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Mechanisms of Facial Emotion Recognition in Autism Spectrum Disorders: Insights from Eye Tracking and Electroencephalography

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Highlights

- Individuals with Autism Spectrum Disorder present with atypical gaze and cortical activation to facially expressed emotions.
- Atypical maturation of visual processing pathways may account for deficits in facial emotion recognition in individuals with Autism Spectrum Disorder.
- Eye tracking and electroencephalography findings may provide an indication of self-regulatory or compensatory strategies during facial emotion recognition in Autism Spectrum Disorder.
- Eye tracking and electroencephalography findings may provide potential markers for diagnosis and treatment targets.

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.

(155/170)

Keywords: affect; electrophysiology; Eye Tracking; Autism; Asperger Syndrome; emotion recognition; EEG

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, van Heijnsbergen, & Gelder, 2005). Facially expressed emotions contribute significantly to this communication with movements presented on the face relaying information about internal emotional and mental states (Ekman & Friesen, 1978; Ekman & Oster, 1979). In typical development, the ability to recognise emotions begins in early infancy, developing and improving throughout adolescence and adulthood (Herba & Phillips, 2004; Somerville, Farni, & McClure, 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 & 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, Geldart, Maurer, & Grand, 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 & Oatley, 1989). Given the increased complexity of these emotions, their processing reaches maturity considerably later (Tonks, Williams, Frampton, Yates, & Slater, 2006), improving throughout adolescence and adulthood (Rodger, Vizioli, Ouyang, & Caldara, 2015; Thomas, Bellis, Graham, & LaBar, 2007).

Impairments in FER are consistently associated with Autism Spectrum Disorder (ASD); an early onset neurodevelopmental condition characterised by deficits in 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, Leslie, & Frith, 1985; Bölte & Poustka, 2003; Harms, Martin, & Wallace, 2010; Kuuskikko et al., 2009; Lozier, Vanmeter, & Marsh, 2014; Uljarevic & Hamilton, 2013). A meta-analysis concluded that these impairments are apparent across the developmental trajectory and the six basic emotions, and cannot be accounted for by the intellectual capabilities of the individual with ASD (Uljarevic & 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, Troubridge, & Walsh, 2012). Studies have reported that individuals with ASD perform no differently to their typically developing (TD) peers on emotion recognition tasks (Castelli, 2005; Evers, Kerkhof, Steyaert, Noens, & Wagermans, 2014; Tracy, Robins, Schriber, & Solomon, 2011), while others have postulated that perhaps not all, but a subset of the ASD population experience difficulty with emotion recognition (Nuske, Vivanti, & Dissanayake, 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 & Hamilton, 2013). Primarily, the demographic characteristics of the participants included in studies, for example age, intellectual capacity (Harms et al., 2010; Uljarevic & Hamilton, 2013) or comorbid conditions (Berggren, Engström, & Bölte, 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 & 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 & Georg, 2011; Messinger, Mattson, Mahoor, & Cohn, 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, Johnson, & Halit, 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 – 200 milliseconds over the temporal – occipital areas and is selectively enhanced in response to faces (Eimer, Gosling, Nicholas, & Kiss, 2011). This component is posited to reflect the structural processing of faces (Schyns, Jentzsch, Johnson, Schweinberger, & Gosselin, 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, Wölwer, Brinkmeyer, Ihl, & Gaebel, 2001). In children, other ERPs such as the N290 and P400 components have been identified (Leppänen, Moulson, Vogel-Farley, & Nelson, 2007) as presenting as possible precursors to the adult N170 (Halit, Csibra, Volein, & Johnson, 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 & Klimsesch, 2008). Desynchronization of alpha frequencies (8-15 Hertz) have been associated with increasing task demands and attention (Klimesch, 1999; Ward, 2003) and an increase in theta power (4-7 Hertz) 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 Hertz) has been associated with local information processing (Schutter & 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, Liberati, Tetzlaff, Altman, & The PRISMA Group, 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. Figure 1 presents a flow chart of the method of data selection in accordance with the eligibility criteria.

<FIGURE 1 HERE>

2.3 Data Extraction and Synthesis

Data were extracted in accordance with the Cochrane handbook for systematic reviews (Higgins & Green, 2011). Participant demographic data was extracted in relation to clinical and comparison samples including number of participants, diagnosis, age and participant matching procedure. Information pertaining to the experimental design and stimuli were also extracted, this included the emotions utilised as well as whether the task was an explicit or implicit FER task. For the purposes of this review, implicit tasks were defined as tasks which required either the passive free-viewing of facial expressions or tasks that required the viewing of facial expressions while completing other recognition tasks (such as gender recognition, or target detection). Further distinction was made in regard to the type of emotion examined in the study. For the purposes of this review basic emotions have been defined as happy, anger, sad, fear, disgust, surprise in accordance with previous literature (Ekman, 1992) and complex emotions as any other emotions. Results extracted related to differences between groups in regard to ET, ERP or quantified EEG outcomes and pertinent within group differences. A summary of extracted data for each study is presented in Tables 1, 2 and 3.

Initial extraction revealed clear trends in relation to the heterogeneity across studies owing to differences in sample ages, stimulus type, outcome measures and the reporting of results. This appeared to be particularly evident in the studies examining ET measures. Due to the considerable variance observed across studies, a narrative review was deemed most appropriate to summarise and explore the findings in the various experimental paradigms. Data synthesis examined ET and EEG studies with respect to their various characteristics. For ET studies synthesis involved the number of fixations and duration of fixations to defined areas of interest as well as scan paths, with ET findings presented according to age and stimulus type. In synthesising EEG studies, ERP and EEG frequency features were extracted. Due to the large number of ERP and EEG measures examined within the studies, this review focused on the most frequently examined ERPs within each age category, such as the N170 and P100. Other less common components are discussed briefly. Due to the expected developmental changes studies were allocated to one of three sets. Studies with participants aged 0-12 years of age were classified as child studies, 13–17 years were classified as adolescent and adult pertained to studies of participants aged 18 and above.

2.4 Study Evaluation

Two reviewers independently assessed the quality of included studies according to the Kmet Form for quantitative analysis (Kmet, Lee, & Cook, 2004). The Kmet form provides a means of appraising the quality of studies on 14 criteria relating to the research hypothesis, methods, study samples, reporting of results, and conclusions. Two criteria of the Kmet form did not apply to the studies included in this review (intervention blinding of assessor and subject), so the form used for the current systematic review included only 12 criteria (Appendix B). For each of the 12 criteria, the study is allocated a score of 2 (yes/addressed), 1 (partially addressed) or 0 (not addressed) according to the degree to which the criterion was met, therefore the maximum score that any study could achieve was 24 (e.g., 2*12) Studies achieving a score of 80% or greater are rated as strong, 70-80% are good, 50-69% are adequate and scores of 50% or lower are considered limited.

3. Results

3.1 Search Results

The search resulted in a total of 744 articles with the following distribution: Cinahl (40), Embase (189), Medline (171), ProQuest (15), Psycinfo (118), and Scopus (211). Duplicate removal resulted in a total of 484 eligible articles. The titles and abstracts of these articles were reviewed by the first author (MB), resulting in 70 articles being forwarded to full text review. The secondary review excluded an additional 15 articles and included an additional four (two EEG and two ET) from the reference lists of the included articles, one article was also included following inter-rater review (described in section 3.2). In total, 54 articles were included in this review (31 ET, 22 EEG, 1 ET and EEG).

<FIGURE ONE HERE>

3.2 Inter-Rater Reliability

A random selection of fifty articles identified from the electronic database search were reviewed by two researchers with a background in ASD and FER according to the inclusion and exclusion criteria in order to assess the inter-rater reliability of article assessment. The two reviewers reached consensus on 48 of the 50 articles (96%) and following discussion the reviewers reached agreement on all 50 articles (100%) with one additional article being included in the review (Figure 1).

3.3 Study Type

Fifty–two studies were case-control in nature whereby a sample of individuals with ASD was compared to a comparison group. Two studies did not have a comparison sample (Gayle, Gal, & Kieffaber, 2012; Lerner, McPartland, & Morris, 2013).

3.4 Methodological Quality

The majority of included studies (k=48) were of strong methodological quality (score of 80% or greater) and six were of good methodological quality (70–80%) as assessed by the Kmet form for quantitative analysis. Tables 1, 2 and 3 outline the assessed methodical quality of the studies. Limitations primarily existed in the description of participant characteristics, process of matching or sample size (Tables 1, 2 and 3).

3.5 Participant Characteristics

As shown in table 1, 2 and 3, Autism, HFA, AS and ASD were the most common clinical samples in this review. Some studies reported including participants with a PDD-NOS diagnosis (Akechi et al., 2010; Bal et al., 2010; Crawford, Moss, Anderson, Oliver, & McCleery, 2015; Dawson, Webb, Carver, Panagiotides, & McPartland, 2004; de Wit, Falck-Ytter, & von Hofsten, 2008; Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010; Fujita et al., 2013; Magnée, de Gelder, van Engeland, & Kemner, 2008; McCabe et al., 2013; Tottenham et al., 2014; Van der Geest, Kemner, Verbaten, & Van Engeland, 2002). Primarily, ASD participants were high functioning (at least average IQ) however, one study reported including a sample of individuals with LFA (Han, Tijus, Le Barillier, & Nadel, 2015).

In the majority of studies, comparison groups consisted of TD individuals. A subset of studies compared the ASD sample to groups of participants with other disabilities or conditions such as ADHD (Gross et al., 2012; Tye et al., 2014), developmental delay (Vlamings, Jonkman, van Daalen, van der Gaag, & Kemner, 2010), Fragile X syndrome (FXS) (Crawford et al., 2015; Dalton, Holsen, Abbeduto, & Davidson, 2008), 22q11 Deletion Syndrome (22q11DS) (McCabe et al., 2013) and Schizophrenia (Sasson et al., 2007) while two studies included in this review did not include a comparison sample (Gayle et al., 2012; Lerner et al., 2013). Participant groups were primarily matched on chronological age and verbal or non-verbal intelligence (Tables 1, 2 and 3).

3.6 Task format

Procedures requiring participants to overtly determine the presented emotion via labelling or matching tasks were employed in 31 studies. Implicit tasks, that is, those that did not require the explicit recognition of emotion or required only the passive viewing of stimuli, were used in 32 EEG and ET studies, with a number of studies employing both.

Stimuli consisted primarily of static photographs. Eight studies presented dynamic stimuli of facially expressed emotions (Bal et al., 2010; Bekele et al., 2014; Bekele et al., 2013; Cooper, Simpson, Till, Simmons, & Puzzo, 2013; de Jong, van Engeland, & Kemner, 2008; Falck-Ytter et al., 2010; Han et al., 2015; Nuske, Vivanti, & Dissanayake, 2014). While whole face stimuli were presented in the majority of studies, some studies utilised experimentally manipulated stimuli including; revealing only certain features of the face via bubbles (Spezio, Adolphs, Hurley, & Piven, 2007a, 2007b) or puzzle pieces (Falkmer, Bjallmark, Larsson, & Falkmer, 2011; Leung, Ordqvist, Falkmer, Parsons, & Falkmer, 2013), presenting upright and inverted stimulus orientation (Falck-Ytter et al., 2010; Fujita et al., 2013; Lassalle & Itier, 2015; Neumann, Spezio, Piven, & Adolphs, 2006), manipulating spatial frequencies (de Jong et al., 2008; Vlamings et al., 2010) or line drawings (Tseng, Yang, Savostyanov, Chien, & Liou, 2015), direct and averted gaze (Akechi et al., 2010; Hernandez et al., 2009; Lassalle & Itier, 2015; Van der Geest et al., 2002), familiar and unfamiliar faces (Nuske, Vivanti, & Dissanayake, 2014), and digitally erased faces (Sasson et al., 2007).

The six basic emotions (happiness, anger, sadness, disgust, fear, surprise) or a subset of these six were presented in the vast majority of studies. For the purposes of this review 'neutral' was also considered a basic expression due to its potential in controlling for effect of emotional content on the outcomes. Complex emotions such as calm (de Wit et al., 2008), contempt (Bekele et al., 2014; Bekele et al., 2013), flirting, admiring, quizzical (Rutherford & Towns, 2008; Sawyer, Williamson, & Young, 2012) and others were presented in a limited number of studies (Bekele et al., 2014; Bekele et al., 2013; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Rutherford & Towns, 2008; Sawyer et al., 2012). Two studies used stimuli that consisted of posed and Duchenne smiles to determine differences in the eye gaze patterns when differentiating genuine and posed smiles in ASD (Boraston, Corden, Miles, Skuse, & Blakemore, 2008; Key et al., 2015).

4 Eye Tracking

4.1 Children

4.1.1 Static Basic Emotions (k=6)

Findings of studies comparing children with ASD to TD samples were mixed in regard to eye gaze patterns to the core facial features. Van der Geest et al. (2002) not only reported a similar number of fixations to the eyes and mouth, but also found that children with ASD made the majority of their first fixations to the eyes, similar to TD populations, when completing a free viewing task of angry, happy, neutral and surprised expressions. de Wit et al. (2008) also failed to find reduced gaze to eyes in children with ASD during the viewing of happy, anger and fearful expressions. Similar findings were reported by Falck-Ytter et al. (2010) when examining the ratio of looking time to happy, angry, disgusted, fearful, neutral and unlabelled grimace emotions, with children with ASD having similar looking times to both the eyes and mouth. Leung et al.

(2013) reported comparable results in response to angry, happy, and surprised emotions. They presented children with ASD with whole face stimuli and puzzle pieces with eyes either bisected or whole. They postulated that the eyes bisected condition would not affect the recognition accuracy of children with ASD due to their purported lower reliance on the eyes in face and emotion processing. However, not only did the children with ASD make a similar number of fixations to the eyes as their TD counterparts, their accuracy in recognition was also impaired in the eyes bisected condition to a similar extent as in the control sample (Leung et al., 2013).

Nuske, Vivanti, Hudry, and Dissanayake (2014) hypothesised that children with ASD would display differences in gaze behaviour in response to emotional faces, presented for either 30msec, 300msec, or 2sec. Consistent with this, children with ASD had shorter fixation durations to the eyes of fearful expressions and neutral faces across all stimuli exposure conditions (30 msec, 300 msec, 2 sec) driven by differences in the longest exposure time (2 sec). Children with ASD also made shorter fixations not only to neutral faces when presented for the longest exposure period (2 sec), but also to fearful expressions when presented for 30 msec and 2 sec (Nuske, Vivanti, Hudry, et al., 2014). Furthermore, children with ASD made shorter fixations to the mouths of neutral, but not fearful faces across display conditions (driven by differences in the 2 sec conditions). Van der Geest et al. (2002), reported no differences between children with ASD and TD children in either the number of fixations or the time spent on the face or non-core face areas,. Nevertheless, de Wit et al. (2008) found that children with ASD had a shorter overall looking time compared to TD children. Similar to the findings in regard to the core features of the face, Leung et al. (2013) reported no differences in the number of fixations but reported longer fixation durations for children with ASD regardless of stimuli type, emotion or area of interest.

When examining correlations between social and communication abilities as measured by the Autism Diagnostic Interview-Revised (ADI-R), de Wit et al. (2008) found a negative correlation between these scores and looking time to the screen and percentage of looking time to the mouth. Similarly, when examining children with and without ASD, Falck-Ytter et al. (2010) found a positive correlation between social impairment and looking time to the mouth and a negative correlation between social impairment and looking time to the eyes, while the inverse was true for communication impairment.

When compared to children with FXS, children with ASD looked significantly more to the eyes of neutral expressions. However, dwell time on faces with happy, disgusted, and neutral expressions was similar in both groups, suggesting that attention to emotional faces is allocated similarly in these groups (Crawford et al., 2015).

4.1.2 Static Complex Emotions (k=1)

The complex emotion of calm was included in one free viewing task (de Wit et al., 2008). While this study did not conduct separate eye gaze analysis comparing basic and complex emotions, it was found that children with ASD had a shorter overall looking time to emotional faces compared to TD children, however no differences were reported in regard to fixation time on the eyes.

4.1.3 Dynamic Basic Emotions (k=3)

Reduced fixations to the eyes were reported for children with ASD in one study (Nuske, Vivanti, & Dissanayake, 2014) that explored the effect of face familiarity on emotion perception. While children with ASD had divergent gaze to the eyes, these differences were present only in response to neutral, but not to fearful faces, with children with ASD making fewer fixations to the eyes regardless of familiarity of the face. In contrast to these findings, Falck-Ytter et al. (2010) reported no differences in the number of fixations children with ASD made to the eye regions of angry, happy, disgusted, fearful, neutral, and grimace facial expressions.

