil diameter is another feature for classification of ASD, ADHD, and ND groups, differentiating especially ADHD from ND participants.

Types of Emotions

Regarding the recognition of different emotions, among brain-based studies, a stronger neural network connectivity for happy than for angry faces was demonstrated in ND and ADHD groups, as was to be expected from the extensive literature showing that happy faces are preferred, more engaging, invitational, and approachable (Nikitin & Freund, 2019), whereas the opposite was true in ASD groups. That angry faces elicited a stronger connectivity than happy faces in children with ASD goes to show that they have different connectivity development trajectories (Mamashli et al., 2018; Safar et al., 2021). Further support for the difficulties with happiness in ASD comes from the finding that a lower adaptive functioning correlated with the weaker connectivity for happy stimuli in the ASD group (Safar et al., 2022). A higher network connectivity in response to angry faces was shown to relate to a lower adaptive functioning often seen in ASD: it seems that autistic individuals allocate excessive resources to modulating anger, leaving insufficient resources for the processing of more adaptive social information (Safar et al., 2022). Consequently, it may take a greater neural effort for participants with ASD than for ND controls to recognize positive emotions, which might contribute to the former's life-long social difficulties (Vandewouw et al., 2020).

However, Safar et al. (2022) also used data-driven subgrouping to verify if different patterns of connectivity occur among the groups, expecting more similar patterns of connectivity in ASD-ADHD dominant group compared to controls. When exposed to happy faces, children in the ASD-ADHD dominant subgroup showed an increase in the network strength in the theta and beta frequency bands, whereas for angry faces in the alpha and gamma bands, contrary to the TD dominant subgroup. Once again, some similarities between ASD and ADHD in ER processing were found.

Although some similarities between neurodevelopmental disorders have been observed, overall the behavioral and brain-based findings considered in our review might therefore go in the direction of supporting the global deficit hypothesis for ASD, because many studies revealed generalized difficulties in ER (Berggren et al., 2016; Greco et al., 2021; Economides et al., 2020; Oerlemans et al., 2013; Ozturk et al., 2018; Safar et al., 2022; Sinzig et al., 2008), even though the paucity of studies, and the lack of differentiation between investigated emotions, prevents us from confirming it as a final conclusion.

The Role of Cognitive Functioning and Age-Related Differences

As well as observing differences in ER ability between ASD and ADHD groups relating to different tasks, stimuli, and emotions, researchers also investigated the influence of cognitive skills, bearing in mind the features of the tasks administered. After excluding the possibility of ER deficits being attributable to any intellectual delay, researchers looked for deficits in other underlying processes. Generally speaking, IQ, ToM, linguistic, and attentional skills were found to correlate the most strongly with ER (Bühler et al., 2011; Bustos-Valenzuela et al., 2022; Dyck et al., 2001; Fine et al., 2008; Löytömäki et al., 2020; Oerlemans et al., 2013).

Although ToM and linguistic skills might explain aspects of ER difficulties seen in children with ASD and ADHD, no striking differences emerged between the two groups regarding these cognitive factors. ToM, which is usually assessed with false beliefs or Reading the Mind with the Eyes (Baron-Cohen et al., 1997) tasks, seems to be strongly linked to ER without any mediating variables. In fact, ER has been described as a part of ToM because it develops earlier than the ability to mentalize, and it is an important component of an understanding of intentionality (Phillips et al., 2002; Saxe et al., 2004). Besides ToM skills, language delays can negatively affect learning in a variety of domains, including the socio-emotional sphere, as revealed by Löytömäki et al. (2020). Generally, having fewer interactive language opportunities as a consequence of linguistic impairments can hinder the accurate encoding (and sharing) of emotions and their social contexts (Nelson et al., 2011).

The best predictor of ER ability, however, to judge from the studies reviewed, is attention. Symptoms of inattention contributed significantly to social misunderstandings across diagnostic groups, with a diagnosis of ASD having a separate influence (Fine et al., 2008; Shin et al., 2008). The effect of attentional problems was confirmed by the lower cognitive vergence responses (indicative of visual attention cognitive processing) in ADHD groups when looking at eye regions of faces, resulting in a poor performance in ER tasks (Bustos-Valenzuela et al., 2022).

