Neuroscience and Biobehavioral Reviews 80 (2017) 488–515

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review article

Mechanisms of facial emotion recognition in autism spectrum disorders: Insights from eye tracking and electroencephalography

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ARTICLE INFO

Keywords:
Affect
Electrophysiology
Eye tracking
Autism
Asperger syndrome
Emotion recognition
EEG

ABSTRACT

While behavioural difficulties in facial emotion recognition (FER) have been observed in individuals with Autism Spectrum Disorder (ASD), behavioural studies alone are not suited to elucidate the specific nature of FER challenges in ASD. Eye tracking (ET) and electroencephalography (EEG) provide insights in to the attentional and neurological correlates of performance, and may therefore provide insight in to the mechanisms underpinning FER in ASD. Given that these processes develop over the course of the developmental trajectory, there is a need to synthesise findings in regard to the developmental stages to determine how the maturation of these systems may impact FER in ASD. We conducted a systematic review of fifty-four studies investigating ET or EEG meeting inclusion criteria. Findings indicate divergence of visual processing pathways in individuals with ASD. Altered function of the social brain in ASD impacts the processing of facial emotion across the developmental trajectory, resulting in observable differences in ET and EEG outcomes.

1. Introduction

A considerable degree of human communication occurs through nonverbal means, with actions, gestures and postures conveying signals to others about an individuals' thoughts, feelings and intentions (Darwin, 1872; Meeran et al., 2005). Facially expressed emotions contribute significantly to this communication with movements presented on the face relaying information about internal emotional and mental states (Ekman and Friesen, 1978; Ekman and Oster, 1979). In typical development, the ability to recognise emotions begins in early infancy, developing and improving throughout adolescence and adulthood (Herba and Phillips, 2004; Somerville et al., 2011). Emotion recognition abilities typically begin with the six basic emotions (happy, sad, fear, anger, disgust, surprise) with discrimination of these emotions reported to be present in children aged five to seven months (Barrera and Maurer, 1981). By 10 years of age, children are postulated to perform at a level similar to adults when asked to match neutral, surprised, happy and disgusted expressions (Mondloch et al., 2003). Complex emotions (such as jealousy or guilt) are distinct from basic emotions in that they are typically more nuanced, rely more heavily on context, and usually involve greater theory of mind and belief-based decision making (Johnson and Oatley, 1989). Given the increased complexity of these emotions, their processing reaches maturity considerably later (Tonks et al., 2006), improving throughout adolescence and adulthood (Rodger et al., 2015; Thomas et al., 2007).

Impairments in FER are consistently associated with Autism Spectrum Disorder (ASD); an early onset neurodevelopmental condition characterised by deficits in social communication and social interaction alongside stereotypic, repetitive, restricted behaviours and interests causing adaptive impairments (American Psychiatric Association, 2013). In previous research these behavioural difficulties have, in part, been attributed to challenges in recognising the emotions of others (Baron-Cohen et al., 1985; B&lte and Poustka, 2003; Harms et al., 2010; Kuuskikko et al., 2009; Lozier et al., 2014; Uljarevic and Hamilton, 2013). A *meta*-analysis concluded that these impairments are apparent across the developmental trajectory and the six basic

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http://dx.doi.org/10.1016/j.neubiorev.2017.06.016
Received 16 December 2016; Received in revised form 7 May 2017; Accepted 30 June 2017
Available online 08 July 2017

emotions, and cannot be accounted for by the intellectual capabilities of the individual with ASD (Uljarevic and Hamilton, 2013). Recent research conducted with children suggests that ASD linked difficulties in FER appear cross-culturally, indicating a universal nature of FER challenges in the ASD population (Fridenson-Hayo et al., 2016).

While it appears that emotion recognition is an area of significant challenge for those with ASD, questions have arisen surrounding the extent of these alterations (Lozier et al., 2014; Rutherford et al., 2012). Studies have reported that individuals with ASD perform no differently to their typically developing (TD) peers on emotion recognition tasks (Castelli, 2005; Evers et al., 2014; Tracy et al., 2011), while others have postulated that perhaps not all, but a subset of the ASD population experience difficulty with emotion recognition (Nuske et al., 2013). These disparate findings have been attributed to a variety of participant and experiment related factors (Harms et al., 2010; Nuske et al., 2013; Uljarevic and Hamilton, 2013). Primarily, the demographic characteristics of the participants included in studies, for example age, intellectual capacity (Harms et al., 2010; Uljarevic and Hamilton, 2013) or comorbid conditions (Berggren et al., 2016) have been identified as playing a potential role in the variability of findings. Other possible explanations relate to the compensatory strategies employed by individuals with ASD, which possibly remediate any observable behavioural deficits (Harms et al., 2010).

While individuals with ASD may exhibit impairments in FER, further empirical efforts have sought to elucidate the mechanisms which may characterize ASD-linked impairment in FER, of note, research incorporating eye tracking (ET) and electroencephalography (EEG) methods has been used to provide crucial insights into these processes which may underpin FER impairments.