In regard to the other core facial features, ASD-linked differences have been found, most notably in relation to gaze time towards the mouth. In Nuske, Vivanti, and Dissanayake (2014), TD children fixated more to the mouths of neutral expressions than children with ASD when viewing familiar and unfamiliar faces. However, Falck-Ytter et al. (2010) reported no group differences in time spent fixating on the mouth.

Children with ASD have also been found to spend less time looking at faces overall in comparison to their TD counterparts in two studies when viewing dynamic stimuli (Bal et al., 2010; Nuske, Vivanti, & Dissanayake, 2014). Children with ASD had smaller fixation duration percentages to regions other than the face when presented with fearful faces, but not other emotions (Bal et al., 2010). Nuske, Vivanti, and Dissanayake (2014) found a reduction in the number of fixations to neutral faces but not fearful faces in children with ASD. Correlations between the ADI-R and gaze behaviour to faces were reported in one study (Falck-Ytter et al., 2010). Similar to the findings with static faces, children with ASD showing high social impairment scores spent more time fixating on the mouth and less on the eyes when viewing dynamic stimuli compared to those with low social impairments. Higher communication impairment scores were associated with less looking time to the mouth, however, there were no correlations between gaze to the eyes and communication impairment. When using the Social Communication Questionnaire (SCQ), a measure of autism symptoms derived from the ADI-R, these findings relating to social impairment and the mouth were replicated. When examining dynamic stimuli presenting an action, those children with ASD who had increased looking time to the face as opposed to the action, had lower social impairment scores but higher communication impairment scores.

4.2 Adolescents

4.2.1 Static Basic Emotions (k=6)

Adolescents with ASD were found to spend less time looking at faces expressing emotion compared to the TD counterparts (McCabe et al., 2013; White, Maddox, & Panneton, 2015). McCabe et al. (2013) reported a lower number of fixations in adolescents with ASD across the six basic emotions compared to TD adolescents. However, when controlling for IQ, this difference was no longer significant. White et al. (2015) found no differences between their sample of adolescents with ASD and matched controls to disgust and angry expressions, however, when accounting for self-reported ratings on the fear of negative evaluation, the adolescents with ASD had shorter fixation durations on the face. When fixation durations were assessed in 500msec bins, adolescents with ASD reduced their fixation durations to disgust expressions more so than TD adolescents and had reduced fixation durations to angry expressions compared to TD adolescents during the first 500msec, suggesting differences in disengagement from disgust and angry expressions in ASD populations. In contrast however, Wagner, Hirsch, Vogel-Farley, Redcay, and Nelson (2013) reported no differences in the time adolescents with ASD spent viewing emotionally expressive faces.

In addition to a decrease in time spent fixating on the face, adolescents with ASD were also reported to spend less time fixating on the eyes of emotionally expressive faces (Dalton et al., 2005; Tottenham et al., 2014; White et al., 2015) with two studies reporting similar ET patterns to the eye region in adolescents with and without ASD (McCabe et al., 2013; Wagner et al., 2013). Tottenham et al. (2014) reported that adolescents with ASD made fewer eye movements towards the eyes of neutral but not angry expressions. Dalton et al. (2005) reported fewer fixations to the eyes for happy, fear, angry and neutral expressions. White et al. (2015) reported no differences in fixations to the eyes, however, when accounting for self-report scores of fear of negative evaluation, adolescents with ASD presented with shorter fixation durations to the eye region. In a similar vein, Tottenham et al. (2014) examined the correlations between how threatening adolescents perceived an emotion to be and their gaze patterns. Adolescents with ASD who perceived neutral faces as more threatening had a higher tendency to look away from the eyes, however, this was not seen in response to angry faces or in the TD adolescents.

None of the static simple emotion recognition studies in adolescents reported differences in the eye gaze patterns to the mouth between adolescents with and without ASD, a finding apparent across task formats, participant matching procedures and emotions (Dalton et al., 2008; Dalton et al., 2005; McCabe et al., 2013; Wagner et al., 2013).

4.2.2 Static Complex Emotions (k=1)

Hanley, McPhillips, Mulhern, and Riby (2012) sought to understand how adolescents process static stimuli with varying levels of social content, presenting adolescents with and without ASD with static images of posed, acted and naturalistic expressions as well as images taken from acted and naturalist social scenes. Hanley et al. (2012) found no differences for posed or acted isolated expressions, however, adolescents with ASD spent significantly more gaze time viewing the hair of naturalistic isolated faces. When viewing items taken from social scenes, adolescents with ASD spent less time fixating on the eyes and more time on the body in acted social scenes and less time on the eyes and face in naturalistic social scenes (Hanley et al., 2012).

4.2.3 Dynamic Complex Emotions (k=2)

Dynamic complex emotions were used by two studies presented by the same authors (Bekele et al., 2014; Bekele et al., 2013). These studies attempted to evaluate the effect of immersive stimuli on emotion recognition in ASD using animated avatar faces expressing facial emotions. Both studies, examined emotion recognition as well as eye gaze patterns while the avatar was telling a story or talking with a neutral expression. Adolescents with ASD had a greater proportion of gaze time to the forehead and less to the mouth than TD adolescents in both studies (Bekele et al., 2014; Bekele et al., 2013). While there was agreement between the two studies in gaze time to the mouth and forehead, differences arose in other features. In Bekele et al. (2013) adolescents with ASD had a smaller gaze time on the face and a greater gaze time on non-face areas when both groups correctly identified the emotion along with shorter gaze time towards the mouth and longer gaze time towards the forehead. When adolescents with ASD were incorrect, only the difference in gaze time towards the forehead and mouth was significant (Bekele et al., 2013).

4.3 Adults

4.3.1 Static Basic Emotions (k=11)

In regard to ET patterns to the core facial features, the most apparent difference between adults with ASD and TD controls related to fixations to the eyes. The majority of studies found that adults with ASD allocated a smaller proportion of time to the eyes, fixated less to the eyes or gazed away from the eyes of emotionally expressive faces more often compared to their TD counterparts (Boraston et al., 2008; Corden, Chilvers, & Skuse, 2008; Falkmer et al., 2011; Hernandez et al., 2009; Kliemann, Dziobek, Hatri, Baudewig, & Heekeren, 2012; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010; Pelphrey et al., 2002). This difference was apparent regardless of emotion (Boraston et al., 2008; Corden et al., 2008; Hernandez et al., 2009; Pelphrey et al., 2002) or whether the task was free viewing (Corden et al., 2008; Hernandez et al., 2009; Pelphrey et al., 2002) or required active recognition (Boraston et al., 2008; Corden et al., 2008; Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010; Pelphrey et al., 2002).

When considering the relationship between gaze to facial features and FER, Boraston et al. (2008) aimed to examine whether adults with ASD were able to differentiate natural from posed smiles, finding that adults with ASD had both a reduced gaze time and made fewer fixations to the eyes of the expressive faces. Corden et al. (2008) found that in both free viewing and active recognition of the six basic emotions, adults with ASD had a smaller proportion of fixations to the eyes, despite both ASD and TD scanning different emotions in a similar manner.

Adults with ASD demonstrated no differentiation in eye gaze in relation to emotional expression, unlike TD adults who altered their eye gaze in response to the emotion presented (Kliemann et al., 2012; Kliemann et al., 2010). Adults with ASD looked downward to the mouth from the eyes more often than TD adults (Kliemann et al., 2010), showing a decreased preference for the eyes of fearful and neutral expressions. This was consistent with Kliemann et al. (2012) who found that adults with ASD made more saccades away from the eye region than TD controls. Hernandez et al. (2009) found that when beginning the exploration of emotional faces, TD adults began their search in the eyes more often than adults with ASD.

Three studies found that individuals with ASD who made more fixations to the eyes had higher proficiency at emotion recognition than those who did not or looked more at other areas of the face (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010). Corden et al. (2008) found that those with ASD who looked less at the eyes had poorer recognition of fear and those who had higher scores of social anxiety fixated less on the eyes.

In regard to looking time to other core facial features findings are more mixed. Studies reporting on fixations to the nose, found that participants with ASD spent less time on the nose that TD adults (Hernandez et al., 2009; Pelphrey et al., 2002).

Falkmer et al. (2011) found that adults with ASD made a similar number of fixations and had similar duration of fixations on the mouth as TD adults when viewing whole faces. Similarly, despite adults with ASD having a smaller percentage of fixation time to the core features, Pelphrey et al. (2002) found no differences between groups in the proportion of time spent on the mouth. Hernandez et al. (2009) found similar results in their free-viewing task of happy, sad, neutral, neutral faces with averted gaze and avatars with no differences in looking time between groups. However, Hernandez et al. (2009) reported that adults with ASD were more likely to begin their exploration of emotional faces on the mouth compared to TD adults.

While some studies reported that adults with ASD fixated less to whole faces than their TD counterparts (Hernandez et al., 2009), others reported no differences between groups (Corden et al., 2008; Neumann et al., 2006; Pelphrey et al., 2002). Hernandez et al. (2009) found that adults with ASD spent more time on regions peripheral to the face than TD adults and while TD spent more time on the core facial features than peripheral regions.

A number of studies used other experimental paradigms involving the manipulation of facial stimuli in order to investigate the differential effect of top down and bottom up visual processing strategies (Falkmer et al., 2011; Neumann et al., 2006; Sasson et al., 2007; Spezio et al., 2007a, 2007b). Manipulations included examining the effect of Gaussian bubbles (Neumann et al., 2006; Spezio et al., 2007a, 2007b) or puzzle pieces (Falkmer et al., 2011), inverted faces (Neumann et al., 2006) and digitally erased faces (Sasson et al., 2007). When viewing inverted stimuli, Neumann et al. (2006) found that adults with ASD had longer fixation times to the mouth compared to the TD group. When examining bubbled or puzzled stimuli, adults with ASD looked more at the mouth and less at the eyes than TD adults in four studies (Falkmer et al., 2011; Neumann et al., 2006; Spezio et al., 2007a, 2007b). Spezio et al. (2007b) found that when information was available in the eyes that could assist in the recognition of emotion, adults with ASD looked more towards the mouth than TD adults. Sasson et al. (2007) presented adults with and without ASD and schizophrenia with static images of social scenes with the faces present or digitally erased, hypothesising that the performance of the clinical populations would be more impacted by the face-present condition. The adults with ASD had a shorter fixation duration to faces in the face present condition in comparison to TD adults with TD adults orientating to the face faster when the face was present versus absent while ASD did not differentiate in orientation speed (Sasson et al., 2007). In contrast to the findings of increased eye fixations and performance (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010), Sasson et al. (2007) found the opposite effect, with adults with ASD having a negative correlation between recognition accuracy and fixation duration to the face.

4.3.2 Static Complex Emotions (k=3)

When viewing static complex emotions, a single study reported that adults with ASD made fewer fixations to faces expressing complex emotions (Kirchner et al., 2011). However, a decrease in looking time to the eyes (Kirchner et al., 2011; Rutherford & Towns, 2008; Sawyer et al., 2012) or divergent eye gaze patterns to other core features of the face, including the mouth (Kirchner et al., 2011; Rutherford & Towns, 2008; Sawyer et al., 2012) was not found. Similar to the findings with static basic emotions (Falkmer et al., 2011; Kliemann et al., 2012; 2010), Kirchner et al. (2011) found a positive association with looking time to the eyes and a negative association with looking time to the mouth for recognition performance of complex negative stimuli in their ASD populations.

Two studies compared the time spent viewing the features of complex emotions in comparison with basic emotions (Rutherford & Towns, 2008; Sawyer et al., 2012). One study reported no differences in time spent examining the eyes and mouth of complex compared to basic emotions in their ASD and TD groups (Sawyer et al., 2012), while Rutherford and Towns (2008) found that adults with ASD spent more time on the eyes and mouth of faces expressing basic emotions compared to complex emotions, while the opposite was true for TD adults.

4.3.3 Dynamic Basic Emotions (k=1)

Dynamic representations of simple emotions were presented to adults in one study. Han et al. (2015) examined a sample of adults with ASD who presented with a comorbid intellectual disability. This study used morphing facial expressions as well as mechanical displays representing emotional expressions with the aim of determining whether motion processing was more enhanced in ASD as opposed to the processing of emotion. Adults with ASD had a lower percentage of fixation time; however fixations to the eyes and mouth of human emotional stimuli were similar to that of their TD control groups. To the mechanical display, adults with ASD made fewer fixations to the core features of the face, differentiating their gaze to the robotic setup from that to the emotional display, a difference not seen in the TD control groups. This suggests that adults with ASD may process motion rather than emotion when viewing dynamic facial expressions.

5 EEG Evoked Potentials

EEG evoked potentials were examined by 18 of the studies included. Of these studies, the most reported components were N170 and P100.

5. 1 Children

5.1.1 N170 (k=6)

Children with ASD were found to be atypical in both the latency and amplitude of the N170 component in three studies (Batty, Meaux, Wittemeyer, Roge, & Taylor, 2011; de Jong et al., 2008; Tye et al., 2014). Delayed N170 latencies in children with ASD were found in one study (Batty et al., 2011) with another study finding differences in the latencies between children with ASD and ASD with comorbid ADHD (Tye et al., 2014). Batty et al. (2011) found that across basic emotions, children with ASD had slower N170 latencies compared to children matched for chronological age. In regard to the amplitude of the N170, de Jong et al. (2008) reported reduced amplitude of the N170 in children with ASD compared to TD children in response to fearful expressions. Furthermore, fearful expressions elicited larger N170 responses in TD children when compared to neutral with no modulation effect seen in children with ASD (de Jong et al., 2008).

ADHD comorbidity has also been associated with divergent N170 latencies and amplitudes in ASD populations. Tye et al. (2014) found that children with ASD had shorter N170 latencies to neutral faces compared to angry faces and longer latencies to fearful expressions in comparison to happy faces while children with co-occurring ASD and ADHD had the opposite response to these emotions. In addition, children with ASD and ASD/ADHD comorbidity had decreased N170 amplitude across happy, angry, fearful and disgusted expressions in comparison to TD controls. In contrast to the findings of de Jong et al. (2008), the amplitude of the N170 was modulated by emotion in the ASD group with fear eliciting larger amplitudes compared to neutral. This same modulation effect was not seen in TD children or children with ADHD.

5.1.2 P100 (k=4)

Two child studies reported that children with ASD and TD matched controls had similar P100 ERPs in response to emotional faces (O'Connor, Hamm, & Kirk, 2005; Wong, Fung, Chua, & McAlonan, 2008). In contrast, two free-viewing studies reported differences in both latency and amplitude of the P100 ERP (Batty et al., 2011; Vlamings et al., 2010). Batty et al. (2011) compared children with ASD to two groups of TD children, one matched for chronological age and one matched on verbal equivalent age, and compared to both, children with ASD had smaller P100 amplitudes in response to the six basic emotions, but slower latencies only in comparison to chronologically age matched controls.

The effect of spatial processing bias in ASD was examined in one study using neutral and fearful faces presented in high and low spatial frequencies. Vlamings et al. (2010) postulated that high spatial frequencies represented more detail supporting local orientated processing and low spatial frequency related to global pattern processing. Fear faces presented in high spatial frequency elicited larger P100 amplitudes compared to neutral faces in children with ASD aged 3-4 years. Conversely, IQ matched TD control children were found to show larger P100 amplitudes to neutral faces compared to fear faces presented in low spatial frequency (Vlamings et al., 2010).

5.1.3 Other ERPs

The P200 ERP was examined in three child studies (Dawson et al., 2004; O'Connor et al., 2005; Wong et al., 2008). Of these, one reported differences with children with ASD having smaller and slower P200 responses to neutral faces during an implicit recognition task compared to chronologically age matched children (Dawson et al., 2004). When matched on verbal equivalent age, however, children with ASD had larger P200 amplitudes than TD children in the midline and central regions only (Dawson et al., 2004).

Within the child ERP studies, other not as commonly explored components included the N300 (Dawson et al., 2004), P300 and P500 (Dawson et al., 2004), N400 (Key et al., 2015), P400 (Key et al., 2015), Negative Slow Wave (NSW) (Dawson et al., 2004), N290 (Key et al., 2015)and Nc (Dawson et al., 2004; Key et al., 2015).

Children with ASD were found to have no differentiation in the amplitude of the N300 and NSW while TD children showed larger amplitudes to fear compared to neutral faces (Dawson et al., 2004). Differences in P300 emerged with ASD children having larger amplitudes to neutral compared to fear expressions while verbally equivalent aged children showed the opposite (Dawson et al., 2004). Infants at a high risk of developing ASD showed altered differentiation of P400 and Nc ERPs in response to neutral, small and large smiles compared to low risk infants (Key et al., 2015).