As for the effect of age-related differences on ER ability in ASD and ADHD (Bühler et al., 2011; Oerlemans et al., 2013; Vandewouw et al., 2020), based on the studies taken into account in the present review, while children with ASD showed early ER difficulties because they lack a prerequisite for the development of social skills, those with ADHD seemed to develop problems with ER as they grew older. This could happen because their diminished inhibition leads to social exclusion, reducing their opportunities to build on and practice their social skills. It is worth mentioning, however, that Bühler et al. (2011) did not include a control group in their study; thus, we could not ascertain any differences vis-à-vis ND children's trajectories. At a neural level, differences identified in the brain areas involved in ER in ASD, ADHD, and ND groups at different developmental stages might underlie specific patterns of emotional face processing, with the difficulties associated with neurodevelopmental disorders increasing with age (Vandewouw et al., 2020). Taken together, the results reported in behavioral and brain-based studies of fair-to-good quality seem to suggest that children with such disorders may recognize emotional expressions appropriately, but still struggle to deal with them as they grow older. Nevertheless, further research is needed to confirm these results.

Co-occurrence of ASD and ADHD, and ER as a Transdiagnostic Endophenotype

To explore the influence of comorbidity, several studies of fair quality compared cases of ASD, ADHD, and ASD + ADHD with ND controls. They demonstrated that comorbid ADHD might contribute to more severe ER difficulties than a diagnosis of ASD alone (Oerlemans et al., 2013; Ozturk et al., 2018; Sinzig et al., 2008). Empirical evidence obtained in children with ASD + ADHD showed both ASD- and ADHD-related neural abnormalities, pointing to additive effects of the two conditions (Shephard et al., 2019; Tye et al., 2014). It is worth noting that some of the studies reviewed here included large proportions of participants in the ASD groups who had autism as a first diagnosis and ADHD as a second, as reported in the Participants section (Berggren et al., 2016), or Supplementary materials (Vandewouw et al., 2020), or confirmed by diagnostic measures (Demopoulos et al., 2013; Fine et al., 2008; Semrud-Clikeman et al., 2010). Findings from these studies are therefore not comparable with those involving only participants with either ASD alone or ADHD, in which the two conditions could be compared without considering any comorbidity.

The often-diagnosed comorbidity of ASD and ADHD has induced researchers to reflect on the neurobiology of the two disorders. It has been suggested that ASD and ADHD are related disorders, possibly on the same continuum, with shared genetic components (Mikami et al., 2019; Rommelse et al., 2011). Confirmation of the importance of genetics in ER came from Oerlemans et al. (2013), whose fair-quality study suggests that unaffected siblings of ASD probands have subtle signs of a weaker ER ability, supporting a possible link between genetics, the neurodevelopmental disorder, and ER outcomes. To clarify this association, some studies investigated whether an impaired ER could be a viable endophenotype for ASD and ADHD. Endophenotypes are heritable characteristics that shape a causal link between genes and observable symptoms, enabling researchers to go from cognitive measures back to genes. Following this line of reasoning, studies on ER deficits as a transdiagnostic endophenotype were able to discriminate accurately between ASD and ADHD, by performing classification of participants based on the eye tracker and log-data applications (Ozturk et al., 2018; Uluyagmur-Ozturk et al., 2016), functional connectivity data (Safar et al., 2022; described above), speed and accuracy measures of auditory and visual ER tasks (Waddington et al., 2018), and polygenic risk score (Waddington et al., 2020). The studies confirmed a distinctive pupil diameter in the two groups during ER (though they did not seem to adhere strictly to all the necessary quality criteria) (Ozturk et al., 2018; Uluyagmur-Ozturk et al., 2016). Studies that applied data-driven subgrouping based on functional connectivity data found differences for distinct emotions in frequency bands between the subgroup composed mainly by ASD and ADHD participants, compared to ND dominant subgroup (as already discussed; Safar et al., 2022). Other authors explored whether considering four ER subtypes could shed light on the heterogeneity and comorbidity of ASD and ADHD, but failed to identify any distinctive patterns for the two disorders (Waddington et al., 2018). Given their counterintuitive results, the same authors hypothesized different indirect causative pathways for ASD and ADHD, by assuming previously ignored variables, such as cognitive abilities, that might affect the relationship between genes and symptoms of ER difficulties (Waddington et al., 2020). A moderation model in which ER ability acted as a buffer for the risk of developing ADHD and/or ASD would also be plausible.