ET is a valuable tool in elucidating underlying visual processing strategies (Rayner, 1998). As emotions are expressed on the face through the differential activation of facial muscles (Ekman and Friesen, 1978), eye gaze patterns that most effectively assist in identifying different emotions will vary across expressions. In typical development ET research has shown that gaze patterns differ in relation to the valence of emotions, whereby individuals fixate more on the eyes of negatively valanced emotions and the mouths of emotions that are positively valanced (Eisenbarth and Georg, 2011; Messinger et al., 2012).

In addition to ET, EEG may provide insights into the neurological correlates of information processing during FER. EEG measures the electrical activity of the brain and provides superior temporal resolution to measures such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) (Scheuer, 2002). Electrical activity time locked to events, or event related potentials (ERPs) are one of the most common measures extracted from EEG. In the processing of facial expressions, a number of early and late occurring ERPs appear to change and mature throughout development (de Haan et al., 2003), notably including P100, N170 and N250. The P100 is largest over occipital areas between 80 milliseconds-120 milliseconds after stimulus presentation, and associated with the early processing of visual information (Magnun, 1995). The N170 component, a negative ERP, occurs between 130 and 200 milliseconds over the temporal – occipital areas and is selectively enhanced in response to faces (Eimer et al., 2011). This component is posited to reflect the structural processing of faces (Schyns et al., 2003) and is potentially indicative of the processing of higher order configural information (Eimer et al., 2011). The N250 ERP has been associated with valence specific processing, occurring over frontal regions and peaking at 250 milliseconds (Liu et al., 2012; Streit et al., 2001). In children, other ERPs such as the N290 and P400 components have been identified (Leppänen et al., 2007) as presenting as possible precursors to the adult N170 (Halit et al., 2004). Although less frequently investigated in research on FER, EEG analysed in the frequency domain may provide measures of cortical activity, and the topographical coordination of such activity over time, which may be reflective of a number of relevant cognitive processes (Sauseng and Klimsesch, 2008). Desynchronization of alpha frequencies (815 Hz) have been associated with increasing task demands and attention (Klimesch, 1999; Ward, 2003) and an increase in theta power (4–7 Hz) has been associated with memory and encoding (Klimesch, 1999). Gamma frequencies have been associated with processes such as working memory (Barr et al., 2014) and attention (Ward, 2003), while beta (15–30 Hz) has been associated with local information processing (Schutter and Knyazev, 2012).

To date, no review has been conducted in order to specifically examine the differences in ET and EEG characteristics of individuals with ASD during FER. Both ET and EEG provide insights in to the temporal dynamics of attention and cognition during the processing of facially expressed emotion. Therefore, the objective of this review was to systematically appraise the literature examining ET or EEG during FER in individuals with ASD, providing an overview of the current state of the field.

2. Method

2.1. Study design

This systematic review was conducted in accordance with PRISMA guidelines for systematic reviews and *meta*-analyses (Moher et al., 2009). Six databases including Cinahl, Embase, Medline, Proquest, Psycinfo and Scopus were searched for full- length articles published up to the 20th (Psycinfo) or 27th (all other databases) of January 2016. Searches were conducted using a combination of MeSH terms and key words. The following is a sample of the expressions used: ("Autistic Disorder" OR "Child Development Disorders, Pervasive" OR, "Autism Spectrum Disorder") AND ("Evoked Potentials", OR "Electroencephalography" OR "Eye Movements", OR "Fixation, Ocular") AND ("Emotions", "Expressed Emotion", OR "Affect"). These search terms were tailored to match specific databases (refer to Appendix A) and limited to studies in the English language. The reference lists of included articles were manually searched for articles meeting the eligibility criteria.

2.2. Study inclusion criteria

Studies were included if they had a sample of individuals with ASD or individuals with high autistic symptomology, broader autism phenotype or risk of ASD development. As the majority of studies (77%) were conducted prior to 2013, i.e. before the release of the latest version of the Diagnostic and Statistical Manual for Mental Disorders – 5th Edition (DSM-5) (American Psychiatric Association, 2013), the DSM-IV (American Psychiatric Association, 2010) was utilised to classify ASD in this review. Therefore, for the purposes of this review ASD was classified as Autism, Asperger syndrome (AS), Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), and childhood disintegrative disorder (American Psychiatric Association, 2010). No specification was made as to whether the study included individuals with high functioning Autism (HFA; at least average IQ) or low functioning Autism (LFA; below average IQ). Studies primarily involving participants with Rett syndrome were excluded. No limits were placed on age, demographics or intelligence level of the sample with ASD. Studies were required to employ a facial emotion recognition paradigm with studies primarily investigating social scene perception, object recognition or non-emotionally relevant face processing excluded. Finally, studies were required to provide a measure of ET or EEG or a combination of both to be eligible for inclusion. Fig. 1 presents a flow chart of the method of data selection in accordance with the eligibility criteria.

2.3. Data extraction and synthesis

Data were extracted in accordance with the Cochrane handbook for