5.2 Adolescents

5.2.1 N170 (k=3)

The amplitude and latency of the N170 component may not be modulated by emotion in adolescents with ASD. Adolescents with ASD were found to show no modulation of the N170 amplitude in response to fear and angry faces while TD adolescents showed different N170 amplitudes as a function of emotion (Wagner et al., 2013). A similar effect was seen when Akechi et al. (2010) examined the effect of eye gaze on emotion processing. It was proposed that the processing of gaze and emotion are not independent and gaze direction may facilitate the processing of emotion whereby approach orientated emotions such as happiness are processed faster with direct gaze while avoidant orientated emotions are processed faster with indirect gaze. It was found that TD adolescents displayed larger N170 amplitudes to stimuli showing congruent emotions and gaze direction (fear faces with indirect gaze, angry with direct gaze) compared to incongruent emotions and gaze direction while the adolescents with ASD did not show this difference, indicating that adolescents with ASD may experience difficulty integrating gaze and expression cues.

A single group experimental study examined the correlation between N170 and the accuracy of adolescents with ASD at recognising emotions (Lerner et al., 2013). This study found that adolescents diagnosed with ASD who had longer latencies and smaller amplitudes of the N170 were less likely to correctly identify emotion accurately and had longer response times (Lerner et al., 2013).

5.2.2 P100 (k=2)

Two studies examined the P100 component in adolescents with ASD (Akechi et al., 2010; Wagner et al., 2013). One of these studies reported negligible differences in both the latency and the amplitude of the P100 in adolescents with and without ASD in response to the six basic emotions (Wagner et al., 2013). The sole difference between ASD and TD adolescents was found in response to angry and fear expressions. The P100 latency differed between O1 and O2 electrodes in TD participants but not ASD participants (Akechi et al., 2010).

5.3 Adults

5.3.1 N170 (k=5)

Three studies reported differences between adults with ASD and controls (Magnée, de Gelder, van Engeland, & Kemner, 2011; O'Connor, Hamm, & Kirk, 2007; O'Connor et al., 2005) while two studies did not find between group differences (Magnée et al., 2008; Tseng et al., 2015). O'Connor et al. (2005) found that adults with ASD had smaller and delayed N170 ERPs to happy, sad, angry and scared expressions compared to controls. In a later study, O'Connor et al. (2007) found that when examining emotional faces in comparison to objects, N170 in adults with ASD did not differentiate face from object processing while TD controls had earlier N170 responses to faces when compared to objects. Furthermore, TD individuals had earlier N170 responses to faces and the eye and mouth regions of emotionally expressive faces compared to adults with ASD.

Difficulty with the integration of multisensory information was evident in two studies (Magnée et al., 2011, 2008). When presented with only visual input, the ASD groups did not differ from TD adults in regard to the N170 (Magnée et al., 2011, 2008), however, when required to divide attention, adults with ASD did not show differentiation based on the congruency of auditory and visual stimuli as seen in TD adults (Magnée et al., 2011).

5.3.2 P100 (k=4)

The P100 component was examined in four ERP studies in adults (Lassalle & Itier, 2015; Magnée et al., 2008; O'Connor et al., 2007, 2005). Adults with ASD were found to have longer latencies to happy, sad and angry expressions in one study (O'Connor et al., 2005). TD individuals with high autistic traits were also found to differ in P100 with gaze and emotion having a congruency effect on the P100 of TD adults with low autistic symptomology, but not in adults with high autistic symptomology (Lassalle & Itier, 2015).

5.3.3 Other ERPs

Other ERPs examined in adult populations were the N100 (Fujita et al., 2013), P300 (Fujita et al., 2013), N200 (Magnée et al., 2008), N400 (Tseng et al., 2015), Visual Mismatch Negativity (vMMN) (Gayle et al., 2012), Early Directing Attention Negativity (EDAN) and Anterior Directing Attention Negativity (ADAN) (Lassalle & Itier, 2015). N100 amplitudes were not modulated by emotional faces or objects in adults with ASD while TD adults showed larger N100 ERPs in response to emotional faces compared to objects (Fujita et al., 2013). Similarly, the N400 ERP was similar in TD and ASD adults when shown line drawings of expressions, however the N400 was not apparent in adults with ASD when shown photographs of expressions (Tseng et al., 2015). In regard to vMMN, TD adults with high autistic traits showed smaller vMMN amplitudes to happy faces compared to TD adults with low autistic traits (Gayle et al., 2012). Lassalle and Itier (2015) examined both EDAN and ADAN, EDAN occurring 200ms–300ms after stimulus presentation and ADAN, occurring 300-500ms after stimulus presentation have previously been associated with the orientation of attention and the maintenance of attention, respectively. These authors examined the effect of stimulus inversion and gaze direction on the processing of emotional stimuli, finding an effect of gaze direction on ADAN in individuals with low but not high autistic traits on the Autism Spectrum Quotient (AQ).

5.4 Quantitative EEG (k=6)

Quantitative methods of examining EEG were used in six studies. Alpha, theta and beta frequencies were the most explored followed by delta and gamma. The particular methods used varied across studies and included dipole source analysis, phase synchronization, desynchronization, coherence, mu suppression and oscillations. All studies reported atypical cortical activation in ASD populations with differences being reported across the frequency spectrum.

The theta wave occurring between 4 and 7.5 Hertz has been previously associated with the processing of affect, and was examined in three studies (Tseng et al., 2015; Yang, Savostyanov, Tsai, & Liou, 2011; Yeung, Han, Sze, & Chan, 2014). Children with ASD were found to have lower right frontal theta coherence compared to TD children and did not show the same increase in theta coherence observed in TD children in response to emotional faces compared to neutral faces (Yeung et al., 2014). In addition, children with higher theta coherence appeared to have lower autistic symptomology (Yeung et al., 2014). Tseng et al. (2015) found similar results with adolescents and adults with ASD displaying weaker delta/theta synchronization than typically developing controls in both early and late stages of emotion recognition. Weaker theta synchronization in ASD was also reported by Yang et al. (2011).

ASD populations were found to have greater beta 2 synchronization and alpha desynchronization in posterior regions compared to TD populations (Yang et al., 2011), however, these findings were not consistent across studies (Tseng et al., 2015)

Mu rhythm activity, the suppression of which is believed to be associated with mirror neuron function (Pineda, 2005), was investigated in one study. Cooper et al. (2013) examined event related desynchronization in the low beta and alpha bands mu activity, postulated to reflect mirror neuron activity in the motor cortex and somatosensory cortex respectively. TD adults with low autistic traits presented with greater low beta desynchronization compared to adults with high autistic traits when examining happy faces, reflecting reduced activation of the mirror neuron system to happy faces in individuals with high autistic traits on the AQ. Furthermore, while low trait autism individuals showed greater low beta desynchronization to happy as compared to angry faces, the inverse was true for the high autism trait group, also suggesting divergent mirror neuron activity. No group differences emerged in the alpha mu component, indicating divergent mu rhythm activity may arise in the motor cortex (Cooper et al., 2013).

Gamma oscillations were explored in one study of adolescents with ASD compared to a group of adolescents with ADHD and a group of TD adolescents in emotion and gender recognition tasks. Adolescents with ASD were shown to have lower gamma power to anger and disgust emotions when compared to gender recognition tasks while TD adolescents showed a smaller differentiation of gamma power between these two tasks (Gross et al., 2012).

6. General Discussion

Evidence from both ET and EEG studies included in this review suggests that the attentional and cognitive processes involved in FER are atypical in ASD populations. Eye tracking studies reported atypical gaze to the emotional faces and core facial features in individuals with ASD during FER while EEG studies most consistently reported atypical modulation of the N170 ERP. In addition, while less examined, findings in the frequency domain also indicate atypical cortical activity during FER in ASD samples.

It seems somewhat surprising that the pattern of ET results was not more consistent across studies. Reduced gaze to the eyes is frequently cited as observed in ASD and is generally considered a key characteristic of the diagnosis (American Psychiatric Association, 2013; Baron-Cohen et al., 2000). However, a number of studies in this review failed to find any significant difference in the gaze behaviour of individuals with ASD in comparison to TD controls and there appeared to be a clear effect of age on between group differences in gaze behaviour. Only two of the nine child studies that compared children with ASD to TD children, reported a reduced number of fixations or duration of time spent looking at the eyes (Nuske, Vivanti, & Dissanayake, 2014; Nuske, Vivanti, Hudry, et al., 2014). Similarly, of the eight adolescent studies, only three reported reduced gaze to the eyes in individuals with ASD (Dalton et al., 2005; Tottenham et al., 2014; White et al., 2015). When examining the adult studies, results were more consistent with 11 of the 16 studies reporting reduced use of information presented in the eyes by persons with ASD (Boraston et al., 2008; Corden et al., 2008; Falkmer et al., 2011; Han et al., 2015; Hanley et al., 2012; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007a, 2007b). This apparent change of gaze behaviour across the developmental trajectory may have several potential origins. The failure to find stable, significant differences between ASD and TD children, may in part be explained by the stimuli or tasks used and their inability to adequately capture attention in either group. It is possible that the stimuli presented do not engage children sufficiently, and thus were not capable of eliciting divergent gaze behaviour. Those child studies which did find reduced gaze in children with ASD varied exposure time (30ms, 300ms, 2secs) (Nuske, Vivanti, Hudry, et al., 2014) or used familiar and unfamiliar faces (Nuske, Vivanti, & Dissanayake, 2014) whereas the study reporting increased gaze to the eyes in ASD children used very unusual puzzle piece stimuli (Leung et al., 2013). The remaining child studies typically examined gaze to stimuli that were presented for longer durations (4 – 10 secs) and utilised prototypical static and dynamic faces. It is possible that the additional complexity offered by the varied exposure times, face familiarity or puzzled stimuli required greater cognitive processing, resulting in altered eye gaze.

Adult studies reported reduced gaze in response to not only complex emotions (Hanley et al., 2012) but also in response to basic emotions (Corden et al., 2008; Falkmer et al., 2011; Han et al., 2015; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007a, 2007b), with significantly reduced gaze to the eyes being found with prototypical static faces (Corden et al., 2008; Kliemann et al., 2010; Pelphrey et al., 2002), dynamic faces (Han et al., 2015) and experimentally manipulated stimuli (Hernandez et al., 2009; Neumann et al., 2006; Spezio et al., 2007a, 2007b). Given that the development of basic emotion recognition typically reaches maturity in late childhood (Tonks et al., 2006), it appears unlikely that the increased consistency to document reduced eye gaze in adults with ASD was due to the increased complexity of the stimuli used in adult populations. It is possible that this difference in gaze behaviour becomes more apparent in adult populations as a result of divergent development of facial emotion processing in late childhood or adolescence.

Two accounts have been offered to explain divergent eye gaze patters in ASD, the social salience and the eye avoidance accounts. The social salience account proposes that the eye region may provide particularly salient information assisting in the decoding of facial information and emotional expressions (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Langton, Watt, & Bruce, 2000). A lack of orientation or focus on the eyes in ASD populations may therefore suggest that individuals with ASD do not perceive the eyes as being socially salient or meaningful (Baron-Cohen et al., 1997; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). As a result, individuals with ASD may select to look at more physically salient features, such as the mouth which has greater variability and motion than the eye region, perhaps capturing the attention of individuals with ASD to a greater degree. Reduced saliency of social information for individuals with ASD, may be indicative of possible altered function of a number of structures within the social brain such as the fusiform face area (FFA) (Kanwisher, McDermott, & Chun, 1997), amygdala (Rudrauf et al., 2008; Santos, Mier, Kirsch, & Meyer-Lindenberg, 2011), orbitofrontal cortex and temporal poles (Rudrauf et al., 2008). These structures have been shown to engage in feedback processes with visual processing streams, influencing visual attention during emotion processing (Rudrauf et al., 2008). Atypical eye gaze in ASD individuals, particularly to the eye regions may suggest that the pathways involved in the rapid evaluation and processing of emotional stimuli are altered in ASD. The eye avoidance hypothesis (Tanaka & Sung, 2016) postulates that individuals with ASD may present with over-arousal of the amygdala and hyper-physiological arousal in response to social stimuli. As a result, reduced gaze to the eyes in individuals with ASD may be an attempt to self-regulate and mediate the level of threat perceived from the eyes (Dalton et al., 2005; Tanaka & Sung, 2016).

On a related note, anxiety or fear of negative evaluation appeared to have an effect on gaze towards the eyes in a number of ET studies included in this review. Comorbid anxiety is common within ASD populations (Maddox & White, 2015) and atypical gaze to faces, particularly resulting in a reduction in fixation towards the eyes has been reported in anxiety disorders (Daly, 1978; Wang, Hu, Short, & Fu, 2012). Moreover, anxiety disorders when combined with ASD, have been shown to exacerbate ASD symptoms (Farrugia & Hudson, 2006). Few studies have examined the impact of co-occurring anxiety in ASD populations and most have failed to control for anxiety in their clinical and control populations. Those that have included a measure of social anxiety or threat rating found that those with ASD who had higher anxiety scores, or who rated emotions as more threatening, looked at the eyes significantly less than their TD counterparts (Corden et al., 2008; Tottenham et al., 2014; White et al., 2015).

Atypical gaze to other core facial features such as the mouth, was also observed in some studies (Bal et al., 2010; Bekele et al., 2014; Corden et al., 2008; Leung et al., 2013; Nuske, Vivanti, & Dissanayake, 2014; Nuske, Vivanti, Hudry, et al., 2014). As a result, atypical gaze to faces during FER may also indicate atypical processing of information from the mouth region, however, findings overall remain inconclusive.

There was also a clear tendency in the ET literature towards the report of non-significant trends, with the majority of these trends reporting results consistent with the significant findings (Bal et al., 2010; Bekele et al., 2013; Boraston et al., 2008; Corden et al., 2008; de Wit et al., 2008; Kliemann et al., 2012; Kliemann et al., 2010; Rutherford & Towns, 2008; Tottenham et al., 2014). This tendency for reports of trends to corroborate significant findings may be seen to provide additional, although weak, support for the notion of reduced gaze towards the eyes during FER. While it is noted that these findings are not statistically significant, the tendency for these trends to be reported and for conclusions to be based on them can make the interpretation and integration of the results reported in the literature problematic. It is, for instance, not clear whether the report of trends is selective, i.e., whether trends are reported only if they are seen to be consistent with an expected pattern of results. Such a bias may help to strengthen a presumed pattern of results that has a less solid empirical base as originally thought. Methodological issues associated with some studies, such as small sample size, may have contributed to this tendency to find and report statistical trends. Future research may benefit from larger scale studies to more accurately determine the gaze behaviour of individuals with ASD.

It should also be noted that across ET studies a number of different outcome measures are reported. For example, studies may examine the duration of the first fixation, the total fixation time, number of fixations, scan paths or location of first fixations and the rationale for choosing one over the other is not always clear. The range of outcome measures examined may impact the resultant findings. For example, it was found that adults with ASD may differentiate their gaze depending on the location of their first fixation, indicating a reduced preference for the eyes compared to TD adults (Kliemann et al., 2012; Kliemann et al., 2010).

Across studies reporting ERPs, the N170 was consistently smaller, delayed and slower in ASD populations. The N170 ERP has been shown to be largest in response to faces (Blau, Maurer, Tottenham, & McCandliss, 2007), suggesting its involvement in the processing of facial information. While the face-specific nature of the N170 ERP is well accepted (Eimer, 2011, 2000; Eimer et al., 2011), the precise function of the N170 ERP continues to be debated. The N170 ERP has been suggested to reflect the early encoding of facial stimuli (Eimer, 2000), whereas other studies have indicated that the N170 can also be modulated by the emotional content of the faces (Batty & Taylor, 2003; Blau et al., 2007). Given the debate in the current literature regarding the processes reflected in the N170 ERP, it is unclear whether FER impairment in ASD reflects altered encoding of facial information, resulting in difficulty processing facial configurations (O'Connor et al., 2007) or altered function in a possible parallel system specific for emotion processing (Blau et al., 2007). Nevertheless, consistently smaller and slower N170 ERPs in the

ASD populations indicate altered function of early visual processing during FER.

An important caveat is that differences in ERPs in ASD populations may also be indicative of heterogeneity in the ASD population. It could be the case that only a subset of individuals with ASD are impacted by FER deficits (Nuske et al., 2013) or that there is more universal disorganisation and variability in neural pathways involved in FER in ASD.