Limitations and Future Directions

The present systematic review of the literature on differences and similarities in ER ability between children and adolescents with ASD and ADHD is not without its limitations. The heterogeneity of the studies identified, resulting from the different methods used, might limit the generalizability of the findings. There is a need to adopt standardized measures for investigating ER (e.g., labeling/matching, simple/complex emotions, visual/vocal ER) in order to endorse the various aspects discussed in this review. Researchers should also try to combine different experimental methods to better investigate the mechanisms underlying ER, by merging behavioral, genetic, and neurocognitive approaches, for instance.

Another limitation concerns the small number of studies included in our review ($n = 24$). Future studies should take into account that ASD and ADHD are frequently diagnosed in comorbidity, and a substantial proportion of children are alternately diagnosed with one or other disorder as they grow up. The significant overlap across ASD and ADHD should encourage researchers to collect more evidence on comorbid cases, also taking alternative approaches to these neurodevelopmental disorders, such as exploring heterogeneity and inter-group variability embracing a dimensional perspective (Astle et al., 2022). More studies on the co-occurrence of ASD and ADHD and its effect on ER (and on social cognition more generally) might lead to a better understanding of the two disorders. Although ER difficulties are not among the primary symptoms associated with ADHD, the present findings confirm that children with comorbid ASD + ADHD are at greatest risk of social impairments. Clinicians and researchers should therefore pay special attention to children suffering from symptoms of both conditions (Magill-Evans et al., 1995).

In addition to studies on comorbid ASD + ADHD, longitudinal findings might also be helpful to explore changes in ER ability over time, since we could draw no conclusions on this aspect. How we develop the ability to understand emotions has been amply investigated in the general population, but little has been done for clinical groups. Broadening our knowledge in the latter might help us to establish whether adults with certain disorders eventually reach the same levels of ER proficiency as ND individuals, or whether their performance remains stable throughout their lives. When treatments to enhance social skills are proposed in childhood and adulthood, it is crucial to know whether an individual has the prerequisites for correctly identifying others' emotions. Future studies should explore the developmental trajectory of ER in individuals with ASD and ADHD, compared with ND individuals, using the same methodology across a wide age range, and taking into account any involvement of the former in treatments to enhance their social skills.

Many reports in the literature have also emphasized that difficulties in social interaction and communication are bidirectional. As the "double empathy hypothesis" states, for example, just as autistic people struggle with ER, neurotypical people also have trouble recognizing the emotions of autistic people (Chown et al., 2020). ER difficulties have been demonstrated in ADHD as well, though the topic has been little investigated in this clinical group. Communication barriers between diagnosed and ND individuals can make it more difficult to connect, share experiences, and empathize with one another. ND individuals may also form negative impressions of people with neurodevelopmental disorders who have peculiar ways of interacting socially because they find them hard to understand. Future research should address this social problem, bearing in mind that interaction difficulties between individuals with and without neurodevelopmental disorders may be attributable to both parties (Edey et al., 2016).

Finally, studies on ER have mainly adopted visual stimuli, so it would be useful to study the underlying processes associated with the ability of children with ASD and ADHD to process visual information in space, because their previously observed visuospatial difficulties (Cardillo, Lanfranchi, & Mammarella, 2020a; Cardillo, Vio, & Mammarella, 2020b) could differently influence their ER performance.

Conclusions

To the best of our knowledge, this is the first systematic review trying to summarize the findings of comparative studies on ER in children and adolescents with ASD or ADHD (or both). Although further studies are needed to clarify the ER difficulties in these clinical groups, most of the studies discussed here found that both disorders are associated with an impaired ER ability, in some cases more pronounced in ASD, but without any clear agreement regarding different stimuli and emotions. The few brain-based and eye-tracking studies suggested that ASD and ADHD have some shared and some distinct neural mechanisms relating to ER. Given the shared genetic components, and the frequent co-occurrence of ASD with ADHD, it would be advisable to take into account additional risk factors that these disorders might disclose.

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Declarations

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