Studies of frequency domain measures of EEG provide further evidence for atypical activation of cortical regions during FER in ASD. Increased theta synchronization has been demonstrated to reflect information encoding and episodic memory (Klimesch, 1999), and a reduction in theta synchronization and reduced right frontal theta coherence in ASD populations (Tseng et al., 2015; Yang et al., 2011) may reflect poor encoding of facial emotion. The hippocampus and amygdala have been shown to be involved in the encoding of emotional memory (Richardson, Strange, & Dolan, 2004) and the amygdala has been found to have atypical structure and function in ASD (Baron-Cohen et al., 2000; Bölte et al., 2015; Dalton et al., 2005). Reduced theta synchronization may be indicative of atypical connectivity between neural networks involving the amygdala and hippocampus resulting in less efficient encoding and memory retrieval of facial expression. A phasic suppression of alpha during task performance has been shown to reflect increasing attention demands (Klimesch, 1999; Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998), thus, greater alpha de-synchronization in ASD may suggest increased concentration or attention to the task, possibly reflecting decreased efficiency of structures involved in FER (Yang et al., 2011). Changes in the frequency domain can be reflective of a number of different cognitive processes (Başar, Başar-Eroglu, Karakaş, & Schürmann, 2001), therefore, caution must be observed when inferring the particular cognitive processes involved in FER.

Yang et al. (2011) and Tseng et al. (2015) both postulated that the observed reduction in the lower frequency bands in people with ASD may be indicative of impaired automatic processing of emotion while increased alpha desynchronization and beta may be reflective of increased conscious control of visual processing. This is possibly indicative of the use of compensatory strategies accounting for weaknesses in the typical automatic processes involved in emotion recognition (Tseng et al., 2015).

While only examined in one study, the role of the mirror neuron system in FER is important to note (Cooper et al., 2013). The mirror neuron network is postulated to be involved in the understanding of movement and imitation (Rizzolatti & Craighero, 2004). For this reason, the function of this system in understanding the movement of others has been proposed to be linked to the understanding of social situations, theory of mind (Gallese, 2007; Schulte-Rüther, Markowitsch, Fink, & Piefke, 2007; Williams, Whiten, Suddendorf, & Perrett, 2001) and facial expressions (Enticott, Johnston, Herring, Hoy, & Fitzgerald, 2008). Suppression of mu rhythm has been suggested to reflect mirror neuron activity (Pineda, 2005; Rizzolatti & Craighero, 2004). Atypical patterns of mu activity found in individuals with high autistic symptomology (Cooper et al., 2013) suggest that the mirror neuron system involved in the understanding of actions may contribute to an FER impairment in ASD and warrants further investigation (Hickok, 2009).

The effect of emotion per se as well as of specific emotions on the differences reported between groups was difficult to elucidate from the extant literature. A number of studies reported differences in ET and ERP responses to neutral faces in addition to differences in response to emotional expressions. Therefore, it is unknown whether impairments in face recognition in general result in a FER deficit, or whether there are additional impairments in ASD related specifically to the processing of facially expressed emotion. Previous reviews have suggested that individuals with ASD have a deficit in face processing (Tang et al., 2015; Weigelt, Koldewyn, & Kanwisher, 2012), and diminished fixations to the eyes during tasks such as face recognition have been identified in ASD (Harms et al., 2010; Senju & Johnson, 2009; Tanaka & Sung, 2016). Certainly, atypical gaze to faces would also manifest in FER tasks. A number of studies across the developmental trajectory reported that while ERPs were modulated by emotion in TD samples, this modulation was absent in ASD samples. This suggests that whereas TD display differentiated neural activity based on the emotional content of faces, persons with ASD may not display this same differentiation, suggesting that while general face processing in ASD is impaired, there may be an additional or compounding impairment in the processing of emotion.

7. Future Directions and Challenges

Facial emotion recognition is a complex task drawing on a number of neural networks (Adolphs, 2002). Given the complexity of these processes, a significant body of research has emerged across diverse areas to elucidate the nature of FER impairment in ASD. However, the large degree of heterogeneity in the studies included in this review owing to differences in experimental paradigms and tasks makes synthesising results difficult. The methodological differences across studies may affect the findings. Participant factors, for example sample size, ASD population characteristics or matching procedure may also result in differing outcomes. ERPs have been shown to be influenced by the experimental paradigm selected. For example, a P100 elicited by a target following an emotional face (Lassalle & Itier, 2015) may reflect a different process as does a P100 elicited by the emotional face (O'Connor et al., 2005). Thus, caution must be used when interpreting the available results. The complexity of this field renders the synthesis of results across studies difficult and will continue to challenge researchers.

One option to generate more clarity to the pattern of FER results in ASD might be subgroup analyses. While attempts have been made to determine subtypes of ASD (Beglinger & Smith, 2001; Georgiades et al., 2013; Ousley & Cermak, 2015), the phenotype of ASD remains heterogeneous (Georgiades et al., 2013) changing across the developmental trajectory and in response to intervention or treatment. Comparison of different samples and different individuals with ASD may not provide an accurate representation of FER in ASD. Falck-Ytter et al. (2010) found differences in the way in which social impairment and communication impairment scores on the ADI-R correlated with gaze behaviour, possibly providing some evidence to suggest that the individual profiles of individuals with ASD may inform the gaze behaviour elicited by FER. Future research may take into account the individual developmental profile of ASD participants and conduct longitudinal studies to determine how the attentional and neurological processes involved in FER may develop across the lifespan.

In addition to the variable diagnosis of ASD itself, ASD often presents with co-occurring diagnoses (Joshi et al., 2010). Social anxiety and ASD can present with similar symptomology, particularly in high functioning individuals (Tyson & Cruess, 2012) and anxiety may present with atypical gaze to faces (Daly, 1978; Wang et al., 2012). Approximately 30 percent of the ASD population have an ADHD diagnosis (Simonoff et al., 2008). Behavioural studies have shown that ASD with comorbid ADHD results in reduced recognition of facial emotion (Sinzig, Morsch, & Lehmkuhl, 2008). A recent study suggests that variability in FER performance may be explained in part by the attentional distractibility profile of the individuals with ASD (Berggren et al., 2016). To date, few studies have accounted for comorbid diagnoses when examining FER performance in ASD. Subsequently, it is difficult to conclude if FER impairment is resultant of ASD itself, or can be explained by co-occurring conditions, such as social anxiety or ADHD. Future research may be able to extricate to what extent atypical gaze and brain activity are due to co-occurring diagnoses or cognitive profiles.

A number of outcome related questions arose from this review. Firstly, the P100 and N170 were the most commonly explored ERPs in both child and adult studies with the majority of studies reporting both slower latencies and smaller amplitudes of the N170 in ASD populations. The P100 and N170 represent both the early processing of visual information and the intermediate stages whereby configural and emotional encoding of faces occurs (Zhu et al., 2015). There was limited research investigating later components including N300 (Dawson et al., 2004), N400 (Tseng et al., 2015), P400 (Key et al., 2015), N250 and Late Stage Positive Potential (LPP). As these later occurring components are reflective of more cognitive processing (Sur & Sinha, 2009), future research may benefit from examining these later components in ASD to determine the extent and nature of the emotion processing differences.

Secondly, while the EEG and ET studies in isolation provide valuable insights into the neurophysiological and attentional processes underlying emotional face processing in ASD only one study examined them together (Wagner et al., 2013). However, this study only examined the two measures in parallel and did not integrate them. The integration of ET with other neuroimaging measures such as fMRI is more common, and contributes to advances in knowledge, such as the finding that the amygdala activity is moderated by fixations to the eyes (Dalton et al., 2005). EEG provides superior temporal resolution to fMRI, therefore combining EEG and ET may provide greater insights in to the very precise electrophysiological mechanisms which may be moderated by specific gaze behaviours.

The findings of this review also have potential clinical utility. ET patterns and specific electrocortical activity related to the processing of emotionally expressive faces may prove valuable as markers from both a diagnostic or predictive standpoint as well as a potential target for treatment. ET and EEG markers when used in combination may prove clinically significant as markers for diagnosing ASD, treatment outcome or predicting emotion recognition or social skills.

These EEG and ET markers may also lead to effective intervention methods in themselves. The findings that fixations to the eyes was associated with greater proficiency in FER in ASD populations may indicate that if these patterns are modified, proficiency in these tasks may improve. Biofeedback is an intervention which involves the training of the self-regulation of certain physiological processes with the aim of modifying behaviour. EEG and ET biofeedback has proved effective in increasing attention in children with ADHD and ASD, therefore, if biomarkers exist for FER, biofeedback may assist individuals with ASD to enhance their ability to detect and recognize facially expressed emotion (Bölte et al., 2015; Holtmann et al., 2011; Kouijzer, van Schie, Gerrits, Buitelaar, & de Moor, 2013).

8. Conclusion

The ET and EEG results summarized in this review suggest that the attentional and cognitive processing of emotional faces is atypical in ASD across the developmental trajectory. Atypicalities in eye gaze, while not conclusive, indicate altered visual attention to facial emotions in individuals with ASD. A clear developmental effect was evident in the ET findings, indicating altered gaze to the eyes during FER is more apparent in adult populations. Atypical activation of cortical areas associated with the processing of facially expressed emotion is supported by the findings of EEG studies reporting differences in the elicitation of ERPs across the developmental trajectory.

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References

Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology, 12*(2), 169-177. http://dx.doi.org/http://dx.doi.org/10.1016/S0959-4388(02)00301-X

Akechi, H., Senju, A., Kikuchi, Y., Tojo, Y., Osanai, H., & Hasegawa, T. (2010). The effect of gaze direction on the processing of facial expressions in children with autism spectrum disorder: an ERP study. *Neuropsychologia, 48*(10), 2841-2851. http://dx.doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2010.05.026

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®).* Washington: American Psychiatric Publishing.

American Psychiatric Association. (2010). *Diagnostic and Statistical Manual for Mental Disorders (DSM-IV-R).* Washington: American Psychiatric Publishing.

Bal, E., Harden, E., Lamb, D., Van Hecke, A., Denver, J., & Porges, S. (2010). Emotion recognition in children with autism spectrum disorders: Relations to eye gaze and autonomic state. *Journal of Autism and Developmental Disorders, 40*(3), 358-370. http://dx.doi.org/http://dx.doi.org/10.1007/s10803-009-0884-3

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: Evidence from very high functioning adults with autism or asperger syndrome. *Journal of Child Psychology & Psychiatry, 38*(7), 813-822.

Baron-Cohen, S., Leslie, A., & Frith, U. (1985). Does the autistic child have a "theory of mind". *Cognition, 21*(1), 47-46. http://dx.doi.org/http://dx.doi.org/10.1016/0010-0277(85)90022-8

Baron-Cohen, S., Ring, H., Bullmore, E., Wheelwright, S., Ahwin, C., & Williams, S. (2000). The amygdala theory of autism. *Neuroscience & Biobehavioral Reviews, 24*(3), 355-364. http://dx.doi.org/http://dx.doi.org/10.1016/S0149-7634(00)00011-7

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" Test Revised Version: A study with normal adults, and adults with asperger syndrome or high-functioning autism. *Journal of Child Psychology & Psychiatry, 42*(2), 241-251.

Barr, M., Radhu, N., Guglietti, C., Zomorrodi, R., Rajji, T., Ritvo, P., & Daskalakis, Z. (2014). Age-related differences in working memory evoked gamma oscillitations. *Brain Research, 1576*, 43-51. http://dx.doi.org/10.1016/j.brainres.2014.05.043

Barrera, M., & Maurer, D. (1981). The Perception of facial expressions by the three-month-old. *Child Development, 52*(1), 203-206. http://dx.doi.org/10.2307/1129231

Başar, E., Başar-Eroglu, C., Karakaş, S., & Schürmann, M. (2001). Gamma, alpha, delta and theta oscillitations govern cognitive processes *International Journal of Psychophysiology, 39*(2-3), 241-248. http://dx.doi.org/http://dx.doi.org/10.1016/S0167-8760(00)00145-8

Batty, M., Meaux, E., Wittemeyer, K., Roge, B., & Taylor, M. (2011). Early processing of emotional faces in children with autism: An event-related potential study. *Journal of Experimental Child Psychology, 109*(4), 430-444. http://dx.doi.org/http://dx.doi.org/10.1016/j.jecp.2011.02.001

Batty, M., & Taylor, M. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research, 17*, 613-620. http://dx.doi.org/10.1016 /S0926-6410(03)00174-5

Beglinger, L., & Smith, T. (2001). A review of subtyping in autism and proposed dimensional classification model. *Journal of Autism and Developmental Disorders, 31*(4) http://dx.doi.org/10.1023/A:1010616719877

Bekele, E., Crittendon, J., Zheng, Z., Swanson, A., Weitlauf, A., Warren, Z., & Sarkar, N. (2014). Assessing the utility of a virtual environment for enhancing facial affect recognition in adolescents with autism. *Journal of Autism and Developmental Disorders, 44*(7), 1641-1650. http://dx.doi.org/10.1007/s10803-014-2035-8

Bekele, E., Zheng, Z., Swanson, A., Crittendon, J., Warren, Z., & Sarkar, N. (2013). Understanding how adolescents with autism respond to facial expressions in virtual reality environments. *IEEE Transactions on Visualization and Computer Graphics, 19*(4), 711-720. http://dx.doi.org/10.1109/TVCG.2013.42

Berggren, S., Engström, A., & Bölte, S. (2016). Facial affect recognition in autism, ADHD and typical development. *Cognitive Neuropsychiatry, 21*(3), 213-227. http://dx.doi.org/10.1080/13546805.2016.1171205

Blau, V., Maurer, U., Tottenham, N., & McCandliss, B. (2007). The face-specific N170 component is modulated by emotional facial expression. *Behavioural and Brain Functions, 3*(7), 1-13. http://dx.doi.org/10.1186/1744-9081-3-7

Bölte, S., Ciaramidaro, A., Schlitt, S., Hainz, D., Kliemann, D., Beyer, A., . . . Walter, H. (2015). Training-induced plasticity of the social brain in autism spectrum disorder. *The British Journal of Psychiatry, 207*(2), 149-157. http://dx.doi.org/10.1192/bjp.bp.113.143784

Bölte, S., & Poustka, F. (2003). The recognition of facial affect in autistic and schizophrenic subjects and their first-degree relatives. *Psychological Medicine, 33*(5), 907-915.

Boraston, Z., Corden, B., Miles, L., Skuse, D., & Blakemore, S. (2008). Brief report: Perception of genuine and posed smiles by individuals with autism. *Journal of Autism and Developmental Disorders, 38*(3), 574-580. http://dx.doi.org/10.1007/s10803-007-0421-1

Castelli, F. (2005). Understanding emotions from standardized facial expressions in autism and normal development. *Autism, 9*(4), 428-449. http://dx.doi.org/10.1177/1362361305056082

Cooper, N., Simpson, A., Till, A., Simmons, K., & Puzzo, I. (2013). Beta event-related desynchronization as an index of individual differences in processing human facial expression: Further investigations of autistic traits in typically developing adults. *Frontiers in Human Neuroscience, 7*, 1-8. http://dx.doi.org/10.3389/fnhum.2013.00159

Corden, B., Chilvers, R., & Skuse, D. (2008). Avoidance of emotionally arousing stimuli predicts social-perceptual impairment in asperger's syndrome. *Neuropsychologia, 46*(1), 137-147. http://dx.doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2007.08.005

Crawford, H., Moss, J., Anderson, G., Oliver, C., & McCleery, J. (2015). Implicit discrimination of basic facial expressions of positive/negative emotion in fragile X syndrome and autism spectrum disorder. *American Journal on Intellectual and Developmental Disabilities, 120*(4), 328-345. http://dx.doi.org/10.1352/1944-7558-120.4.328

Dalton, K., Holsen, L., Abbeduto, L., & Davidson, R. (2008). Brain function and gaze fixation during facial-emotion processing in fragile X and autism. *Autism research : official journal of the International Society for Autism Research, 1*(4), 231-239. http://dx.doi.org/10.1002/aur.32

Dalton, K., Nacewicz, B., Johnstone, T., Schaefer, H. S., Gernsbacher, M., Goldsmith, H., . . . Davidson, R. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience, 8*(4), 519-526. http://dx.doi.org/10.1038/nn1421

Daly, S. (1978). Behavioural correlates of social anxiety. *British Journal of Social and Clinical Psychology, 17*(2), 117-120. http://dx.doi.org/10.1111/j.2044-8260.1978.tb00252.x

Darwin, C. (1872). *The Expression of the Emotions in Man and Animals*. London: John Murray.

Dawson, G., Webb, S., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with Autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*(3), 340-359. http://dx.doi.org/http://dx.doi.org/10.1111/j.1467-7687.2004.00352.x

de Haan, M., Johnson, M., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: a review. *International Journal of Psychophysiology, 51*(1), 45-58.

de Jong, M., van Engeland, H., & Kemner, C. (2008). Attentional effects of gaze shifts are influenced by emotion and spatial frequency, but not in Autism. *Journal of the American Academy of Child & Adolescent Psychiatry, 47*(4), 443-454. http://dx.doi.org/http://dx.doi.org/10.1097/CHI.0b013e31816429a6

de Wit, T. C., Falck-Ytter, T., & von Hofsten, C. (2008). Young Children with Autism Spectrum Disorder Look Differently at Positive versus Negative Emotional Faces. *Research in Autism Spectrum Disorders, 2*(4), 651-659.

Eimer, M. (2011). The Face-sensitivity of the N170 component. *Frontiers in Human Neuroscience, 5*, 119. http://dx.doi.org/10.3389/fnhum.2011.00119

Eimer, M. (2000). The face-specific N170 ERP component reflects late stages in the structural encoding of faces. *Neuroreport, 11*(10), 2319-2324.

Eimer, M., Gosling, A., Nicholas, S., & Kiss, M. (2011). The N170 component and its links to configural face processing: A rapid neural adaptation study. *Brain Research, 1376*, 76-87. http://dx.doi.org/http://dx.doi.org/10.1016/j.brainres.2010.12.046

Eisenbarth, H., & Georg, A. (2011). Happy mouth and sad eyes: Scanning emotional facial expressions. *Emotion, 11*(4) http://dx.doi.org/10.1037/a0022758860

Ekman, P. (1992). An argument for basic emotions. *Cogntion and Emotion, 6*(3-4), 169-200. http://dx.doi.org/http://dx.doi.org/10.1080/02699939208411068

Ekman, P., & Friesen, W. (1978). *The Facial Action Coding System (FACS): A technique for the measurement of facial action*. Palo Alto, CA: Consulting Psychologists Press.

Ekman, P., & Oster, H. (1979). Facial Expressions of Emotion. *Annual Review of Psychology, 30*, 527-554.

Enticott, P., Johnston, P., Herring, S., Hoy, K., & Fitzgerald, P. (2008). Mirror neuron activation is associated with facial emotion processing. *Neuropsychologia, 46*(11), 2851-2854. http://dx.doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2008.04.022

Evers, K., Kerkhof, I., Steyaert, J., Noens, I., & Wagermans, J. (2014). No differences in emotion recognition strategies in children with Autism Spectrum Disorder: Evidence from hybrid faces. *Autism Research and Treatment,* http://dx.doi.org/10.1155/2014/345878

Falck-Ytter, T., Fernell, E., Gillberg, C., & von Hofsten, C. (2010). Face scanning distinguishes social from communication impairments in autism. *Developmental Science, 13*(6), 864-875. http://dx.doi.org/10.1111/j.1467-7687.2009.00942.x

Falkmer, M., Bjallmark, A., Larsson, M., & Falkmer, T. (2011). Recognition of facially expressed emotions and visual search strategies in adults with Asperger syndrome. *Research in Autism Spectrum Disorders, 5*(1), 210-217.

Farrugia, S., & Hudson, J. (2006). Anxiety in adolescents with Asperger syndrome: Negative thoughts, behavioral problems, and life interference. *Focus on Autism and other Developmental Disabilities, 21*, 25-35.

Fridenson-Hayo, S., Berggren, S., Lassalle, A., Tal, S., Pigat, D., Bolte, S., . . . Golan, O. (2016). Basic and complex emotion recognition in children with autism: Cross cultural findings. *Molecular Biology, 7*(52) http://dx.doi.org/10.1186/s13229-016-0113-9

Fujita, T., Kamio, Y., Yamasaki, T., Yasumoto, S., Hirose, S., & Tobimatsu, S. (2013). Altered automatic face processing in individuals with Hig Functioning Autism Spectrum Disorders: Evidence from visual evoked potentials. *Research in Autism Spectrum Disorders, 7*(6), 710-720. http://dx.doi.org/10.1016/j.rasd.2013.03.001

Gallese, V. (2007). Before and below theory of mind: embodied simulation and the neural correlates of social cognition. *Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences, 362*, 659-669. http://dx.doi.org/http://dx.doi.org/10.1098/rstb.2006.2002

Gayle, L., Gal, D., & Kieffaber, P. (2012). Measuring affective reactivity in individuals with autism spectrum personality traits using the visual mismatch negativity event-related brain potential. *Frontiers in human neuroscience, 6*, 334. http://dx.doi.org/http://dx.doi.org/10.3389/fnhum.2012.00334

Georgiades, S., Szatmari, P., Boyle, M., Hanna, S., Duku, E., Zwaigenbaum, L., . . . Pathways in ASD Study Team. (2013). Investigating phenotypic heterogeneity in children with autism spectrum disorder: A factor mixture modeling approach. *The Journal of Child Psychology and Psychiatry, 54*(2), 2016-2215. http://dx.doi.org/10.1111/j.1469-7610.2012.02588.x

Gross, E., El-Baz, A., Sokhadze, G., Sears, L., Casanova, M., & Sokhadze, E. (2012). Induced EEG Gamma Oscillation Alignment Improves Differentiation Between Autism and ADHD Group Responses in a Facial Categorization Task. *Journal of Neurotherapy, 16*(2), 78-91. http://dx.doi.org/10.1080/10874208.2012.677631

Halit, H., Csibra, G., Volein, A., & Johnson, M. (2004). Face-sensitive cortical processing in early infancy. *Journal of Child Psychology & Psychiatry, 45*(7), 1228-1234. http://dx.doi.org/10.1111/j.1469-7610.2004.00321.x

Han, B., Tijus, C., Le Barillier, F., & Nadel, J. (2015). Morphing technique reveals intact perception of object motion and disturbed perception of emotional expressions by low-functioning adolescents with Autism Spectrum Disorder. *Research in Developmental Disabilities, 47*, 393-404.

Hanley, M., McPhillips, M., Mulhern, G., & Riby, D. (2012). Spontaneous attention to faces in Asperger Syndrome using ecologically valid static stimuli. *Autism, 17*(6), 754-761. http://dx.doi.org/10.1177/1362361312456746

Harms, M. B., Martin, A., & Wallace, G. L. (2010). Facial emotion recognition in autism spectrum disorders: A review of behavioral and neuroimaging studies. *Neuropsychology Review, 20*(3), 290-322. http://dx.doi.org/http://dx.doi.org/10.1007/s11065-010-9138-6

Herba, C., & Phillips, M. (2004). Annotation: Development of facial expression recognition from childhood to adolescence: behavioural and neurological perspectives. *Journal of Child Psychology and Psychiatry, 45*(7), 1185-1198. http://dx.doi.org/10.1111/j.1469-7610.2004.00316.x

Hernandez, N., Metzger, A., Magné, R., Bonnet-Brilhault, F., Roux, S., Barthelemy, C., & Martineau, J. (2009). Exploration of core features of a human face by healthy and autistic adults analyzed by visual scanning. *Neuropsychologia, 47*(4), 1004-1012. http://dx.doi.org/10.1016/j.neuropsychologia.2008.10.023

Hickok, G. (2009). Eight problems for the mirror neuron theory of action understanding in monkeys and humans. *Journal of Cognitive Neuroscience, 21*(7), 1229-1243. http://dx.doi.org/10.1162/jocn.2009.21189

Higgins, J., & Green, S. (2011). Cochrane handbook for systematic reviews of interventions.doi http://handbook.cochrane.org

Holtmann, M., Stiener, S., Hohmann, S., Poustka, L., Banaschewski, T., & Bolte, S. (2011). Neurofeedback in autism spectrum disorders. *Developmental Medicine & Child Neurology, 53*(11), 986-993.

Johnson, L., & Oatley, K. (1989). The language of emotions: An analysis of a semantic field. *Cognition and Emotion, 3*(2), 81-123. http://dx.doi.org/http://dx.doi.org/10.1080/02699938908408075

Joshi, G., Petty, C., Wozniak, J., Henin, A., Fried, R., Galdo, M., . . . Biederman, J. (2010). The heavy burden of psychaitric comorbidity in youth with autism spectrum disorders: A large comparative study of a psychiatrically referred population. *Journal of Autism and Developmental Disorders, 40*(11), 1361-1370. http://dx.doi.org/10.1007/s10803-010-0996-9

Kanwisher, N., McDermott, J., & Chun, M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience, 17*(11), 4302-4311.

Key, A., Ibanez, L., Henderson, H., Warren, Z., Messinger, D., & Stone, W. (2015). Positive affect processing and joint attention in infants at high risk for Autism: An exploratory study. *Journal of Autism & Developmental Disorders, 45*(12), 4051-4062 4012p. http://dx.doi.org/10.1007/s10803-014-2191-x

Kirchner, J. C., Hatri, A., Heekeren, H. R., & Dziobek, I. (2011). Autistic symptomatology, face processing abilities, and eye fixation patterns. *Journal of Autism and Developmental Disorders, 41*(2), 158-167.

Kliemann, Dziobek, Hatri, Baudewig, & Heekeren. (2012). The role of the amygdala in atypical gaze on emotional faces in autism spectrum disorders. *Journal of Neuroscience, 32*(28), 9469-9476.

Kliemann, Dziobek, Hatri, Steimke, & Heekeren. (2010). Atypical reflexive gaze patterns on emotional faces in autism spectrum disorders. *The Journal of Neuroscience, 30*(37), 12281-12287. http://dx.doi.org/http://dx.doi.org/10.1523/JNEUROSCI.0688-10.2010

Klimesch, W. (1999). EEG alpha and theta oscillitations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews, 29*, 169-195.

Klimesch, W., Doppelmayr, H., Russegger, H., Pachinger, T., & Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience Letters, 244*, 73-76.

Kmet, L., Lee, R., & Cook, L. (2004). Standard quality assessment criteria for evaluating primary research papers from a variety of fields. (Alberta Heritage Foundation for Medical Research).

Kouijzer, M. E. J., van Schie, H. T., Gerrits, B. J. L., Buitelaar, J. K., & de Moor, J. M. H. (2013). Is EEG biofeedback an effective treatment in autism spectrum disorders? A randomized controlled trial. *Applied Psychophysiology Biofeedback, 38*(1), 17-28.

Kuuskikko, S., Haapsano, H., Jansson-Verkasalo, E., Hurtig, T., Mattila, M., Ebeling, H., . . . Moilanen, I. (2009). Emotion recognition in children and adolesents with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders,* http://dx.doi.org/10.1007/s10803-009-0700-0

Langton, S., Watt, R., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences, 4*, 50-59.

Lassalle, A., & Itier, R. (2015). Autistic traits influence gaze-oriented attention to happy but not fearful faces. *Social Neuroscience, 10*(1), 70-88.

Leppänen, J., Moulson, M., Vogel-Farley, V., & Nelson, C. (2007). An ERP study of emotional face processing in the adult and infant brain. *Child Development, 78*(1), 232-245. http://dx.doi.org/10.1111/j.1467-8624.2007.00994.x

Lerner, M., McPartland, J., & Morris, J. (2013). Multimodal emotion processing in Autism Spectrum Disorders: An event-related potential study. *Developmental Cognitive Neuroscience, 3*(1), 11-21. http://dx.doi.org/http://dx.doi.org/10.1016/j.dcn.2012.08.005

Leung, D., Ordqvist, A., Falkmer, T., Parsons, R., & Falkmer, M. (2013). Facial emotion recognition and visual search strategies of children with High Functioning Autism and Asperger syndrome. *Research in Autism Spectrum Disorders, 7*(7), 833-844.

Liu, T., Pinheiro, A., Zhao, Z., Nestor, P. G., McCarley, R. W., & Niznikiewicz, M. A. (2012). Emotional Cues during Simultaneous Face and Voice Processing: Electrophysiological Insights. *PLoS One, 7*(2) http://dx.doi.org/http://dx.doi.org/10.1371/journal.pone.0031001

Lozier, L. M., Vanmeter, J. W., & Marsh, A. A. (2014). Impairments in facial affect recognition associated with autism spectrum disorders: A meta-analysis. *Development and Psychopathology, 26*(4), 933-945. http://dx.doi.org/http://dx.doi.org/10.1017/S0954579414000479

Maddox, B., & White, S. (2015). Comorbid social anxiety disorder in autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(12), 3949-3960. http://dx.doi.org/10.1007/s10803-015-2531-5

Magnée, M., de Gelder, B., van Engeland, H., & Kemner, C. (2011). Multisensory integration and attention in Autism Spectrum disorder: Evidence from event-related potentials. *PLoS ONE, 6*(8) http://dx.doi.org/10.1371/journal.pone.0024196

Magnée, M., de Gelder, B., van Engeland, H., & Kemner, C. (2008). Atypical processing of fearful face-voice pairs in Pervasive Developmental Disorder: An ERP study. *Clinical Neurophysiology, 119*(9), 2004-2010. http://dx.doi.org/10.1016/j.clinph.2008.05.005

Magnun. (1995). Neural mechanisms of visual selective attention. *Psychophysiology, 32*, 4-18.

McCabe, K. L., Melville, J. L., Rich, D., Strutt, P. A., Cooper, G., Loughland, C. M., . . . Campbell, L. E. (2013). Divergent patterns of social cognition performance in autism and 22q11.2 deletion syndrome (22q11DS). *Journal of Autism and Developmental Disorders, 43*(8), 1926-1934. http://dx.doi.org/10.1007/s10803-012-1742-2

Meeran, H., van Heijnsbergen, J., & Gelder, B. (2005). Rapid perceptual integration of facial expression and body language. *Proceeedings of the National Academy of Science of the United States of America, 102*(45), 16518-16523. http://dx.doi.org/10.1073/pnas.0507650102

Messinger, D., Mattson, W., Mahoor, M., & Cohn, J. (2012). The eyes have it: making positive expressions more positive and negative expressions more negative. *Emotion, 12*(3), 430-436. http://dx.doi.org/10.1037/a0026498

Moher, D., Liberati, A., Tetzlaff, J., Altman, D., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. *PLoS Medicine, 6*(7), 1-6.

Mondloch, C. J., Geldart, S., Maurer, D., & Grand, R. L. (2003). Developmental changes in face processing skills. *Journal of Experimental Child Psychology, 86*(1), 67-84. http://dx.doi.org/http://dx.doi.org/10.1016/S0022-0965(03)00102-4

Neumann, D., Spezio, M., Piven, J., & Adolphs, R. (2006). Looking you in the mouth: abnormal gaze in autism resulting from impaired top-down modulation of visual attention. *Social Cognitive and Affective Neuroscience, 1*(3), 194-202.

Nuske, H., Vivanti, G., & Dissanayake, C. (2013). Are emotion impairments unique to, universal, or specific in autism spectrum disorder? A comprehensive review. *Cognition and Emotion, 27*(6), 1042-1061. http://dx.doi.org/http://dx.doi.org/10.1080/02699931.2012.762900

Nuske, H., Vivanti, J., & Dissanayake, C. (2014). Reactivity to fearful expressions of familiar and unfamiliar people in children with autism: An eye-tracking pupillometry study. *Journal of Neurodevelopmental Disorders, 6* (1)

Nuske, H., Vivanti, J., Hudry, K., & Dissanayake, C. (2014). Pupillometry reveals reduced unconscious emotional reactivity in autism. *Biological Psychology, 101*(1), 24-35.

O'Connor, K., Hamm, J., & Kirk, I. (2007). Neurophysiological responses to face, facial regions and objects in adults with Asperger's Syndrome: An ERP investigation. *International Journal of Psychophysiology, 63*(3), 283-293. http://dx.doi.org/10.1016/j.ijpsycho.2006.12.001

O'Connor, K., Hamm, J., & Kirk, I. (2005). The neurophysiological correlates of face processing in adults and children with Asperger's syndrome. *Brain and Cognition, 59*(1), 82-95. http://dx.doi.org/10.1016/j.bandc.2005.05.004

Ousley, O., & Cermak, T. (2015). Autism spectrum disorder: defining dimensions and subgroups. *Current Developmental Disorder Report, 1*(1), 20-28. http://dx.doi.org/10.1007/s40474-013-0003-1

Pelphrey, K., Sasson, N., Reznick, J., Paul, G., Goldman, B., & Piven, J. (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders, 32*(4), 249-261. http://dx.doi.org/10.1023/A:1016374617369

Pineda, J. (2005). The functional significant of mu rhythms: Translating "seeing" and "hearing" into "doing". *Brain Research Reviews, 50*, 57-68.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372-422.

Richardson, M., Strange, B., & Dolan, R. (2004). Encoding of emotional memories depends on the amygdala and hippocampus and their interactions. *Nature Neuroscience, 7*(3), 278-285. http://dx.doi.org/10.1038/nn1190

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*, 169-192. http://dx.doi.org/10.1146/annurev.neuro.27.070203.144230

Rodger, H., Vizioli, L., Ouyang, X., & Caldara, R. (2015). Mapping the development of facial expression recognition. *Developmental Science, 18*(6), 926-939. http://dx.doi.org/10.1111/desc.12281

Rudrauf, D., David, O., Lachaux, J., Kovach, C., Martinerie, J., Renault, B., & Damasio, A. (2008). Rapid interactions between ventral visual stream and emotion-related structures rely on a two-pathway architecture. *Journal of neuroscience, 11*, 2793-2803. http://dx.doi.org/https://doi.org/10.1523/JNEUROSCI.3476-07.2008

Rutherford, M., & Towns, A. (2008). Scan path differences and similarities during emotion perception in those with and without autism spectrum disorders. *Journal of Autism and Developmental Disorders, 38*(7), 1371-1381. http://dx.doi.org/http://dx.doi.org/10.1007/s10803-007-0525-7

Rutherford, M., Troubridge, E., & Walsh, J. (2012). Visual afterimages of emotional faces in high functioning autism. *Journal of Autism and Developmental Disorders, 42*(2), 221-229. http://dx.doi.org/10.1007/s10803-011-1233-x

Santos, A., Mier, D., Kirsch, P., & Meyer-Lindenberg, A. (2011). Evidence for a gernal face salience signal in human amygdala. *Neuroimage, 54*, 3111-3116. http://dx.doi.org/10.1016/j.neuroimage.2010.11.024

Sasson, N., Tsuchiya, N., Hurley, R., Couture, S., Penn, D., Adolphs, R., & Piven, J. (2007). Orienting to social stimuli differentiates social cognitive impairment in autism and schizophrenia. *Neuropsychologia, 45*(11), 2580-2588. http://dx.doi.org/10.1016/j.neuropsychologia.2007.03.009

Sauseng, P., & Klimsesch, W. (2008). What does phase information of oscillatory brain activity tell us about cognitive processes. *Neuroscience & Biobehavioral Reviews, 32*(5), 1001-1013. http://dx.doi.org/http://dx.doi.org/10.1016/j.neubiorev.2008.03.014

Sawyer, A., Williamson, P., & Young, R. (2012). Can gaze avoidance explain why individuals with asperger's syndrome can't recognise emotions from facial expressions? *Journal of Autism and Developmental Disorders, 42*(4), 606-618. http://dx.doi.org/http://dx.doi.org/10.1007/s10803-011-1283-0

Scheuer, M. (2002). Continuous EEG monitoring in the intensive care unit. *Epilepsia, 43*(s3), 114-127. http://dx.doi.org/10.1046/j.1528-1157.43.s.3.7.x

Schulte-Rüther, M., Markowitsch, H., Fink, G., & Piefke, M. (2007). Mirror Neuron and Theory of Mind Mechanisms Involved in Face-to-Face Interactions: A Functional Magnetic Resonance Imaging Approach to Empathy. *Journal of Cognitive Neuroscience, 19*(8), 1354-1372. http://dx.doi.org/10.1162/jocn.2007.19.8.1354

Schutter, D., & Knyazev, G. (2012). Cross-frequency coupling of brain oscillitations in studying motivation and emotion. *Motivation and Emotion, 36*(1), 46-54. http://dx.doi.org/10.1007/s11031-011-9237-6

Schyns, P., Jentzsch, I., Johnson, M., Schweinberger, S., & Gosselin, F. (2003). A principled method for determining the functionality of brain responses. *NeuroReport: For Rapid Communication of Neuroscience Research, 14*(13), 1665-1669. http://dx.doi.org/http://dx.doi.org/10.1097/00001756-200309150-00002

Senju, A., & Johnson, M. (2009). Atypical eye contact in autism: Models, mechanisms and development. *Neuroscience & Biobehavioral Reviews 33*(8), 1204-1214. http://dx.doi.org/10.1016/j.neubiorev.2009.06.001

Simonoff, E., Pickles, A., Charman, T., Chandler, S., Loucas, T., & Baird, G. (2008). Psychiatric disorders in children with autism spectrum disorders: Prevelance, comorbidity, and associated factors in a population-derived sample. *Journal of the American Academy of Child & Adolescent Psychiatry, 47*(8), 921-929. http://dx.doi.org/10.1097/CHI.0b013e318179964f

Sinzig, J., Morsch, D., & Lehmkuhl, G. (2008). Do hyperactivity, impulsivity and inattention have an impact on the ability of facial affect recognition in children with autism and ADHD? *European Child and Adolescent Psychiatry, 17*, 63-72. http://dx.doi.org/10.1007/s00787-007-0637-9

Somerville, L., Farni, N., & McClure, T., Erin. (2011). Behaviouaral and neural representation of emotional facial expressions across the lifespan. *Developmental Neuropsychology, 36*(4), 408-428. http://dx.doi.org/10.1080/87565641.2010.549865

Spezio, M., Adolphs, R., Hurley, R., & Piven, J. (2007a). Abnormal use of facial information in high-functioning autism. *Journal of Autism and Developmental Disorders, 37*(5), 929-939. http://dx.doi.org/http://dx.doi.org/10.1007/s10803-006-0232-9

Spezio, M., Adolphs, R., Hurley, R., & Piven, J. (2007b). Analysis of face gaze in autism using "Bubbles". *Neuropsychologia, 45*(1), 144-151. http://dx.doi.org/10.1016/j.neuropsychologia.2006.04.027

Streit, M., Wölwer, W., Brinkmeyer, J., Ihl, R., & Gaebel, W. (2001). EEG-correlates of facial affect recognition and categorisation of blurred faces in schizophrenic patients and healthy volunteers. *Schizophrenia Research, 49*(1-2), 145-155.

Sur, S., & Sinha, V. (2009). Event-related potential: An overview. *Industrial Psychiatry Journal, 18*(1), 70-73. http://dx.doi.org/10.4103/0972-6748.57865

Tanaka, J., & Sung, A. (2016). The "Eye Avoidance" hypothesis of autism face processing. *Journal of Autism and Developmental Disorders, 46*(5), 1538-1552. http://dx.doi.org/10.1007/s10803-013-1976-7

Tang, J., Falkmer, M., Horlin, C., Tan, T., Vaz, S., & Falkmer, T. (2015). Face recognition and visual search strategies in autism spectrum disorders: Amending and extending a recent review by Weigelt et al. *PLoS One, 10*(8), 1-19. http://dx.doi.org/http://dx.doi.org/10.1371/journal.pone.0134439

Thomas, L., Bellis, D., Graham, R., & LaBar, K. (2007). Development of emotional facial recognition in late childhood and adolescence. *Developmental Science, 10*, 547-558. http://dx.doi.org/10.1111/j.1467-7687.2007.00614.x

Tonks, J., Williams, W., Frampton, I., Yates, P., & Slater, A. (2006). Assessing emotion recognition in 9-15-years olds: Preliminary analysis of abilities in reading emotion from faces, voices and eyes. *Brain Injury, 27*(6), 623-629. http://dx.doi.org/http://dx.doi.org/10.1080/02699050701426865

Tottenham, N., Hertzig, M., Gillespie-Lynch, K., Gilhooly, T., Millner, A., & Casey, B. (2014). Elevated amygdala response to faces and gaze aversion in autism spectrum disorder. *Social Cognitive and Affective Neuroscience, 9*(1), 106-117. http://dx.doi.org/10.1093/scan/nst050

Tracy, J., Robins, R., Schriber, R., & Solomon, M. (2011). Is emotion recognition impaired in individuals with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 41*(1), 102-109. http://dx.doi.org/10.1009/s/10803-010-1030-y

Tseng, Y., Yang, H., Savostyanov, A., Chien, V., & Liou, M. (2015). Voluntary attention in asperger's syndrome: Brain electrical oscillation and phase-synchronization during facial emotion recognition. *Research in Autism Spectrum Disorders, 13-14*, 32-51. http://dx.doi.org/http://dx.doi.org/10.1016/j.rasd.2015.01.003

Tye, C., Battaglia, M., Bertoletti, E., Ashwood, K., Azadi, B., Asherson, P., . . . McLoughlin, G. (2014). Altered neurophysiological responses to emotional faces discriminate children with ASD, ADHD and ASD+ADHD. *Biological Psychology, 103*, 125-134. http://dx.doi.org/http://dx.doi.org/10.1016/j.biopsycho.2014.08.013

Tyson, K., & Cruess, D. (2012). Differentiating high-functioning autism and social phobia. *Journal of Autism and Developmental Disorders, 42*(7), 1477-1490. http://dx.doi.org/10.1007/s10803-011-1386-7

Uljarevic, M., & Hamilton, A. (2013). Recognition of emotions in autism: A Formal meta-Analysis. *Journal of Autism and Developmental Disorders, 43*(7), 1517-1526. http://dx.doi.org/http://dx.doi.org/10.1007/s10803-012-1695-5

Van der Geest, J., Kemner, C., Verbaten, M., & Van Engeland, H. (2002). Gaze behavior of children with pervasive developmental disorder toward human faces: A fixation time study. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 43*(5), 669-678. http://dx.doi.org/10.1111/1469-7610.00055

Vlamings, P., Jonkman, L., van Daalen, E., van der Gaag, R., & Kemner, C. (2010). Basic abnormalities in visual processing affect face processing at an early age in autism spectrum disorder. *Biological Psychiatry, 68*(12), 1107-1113. http://dx.doi.org/http://dx.doi.org/10.1016/j.biopsych.2010.06.024

Wagner, J., Hirsch, S., Vogel-Farley, V., Redcay, E., & Nelson, C. (2013). Eye-tracking, autonomic, and electrophysiological correlates of emotional face processing in adolescents with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 43*(1), 188-199. http://dx.doi.org/10.1007/s10803-012-1565-1.

Wang, Q., Hu, C., Short, L., & Fu, G. (2012). The influence of shyness on the scanning of own- and other-race faces in adults. *PLoS ONE, 7*(12), 1-8. http://dx.doi.org/10.1371/journal.pone.0052203

Ward, L. (2003). Sychronous neural oscillitations and cognitive processes. *Trends in Cognitive Sciences, 7*(12) http://dx.doi.org/10.1016/j.tics.2003.10.012

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioural studies. *Neuroscience & Biobehavioral Reviews, 36*(3), 1060-1084. http://dx.doi.org/10.1016/j.neubiorev.2011.12.008

White, S., Maddox, B., & Panneton, R. (2015). Fear of negative evaluation influences eye gaze in adolescents with autism spectrum disorder: A pilot study. *Journal of Autism & Developmental Disorders, 45*(11), 3446-3457 http://dx.doi.org/10.1007/s10803-014-2349-6

Williams, J., Whiten, A., Suddendorf, T., & Perrett, D. (2001). Imitation, mirror neurons and autism. *Neuroscience and Biobehavioural Reviews, 25*(4), 287-295.

Wong, T., Fung, P., Chua, S., & McAlonan, G. (2008). Abnormal spatiotemporal processing of emotional facial expressions in childhood autism: Dipole source analysis of event-related potentials. *European Journal of Neuroscience, 28*(2), 407-416. http://dx.doi.org/http://dx.doi.org/10.1111/j.1460-9568.2008.06328.x

Yang, H., Savostyanov, A., Tsai, A., & Liou, M. (2011). Face recognition in asperger syndrome: A study on EEG spectral power changes. *Neuroscience Letters, 492*(2), 84-88. http://dx.doi.org/http://dx.doi.org/10.1016/j.neulet.2011.01.061

Yeung, M., Han, Y., Sze, S., & Chan, A. (2014). Altered right frontal cortical connectivity during facial emotion recognition in children with autism spectrum disorders. *Research in Autism Spectrum Disorders, 8*(11), 1567-1577. http://dx.doi.org/http://dx.doi.org/10.1016/j.rasd.2014.08.013

Zhu, C., He, W., Qi, Z., Wang, L., Song, D., Zhan, L., . . . Luo, W. (2015). The time course of emotional picture processing: An event-related potential study using a rapid serial visual presentation paradigm. *Frontiers in Psychology, 6*(954) http://dx.doi.org/10.3389/fpsyg.2015.00954

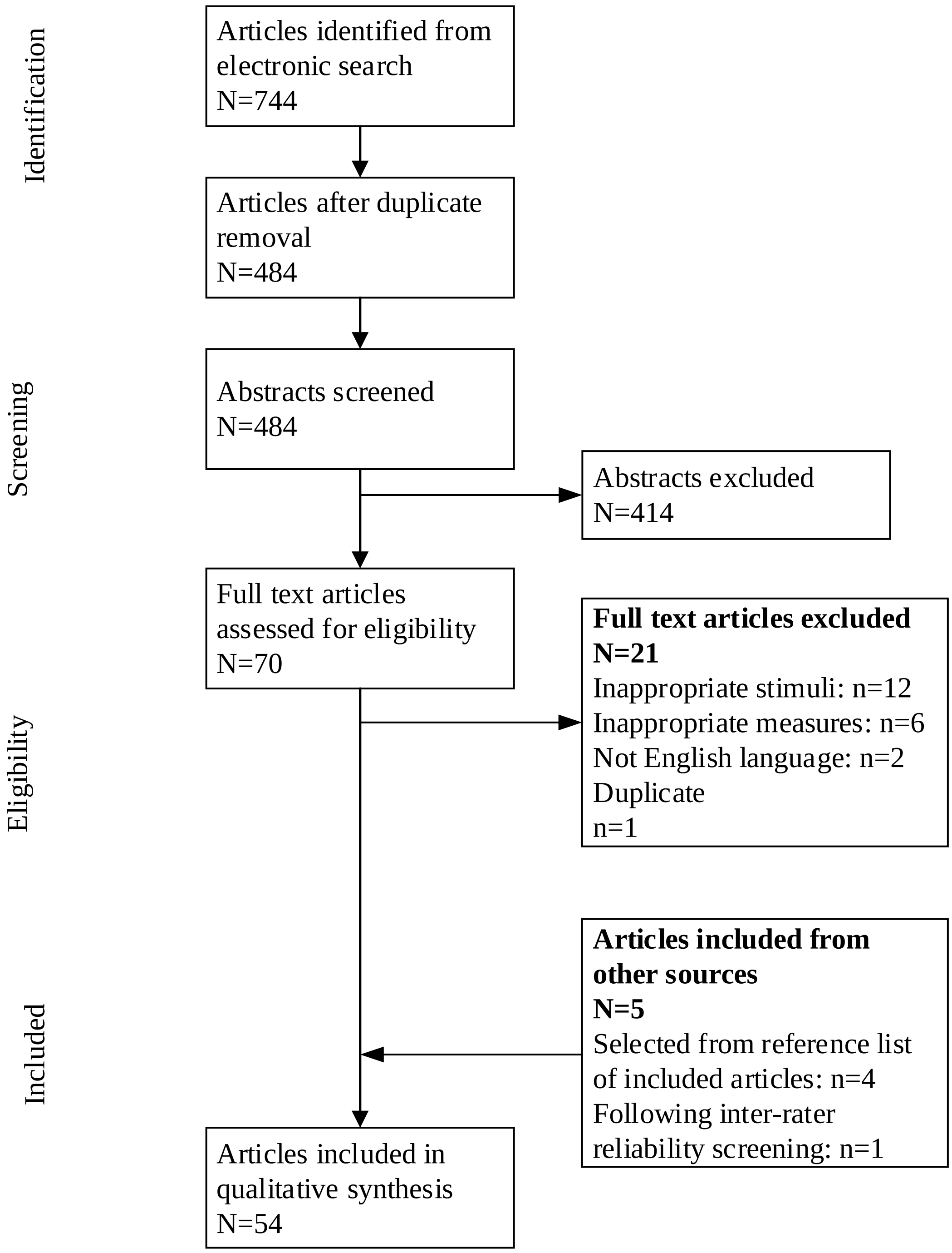

Figure 1. Flow chart demonstrating method of study identification and screening.

Table 1. Child Eye tracking and Electrophysiological studies

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagno sis	N	Mean age (SD)						
Eye Tracking												
Nuske, Vivanti, Hudry, Dissanayake , 2014	Autism, ASD	19	3.97 (1.06)	TD	19	4.20 (0.80)	CA	Implicit	**Static,** photographs 30ms, 300ms and 2s exposure times.	Fear, Neutral	ASD fixation time on fear face for 30ms and 2sec condition < TD. ASD fixation time on eyes of fearful faces < TD. ASD fixation time to neutral face in 2sec condition < TD. ASD fixation time on eyes and mouth < TD for neutral faces. Fixation time not correlated with ASD symptomology.	**92% (22/24).** Participants matched on CA. Correlations with IQ explored. Stimuli counterbalanced .
Nuske, Vivanti, Dissanayake, 2014	Autism, ASD	21	3.98 (1.05)	TD	21	4.27 (0.60)	CA	Implicit	**Dynamic,** videos of familiar and unfamiliar faces expressing emotion.4 second neutral followed by 4 second fearful expression exposure time.	Fear, Neutral	ASD # of fixations on fear = TD. ASD # of fixations on neutral < TD. ASD # of fixations on fear > neutral.TD # of fixations on fear = neutral. ASD fixation time on eyes and mouth of neutral familiar and unfamiliar faces < TD.	**87% (21/24).** Participants matched on CA. Correlations with IQ explored. Counterbalance d exposure duration of stimuli.
De Wit et al., 2008	AS, PDD-NOS, Autism	13	5.17 (.89)	TD	14	4.93 (.11)	N/A	Implicit	**Static,** photographs 10s exposure time.	Calm, Happy, Anger, Fear	ASD fixation time < TD. ASD fixation time on eye region = TD. Social and communication impairment scores negatively correlated with overall fixation time on the screen and fixation time on the mouth.	**83% (20/24).** Sample size small. Participant matching procedure unclear. Stimuli pseudo-randomized. Partial discussion of limitations.

Falck-Ytter et al., 2010. Study 1+2	Autism, AS, PDD-NOS	1;15, 2;13	5.17 (.91)	TD	15	4.91 (.08)	N/A	Implicit	**Static,** photographs followed by **dynamic** videos, 4 s exposure time. Upright and Inverted stimuli	Anger, Happy, Disgust, Fear, Neutral, Unlabeled Grimace	Study 1: ASD fixation time on eyes and mouth = TD. Social impairment positively correlated with fixation time on mouth and negatively correlated with fixation time on eyes. Communication impairment positively correlated with fixation time on eyes and negatively correlated with fixation time on mouth. Dynamic faces showed same results but no correlation between communication impairment and fixation time on eyes. Same pattern as above also for each separate emotion and opposite for happy and disgusted faces. In inverted faces, there was a positive correlation of social impairment and fixation time on mouth. Study 2: positive correlation of fixation time on face in action and fixation time on eyes in study 1 in both groups. In ASD, negative correlation of social impairment and fixation time on face during action execution and opposite for communication impairment.	**83% (20/24).** Sample size small. Participant matching procedure unclear although estimate of developmental age calculated using PEP-R and GMDS. Partial stimuli randomization. Limitations not well described.
Falk-Ytter et al., 2010. Study 3	Autism, AS PDD-NOS	12	6.58 (.67)					Implicit	**Dynamic,** videos, 4s exposure time, upright and inverted stimuli.	Anger, Fear, Happy, Neutral	Positive correlation of fixation time on mouth and social impairment score on SCQ	As Above
Bal et al., 2010	Autism, PDD-NOS	17 (12 ET)	10.3 (2.2)	TD	36 (30 ET)	11.16 (2.89)	CA, K-BIT	Implicit and Labelling (ET behavior obtained only during implicit task)	**Dynamic**, morphing stimuli Exposure time 15-33s	Anger, Disgust, Fear, Happy, Surprise, Sad	ASD fixation time on areas not eyes and mouth = TD. ASD fixation time on non-core/outside regions > TD when viewing fear. ASD children who had shorter fixation time on mouth and longer on eyes more accurate at disgust recognition. TD greater fixation time on eyes and shorter fixation time on mouth more accurate at surprise recognition. Greater fixation time on eyes related to faster fear recognition in TD. ASD greater fixation time on not	**92% (22/24).** ASD sample for eye tracking analysis small. Results reported in partially sufficient detail.

											eyes and mouth = slower surprise recognition.	
Van der Geest et al., 2002	Autism, PDD-NOS	17	10.6 (2.1)	TD	17	10.1 (1.3)	CA, WSI	Implicit	**Static**, Photographs 10s exposure time.	Anger, Happy, Neutral, Surprise	ASD fixation time and # of fixations on all regions = TD. ASD first fixation location = TD.	**92% (22/24)** Stimuli randomization procedure unclear.
Leung et al., 2013	autism, AS	26	10.6 (1.3)	TD	26	10.8(1. 1)	CA	Matching	**Static**, puzzled photograph stimuli presented for 10 s followed by whole face 'choice' stimuli exposed until participant choice selection.	Anger, Happy, Surprised	ASD # fixations on whole face and puzzled stimuli = TD. ASD fixation time > TD regardless of area of stimuli.	**88% (21/24).** Participants matched only on CA. Stimuli not randomized.
Crawford et al., 2015	Autism, AS, PDD-NOS	15	11 (3.48)	1; FXS, 2;TD child, 3; TD adult	1; 13, 2; 16, 3; 12	1; 19.7(9), 2; 7.13 (1.61), 3; 21.92 (2.97)	VABS (matched to FXS only)	Implicit	**Static**, photographs presented side by side. Exposure time 1.5s	Happy, Disgust, Neutral	ASD and FXS fixation time to disgust > neutral. Similar results for TD. ASD fixation time to eyes of neutral faces > FXS. ASD fixation time on mouth = FXS for neutral faces.	**92% (22/24).** Sample size small. Stimuli pseudo-randomized.
EEG												
Key et al., 2015	High risk	16	.75	Low risk	15	.75	CA, Gender, Ethnicity, Maternal education	Implicit	**Static,** photographs, 750ms stimuli exposure time.	Neutral, Small Smile, Duchenne Smile	High risk posterior N290 amplitude and latency and P400 and Nc amplitude = low risk. High risk had shorter P400 to small smiles than low risk. High risk siblings showed shorter latencies to small smiles versus Duchenne smiles, low risk did not discriminate. High risk Nc amplitude to small smiles = neutral. Low risk Nc amplitude to small smiles > neutral.	**92% (22/24).** Sample size small. Stimuli counter-balanced.
Dawson et al., 2004	Autism, PDD-NOS	1; 29 2;11	1; 3.78 (0.83) 2; 2.31 (0.75) (mental age)	TD	1; 22 2; 11	1; 3.64 (0.58) 2; 4.03 (0.6) (mental age)	CA, Gender, SES (1) MSEL (2)	Implicit	**Static**, photographs, 500ms exposure time.	Neutral, Fear	**CA matched:** ASD P200 slower and smaller than TD to neutral. ASD N300 amplitude and latency for fear = neutral. TD faster and larger N300 for fear versus neutral.	**96% (23/24).** Stimuli pseudo-randomized.

										ASD N300 latency to neutral in right hemisphere = left hemisphere. TD faster N300 to neutral in right hemisphere versus left hemisphere. ASD NSW amplitude for neutral = fear. TD NSW amplitude for fear > neutral. P300, Nc and P500 in ASD = TD. **MA matched:** ASD P200 amplitude in right and midline region > TD. ASD N300 amplitude for fear = neutral. TD N300 amplitude for fear > neutral. ASD N300 latency in left hemisphere > TD. ASD P300 amplitude for neutral > fear. TD P300 amplitude for neutral < fear. TD NSW amplitude to fear > neutral. ASD NSW to fear = neutral. ASD Nc and P500 = TD.	
Vlamings et al., 2010	ASD	22	4 (0.1)	DD	17	4.3 (0.2)	CA, Gender, SON-R, WPPSI-R, MSEL, PEP, Reynell Test for Language	Implicit	**Static**, photographs, High and low spatial frequencies, 500ms exposure time.	Neutral, Fear	ASD P100 amplitude to fear > neutral in high spatial frequency condition. TD P100 amplitude to fear < neutral in low spatial frequency condition.	**92% (22/24).** Analytic method partially described. Limited discussion of study limitations.
Wong et al., 2008	Autism	10	8.5 (1.5)	TD	12	8.5 (1.4)	CA, RPM	Implicit and Labelling (neutral/emotion)	**Static**, photographs, stimuli exposure time 750ms	Happy, Sad, Anger, Fear, Neutral	ASD P100, N170 amplitude and latency = TD. ASD P200 amplitude to happy in right hemisphere > fear and neutral in right hemisphere. Dipole source at occipital, temporal, frontal and parietal regions in ASD found cortical regions in ASD weaker or delayed at sub-second latencies.	**92% (22/24).** Sample size small. Stimuli pseudo-randomized.
Yeung et al., 2014	ASD	18	9.61 (3.13)	TD	18	10.72 (3.61)	CA, Gender, WISC IV (Hong Kong) CVT	Labelling	**Static**, photographs, stimuli presented until participant response.	Happy, Fear, Anger, Disgust, Surprise, Sad, Neural	ASD lower right frontal theta coherence for sadness, disgust and surprise. TD higher theta coherence when viewing emotions (except anger) compared to neutral faces. ASD	**96% (23/24).** Stimuli pre-set randomized.

											Theta not higher for emotional faces versus neutral. ASD: increase in right frontal theta coherence in emotion modulation associated with lower autistic symptomology.	
Apicella et al., 2012	Autism	10	10.2	TD	12	9.7	N/A	Implicit	**Static**, photographs, Stimuli exposure time 850ms.	Happy, Fear, Neutral	ASD ppN170 = TD.	**71% (17/24).** Sample size small. Limited discussion of participant characteristics or participant source. Participant matching procedure unclear. Results in partial detail. Limited discussion of limitations.
Batty et al., 2011	Autism	15	10.55(3.31)	1; TD VE 2; TD CA	1; 15, 2; 15	1; 7.70 (3.8), 2;10.51 (3.2)	CA (1), PPVT (French), RPM, WISC III	Implicit	**Static**, photographs, 500ms exposure time.	Happy, Anger, Disgust, Sad, Surprise, Fear	**CA matched.** ASD P100 amplitude < TD. ASD P100 slower than TD. ASD delayed N170. **VE matched**: ASD P100 amplitude < TD. ASD P100 latency = TD.	**92% (22/24).** Sample size small. Limited discussion of study limitations.
De Jong et al., 2008	Autism, ASD	30	10.7 (1.8)	TD	30	10.6 (1.6)	CA Gender WISC III	Implicit	**Static and Dynamic,** (morphing) High and low spatial frequency, direct and averted gaze. Stimuli with direct and averted gaze exposure time = 373ms, morphing stimuli = 440ms (40ms, 11 frames)	Fear, Neutral	ASD N170 amplitude for fear = neutral. TD N170 amplitude for fear > neutral. ASD N170 amplitude to fear < TD. Low spatial frequency versus high spatial frequency effect smaller in ASD group.	**100% (24/24)**
O'Connor et al., 2005	AS	15	11.6 (1.9)	TD	15	11.2 (1.8)	CA, Gender	Labelling	**Static,** photographs,	Happy, Sad, Anger, Fear	ASD N170, P100 and P200 amplitude and latency = TD.	**92% (22/24).** Sample size small.

									Stimuli 1s exposure time.			Participants matched on CA.
Tye et al., 2014	1;ASD, autism, 2; ASD, autism + ADHD	1; 19, 2; 29	1;11.69,2;10.53	1; TD, 2; ADHD	1; 26, 2; 18	1; 10.56 (1.79), 2; 10.48(1.91)	CA, IQ	Implicit	**Static**, photographs, exposure time 1.3s	Disgust, Fear, Anger, Joy, Neutral	ASD/ASD+ADHD N170 amplitude < TD. ASD/ASD+ADHD N170 amplitude to fear < neutral. TD and ADHD only N170 amplitude for fear = neutral. ASD+ADHD N170 shorter to angry compared to neutral. ASD shorter N170 to neutral compared to angry. ASD + ADHD longer N170 to happy compared to fear and ASD longer N170 latency to fear compared to happy. N400 latency shorter in ASD compared to TD and AS+ADHD..	**92% (22/24)**. Participants matched only on CA and verbal IQ. Stimuli not randomized but randomized inter-stimuli period.

Abbreviations: ASD; Autism Spectrum Disorder, TD; Typically developing, CA; Chronological age, PDD-NOS; Pervasive Developmental Disorder Not Otherwise Specified, AS; Asperger Syndrome, K-BIT; Kauffman Brief Intelligence Test, WSI; Wechsler Scale of Intelligence FXS; Fragile X Syndrome, VABS; Vineland Adaptive Behavior Scales SES; Socio-economic Status, MSEL; Mullen Scales of Early Learning, MA; Mental age, SON-R;, Snijders-Oomen Nonverbal Intelligence Test – Revised WPPSI-R; Wechsler Preschool and Primary Scale of Intelligence – Revised, PEP; Psychoeducational Profile, RPM; Ravens Progressive Matrices, WISC; Wechsler Intelligence Scale for Children, CVT; Chinese Vocabulary Test, PPVT; Peabody Picture Vocabulary Test, VE; Verbal Equivalent, ADHD; Attention Deficit Hyperactivity Disorder. N/A denotes areas where sufficient information was not provided by study.

Table 2. Adolescent Eye Tracking and Electrophysiological Studies

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Eye tracking												
Bekele et al., 2013	ASD	10	14.7 (1.1)	TD	10	14.6 (1.2)	CA	Labelling	**Dynamic**, VR avatar, 25-40s exposure time of neutral face lip syncing followed by expression presented for 5s.	Enjoyment, Surprise, Contempt, Sad, Fear, Disgust, Anger	ASD fixation time on forehead > TD and fixation time on mouth < TD. ASD fixation time outside of face > TD. ASD fixation time on face < TD. Similar results for correct/incorrect trials.	**92% (22/24).** Small sample size. Participants only matched on CA
Bekele et al., 2014	ASD	10	14.7 (1.1)	TD	10	14.6 (1.2)	CA, DAS, SB, WISC (ASD), WASI (TD)	Labelling	**Dynamic**, VR avatar, 10-15s exposure time of neutral face lip syncing followed by expression of varying intensity for 5s	Joy, Surprise, Contempt, Sad, Fear, Disgust, Anger	ASD fixation time to face eyes, nose and other = TD. ASD fixation time on mouth < TD. ASD fixation time on forehead > TD.	**92% (22/24).** Sample size small. Outcome measure partially described.
McCabe et al., 2013	Autism, AS, PDD-NOS	14	14.71 (2.87)	1; TD, 2; 22q11DS	1; 31, 2; 20	1;16.55 (3.3), 2; 16.75 (3.71)	CA	Labelling	**Static**, Photographs, 6s exposure time.	Happy, Sad, Surprised, Disgust, Fear, Anger, Neutral	ASD and 22q11DS # of fixations to face < TD. When IQ controlled for this effect was not significant. ASD fixation time on core features = TD.	**88% (21/24).** ASD sample small. Participants matched only on CA but IQ controlled forStimuli not randomized.
White et al., 2015	ASD	15	14.88 (1.55)	TD	18	14.33 (1.52)	CA, Gender	Implicit	**Static**, photographs of single	Face pairs: Disgust, Anger, happy,	ASD fixation time on face and eyes = TD. After controlling for negative evaluation, ASD fixation time on	**88% (21/24).** Sample size small.

									faces and face pairs. Both presented for 4s	calm (instead of neutral), Single face: Happy, Sad, Surprise, Anger, Disgust, fear. Analysis undertaken on Disgust, angry and happy only.	eyes and face < TD. In ASD, Fear of negative evaluation in ASD predicted fixation duration to face for anger and disgust When stimulus presentation divided into 500ms epochs, ASD fixation time on angry in 1st 500ms < TD. Progressive disengagement to disgust more apparent in ASD versus TD. ASD attention to disgust in 1st, 7th and 8th 500ms epoch < TD.	Participants matched on CA.
Dalton et al., 2005	Autism, AS	11	15.9 (4.7)	TD	12	17.1 (2.78)	CA	Labelling (neutral/emotion)	**Static**, photographs. Direct and Averted Gaze. 3s exposure time.	Neutral, Happy, Fear, Anger	ASD fixation time on eyes < TD. ASD fixation time on mouth and face = TD.	**75% (18/24).** Sample size small. Participants matched on CA. Analytic method partially described. Stimuli not randomized. Partial discussion of limitations and confounders.
Dalton et al, 2008	Autism, AS	14	15.9 (4.71)	1; FXS, 2; TD	1;9, 2; 15	1; 20.7 (2.77) 2; 16.8 (2.57)	WRIT (ASD=FXS only)	Labelling (neutral/emotion)	As above.	Happy, Fear, Anger	ASD fixation pattern on eyes and mouth = FXS.	**75% (18/24).** Sample size small. IQ of TD group not assessed, although FXS and ASD group did not differ in IQ. Stimuli not randomized. ET results not reported in sufficient detail. Conclusions partially supported by results.
Wagner et al., 2013	ASD	17	17.0 (2.2)	TD	19	17.9 (2.5)	CA, KBIT-2	Implicit	**Static**, photographs, 5s exposure time.	Anger, Fear, Neutral	ASD fixation time on face, eyes and mouth = TD.	**100% (24/24)**
Tottenham et al., 2014	Autism, AS, PDD-NOS	26	17 (7)	TD	39	17 (9)	WASI, PPVT 3	Labelling and Implicit	**Static**, photographs, 300ms	Anger, Neutral, Happy	ASD gaze towards eyes < TD for neutral. ASD gaze towards eyes of angry = TD. ASD participants who	**100% (24/24).**

								(ET behavior obtained only during Implicit task)	exposure time.		gave higher threat ratings to neutral faces produced less eye movements towards eyes. This was not seen for angry faces or in TD.	
Hanley et al., 2012	AS	14	20.5	TD	14	20.4	CA Gender, WASI	Implicit	**Static,** photographs, 5 conditions: isolated posed faces, isolated acted faces, isolated naturalistic faces, acted social scenes and naturalistic social scenes. 5s exposure time.	Happy, Fear, Sad, Excited, Disgusted, Angry Romantic, Thinking, Bored, sorry	ASD Fixation time on posed and acted faces = TD. For naturalistic isolated faces, ASD fixation time on hair > TD. For acted social scenes, ASD fixation time on eyes < TD and fixation time on body > TD. For naturalistic scenes, ASD fixation time on eyes and face < TD.	**88% (21/24).** Sample size small. Participant characteristics limited in description. Partial description of limitations.
EEG												
Lerner et al., 2013	ASD	34	13.07 (2.07)	Age group Norms				Labelling	**Static**, photographs of child and adult faces with high and low intensity,, stimuli presented until participant response, maximum 3s.	Happy, Sad, Anger, Fear	N170 latency associated with decrease accuracy, after controlling for IQ and age no longer significant. Larger N170 amplitudes had faster responses. Shorter N300 latencies associated with faster response times for adult faces.	**100% (24/24)**
Akechi et al., 2010	Autism, AS, PDD-NOS	14	13.7 (2.3)	TD	14	12.32 (2.1)	CA, Gender, WISC III (Japanese)	Labelling	**Static**, direct and averted gaze, Stimuli exposure time 1.2s	Anger, Fear	ASD P100 amplitude = TD and VPP amplitude and latency = TD. ASD N170 latency = TD. ASD N170 amplitude to congruent (fearful with averted gaze, anger with direct) = incongruent stimuli. TD N170 amplitude to congruent > incongruent stimuli.	**92% (23/24).** Sample size small.
Gross et al., 2012	ASD	10	14.1 (2.7)	1; TD, 2; ADHD	1; 11, 2; 9	1; 14.8 (4.5) 2; 14.2 (3.9)	CA	Implicit and Labelling	**Static,** photographs, 300ms	Anger, Disgust, Fear, Sad	ASD had a lower induced gamma in emotion recognition task versus gender recognition. ADHD higher induced gamma in emotion	**83% (20/24).** Sample size small. Limited discussion of

								(anger, disgust)	exposure time.		recognition versus gender recognition. ADHD higher induced gamma than ASD in emotion recognition.	study limitations. Stimuli randomly selected. IQ measured however matching procedure unclear.
Wagner et al., 2013	ASD	17	17 (2.2)	TD	16	17.9 (2.5)	CA, KBIT-2	Implicit	**Static**, photographs, 5s exposure time.	Anger, Fear, Neutral	ASD P100 amplitude = TD. ASD no difference of N170 between fearful, angry, neutral. TD N170 amplitude to fear > angry.	**100% (24/24)**

Abbreviations: ASD; Autism Spectrum Disorder, TD; Typically Developing, CA; Chronological age, VR; Virtual reality, DAS; Differential Ability Scales SB; Stanford Binet, WISC; Wechsler Intelligence Scale for Children, WASI; Wechsler Abbreviated Scales of Intelligence, AS; Asperger Syndrome, PDD-NOS; Pervasive Developmental Disorder Not Otherwise Specified FXS; Fragile X Syndrome, WRIT; Wide Range Intelligence Test, KBIT-2; ; Kauffman Brief Intelligence Test PPVT; Peabody Picture Vocabulary Test ADHD; Attention Deficit Hyperactivity Disorder. N/A denotes areas where sufficient information were not provided by study.

Table 3. Adult Eye Tracking and Electrophysiological Studies

Citation	Sample						Matching Procedure	Task Format	Stimuli	Emotions	Key Findings	Methodological Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Eye Tracking												
Han et al., 2015	LFAS	12	19.5 (3.1)	1; TD child, 2; TD adolescent	1; 12, 2; 12	1; 7.0 (2.2), 2; 13.4 (0.9)	RCPM	Matching	**Dynamic,** (morphing) Human Face and mechanical Face). 4s exposure time.	Happy, Disgust, Fear, Surprise	ASD fixation time < TD. ASD fixation time on core features > non-core features. ASD fixation time on core features < TD for mechanical display. ASD fixation time on core features of mechanical face < human face. ASD fixation time to mechanical motion > TD. ASD fixation time on core features = mechanical motion. TD fixation time on core features > mechanical motion.	**88% (21/24).** Stimuli not randomized. Limitations partially discussed.
Sawyer et al., 2012	AS	29	21.6 (9.8)	TD	24	24 (9.2)	CA, WASI	Implicit and Labelling (ET obtained only during full face and passive viewing)	**Static**, photographs, 5s exposure time.	Happy, Sad, Surprised, Fear, Anger, Disgust, Scheming, Guilt, Thoughtful, Admiring, Quizzical, Flirting, Bored Interested, Arrogant, Embarrassed	ASD fixations on eyes and mouth = TD. ASD % of time first fixations to eyes = TD.	**92% (23/24).** Partial discussion of limitations.
Neumann et al., 2006	Autism	10	23 (2)	TD	10	28 (3)	CA, WASI, Gender	Labelling	**Static**, Whole Face and Gaussian Bubbles Upright and Inverted Faces. Whole face	Fear, Happy (Gaussian bubbles), happy, sad, anger, fear, disgust, surprise,	ASD viewing of upright whole faces = TD. When faces whole and inverted, ASD fixation time on mouth > TD. In bubbled condition, ASD fixation time on mouth > TD and ASD fixation time on eyes < TD.	**92% (22/24).** Sample size small. Whole face stimuli viewed by 11 participants. Limited

									stimuli exposure time 1s. Bubbled stimuli presented until participant response or a maximum of 10s.	neutral (whole face)		discussion of limitations.
Sasson et al., 2007	Autism	10	23 (5.27)	1;TD,2; Schizophrenia	1;10. 2; 10	1; 22.4 (6.3) 2; 28.1 (5.07)	CA, WASI	Labelling	**Static,** faces and digitally erased faces, exposure time 3s.	Happy, Surprise, Fear, Anger, Sad, Disgust, Neutral	In face present condition: ASD fixation time on face < TD.ASD oriented to faces at the same speed regardless of face condition. ASD showed negative correlation between fixation time on face and recognition accuracy in face present condition. TD oriented faster to face in face present condition compared to face-absent.	**83% (20/24).** Sample size small. Stimuli not randomized. Partial discussion of limitations.
Spezio et al., 2007a	Autism	9 (8 ET)	23 (6.75)	TD	10 (5 whole face)	28 (8.15)	CA, WASI	Labelling	**Static** Whole Face and Gaussian Bubbles. Stimuli displayed until participant response with maximum of 10s. Whole face stimuli displayed for 1s.	Fear, Happy (Gaussian Bubbles), Happy, Fear, Anger, Surprise, Disgust (whole face)	In bubbled condition, ASD fixation time and # of fixations to mouth > TD and ASD fixation time to right eye < TD. ASD fixation time for whole face condition = TD.	**87% (21/24).** Sample size small. Partial discussion of limitations
Spezio et al., 2007b	Autism	8	23 (7.11)	TD	10	28 (8.15)	CA, WASI	Labelling	**Static**, Gaussian Bubbles. Stimuli displayed until participant response with maximum of 10s.	Fear, Happy	When bubbles revealed more information in the left eye, ASD fixation time on mouth > TD. When bubbles revealed more information at the mouth, ASD fixation time on mouth < TD.	**83% (20/24)** Sample size small. Results not reported in sufficient detail. Partial discussion of limitations
Hernandez et al., 2009	Autism	11	24.09 (8.31)	TD	23	22.2 (3.6)	N/A	Implicit	**Static**, photographs, neutral faces with direct and	Happy, Sad, Neutral	ASD fixation time on core features = fixation time on non-core/outside features. TD fixation time on core features > fixation time on non-	**79% (19/24).** Sample size small. Participant matching

									averted gaze, emotional faces and avatar faces.4s exposure time.		core/outside features. ASD fixation time on eyes < TD for netural, happy, sad, neutral with averted gaze and avatar stimuli. ASD fixation on nose < TD for neutral, happy, sad and neutral with averted gaze stimuli. ASD fixation time on mouth = TD. ASD fixation time on outside regions/off screen > TD for all stimuli. ASD started exploration of face on eyes < TD and started exploration on mouth > TD.	procedure unclear. Participant source not described. Participant characteristics partially described Limitations partially discussed.
Pelphrey et al., 2002	HFA	5	25.2	TD	5	28.2	N/A	Implicit and Labelling	**Static**, photographs, 2s exposure time	Happy, Fear, Anger, Disgust, Surprise, Sad	ASD fixation time and # of fixations on core regions < TD. ASD fixation time on eyes and nose < TD, ASD fixation time on mouth = TD. ASD # fixations and fixation time on face = TD	**71% (17/24).** Sample size small. Matching procedure unclear. Results not reported in sufficient detail. Stimuli not randomized.
Rutherford et al., 2008	autism, AS	11	25.8 (6.09)	TD	11	25.7 (8.87)	CA, Gender, WAIS, Education	Labelling	**Static**, photographs, stimuli exposure time 2.5s	Happy, Surprise, Anger, Disgust, Sad, Distress, Scheming, Thoughtful, Flirting, Admiring, Quizzical, Bored, Interested, Guilty, Arrogant.	ASD fixation time to eyes and mouth = TD. ASD fixation time on features of complex emotion < basic emotion.TD fixation time on features of complex emotion > basic emotion.	**83% (20/24).** Sample size small. Stimuli not randomized. Partial discussion of limitations.
Falkmer et al., 2011	AS	24	29 (10.8)	TD	24	28.9 (10.6)	CA, gender	Matching	**Static,** Whole Face and Puzzled. Puzzled stimuli exposure time 10s, whole face stimuli displayed until participant response.	Happy, Anger, Surprise	Puzzled stimuli: ASD # of fixations on eyes < TD. ASD # fixations on mouth > TD. ASD # fixations on non-core/outside face = TD. ASD fixation time on mouth < TD. ASD fixation time to eyes and non-core/outside of face = TD. Whole face stimuli: ASD # fixations on eyes < TD. ASD # fixations on non-core/other parts of face >TD. ASD # fixations on	**88% (21/24).** Participant IQ not accounted for. Stimuli not randomized.

											mouth = TD. ASD fixation time on non-core/other parts of face > TD. ASD fixation time on eyes and mouth = TD. ASD with highest recognition accuracy made more fixations on the eyes of puzzled stimuli, made fewer fixations on non-core/outside regions of whole face stimuli, had shorter fixation times on the eyes of puzzled stimuli and shorter fixation times to the mouth of whole faces compared to ASD participants with lowest recognition accuracy.	
Kliemann et al., 2012	Autism AS	16	30.44 (6.34)	TD	17	30.47 (6.23)	CA, MWT Non-verbal strategic thinking (Leis-tungspru ¨fsystem)	Labelling	**Static**, photographs, 150ms exposure time.	Happy, Fear, Neutral	Emotion effect on eye preference in TD but not ASD. Across emotions TD higher preference index for eyes, while ASD lower preference index for eyes – most pronounced in neutral faces. Eye movements away from eyes correlated with reduced recognition performance in ASD in mouth condition.	**96% (23/24).** Partial discussion of limitations.
Kirchner et al., 2011	autism	20	31.9 (7.6)	TD	21	31.8 (7.4)	CA, gender, education, Wortscha-tztest	Labelling	**Static**, photographs, naturalistic. 4.5s Exposure time.	Complex Negative emotion from MET (e.g., Sad, Anger)	ASD fixation time on eyes and mouth = TD. ASD fixation time on face < TD. Fixation time on eye predictor of performance in ASD group and fixation time on mouth negative predictor of performance in ASD.	**92% (22/24).** Stimuli counterbalanced.
Kliemann et al., 2010	ASD	12	35.4 (8.1)	TD	11	27.1 (2.6)	Gender, MWT	Labelling	**Static**, photographs, 150ms exposure time.	Happy, Fear, Neutral	ASD preference for eyes < TD. ASD tendency to gaze away from eyes downward to mouth when initially fixating on eyes > TD. TD tendency to gaze upward to eyes than downward to mouth for neutral and fear. ASD eye preference index positively correlated with performance, not seen in TD. Eye preference index negatively correlated with ADI-R social score. No correlation of ADI-R communication score, AQ or verbal IQ and gaze patterns.	**96% (23/24).** ET sample size small.

Corden et al., 2008	AS	18	32.9 (13.35)	TD	17	31.9 (11.30)	CA, Gender, WASI, DTVP	Implicit and Labelling	**Static**, photographs. 2.5s stimuli exposure time.	Happy, Sad, Fear, Surprise, Anger, Disgust	ASD fixations on eyes < TD. ASD fixations on face = TD. Fixation time not associated with ASD symptom severity. Reduced recognition of fear in ASD associated with fewer fixations on eyes. High social anxiety in ASD associated with reduced fixations on eyes.	**100% (24/24).**
Boraston et al., 2008	Autism, ASD,AS	11	34.6 (9.01)	TD	11	39.6 (11.1)	CA, WASI	Labelling	**Static**, photographs, 2.5s exposure time.	Neutral, Genuine Smile, Posed Smile	ASD gaze time on eye region <TD ASD fixations to the eye region <TD No correlations found between gaze time or % fixations and performance.	**92% (22/24).** Sample size small. Partial discussion of limitations.
EEG												
Yang et al., 2011	AS	5	19.2	TD	7	N/A	N/A	Labelling (sliding scale angry to happy)	**Static**, photograph, 4s exposure time.	Anger, Happy, Neutral	Theta synchronization weaker in ASD. Beta2 and alpha desynchronization strong in ASD	**71% (17/24).** Sample size small. Limited discussion of participant source or participant characteristics and matching procedures. Control population not described. Limited estimate of variance.
Tseng et al., 2015	AS	10	19.6 (1.96)	TD	10	24.4 (3.24)	Gender, WAIS III	Labelling (sliding scale angry to happy)	**Static**, Photograph and line drawing of face. Exposure time 1s	Neutral, Happy, Anger	ASD N170 amplitude and latency = TD. In line drawing task ASD N400 amplitude = TD. In photograph task N400 amplitude in ASD < TD. ASD weaker delta/theta synchronization than TD in early and late stages of emotion recognition. ASD fewer distant inter-hemispheric connections than TD in photograph task but similar to TD in line drawing task.	**95% (23/24).** Sample size small.
Gayle et al., 2012	AQ traits	37	19.8 (1.67)					Implicit	**Static**, photographs	Neutral, Sad, Happy	vMMN amplitudes to happy positively correlated with AQ score	**92%(22/24)** Limited

									exposure time 150ms.		(smaller/more positive amplitude associated with higher AQ score).	discussion of participant characteristics. Stimuli pseudo-randomized.
Lassalle et al., 2015	High AQ	25	20.44 (2.27)	Low AQ	25	21.28 (2.54)	N/A	Implicit	**Static**, Direct and averted gaze and upright and inverted. Neutral face with direct gaze exposure time 500ms, neutral face with averted gaze exposure time 200ms, emotion face with averted gaze exposure time 300ms.	Fear, Happy	Effect of congruency on P100 significant in low but not high AQ group. EDAN in high AQ = EDAN in low AQ. Laterality effect of ADAN present in low AQ group only.	**92% (22/24).** Participant matching procedure unclear, however, anxiety measured for all participants. Limited discussion of limitations.
Magnee et al., 2008	PDD	12	21.5 (4.0)	TD	13	23.0 (2.9)	CA, WAIS III	Implicit	**Static**, photographs with congruent and incongruent auditory pairs. Face stimuli presented for 900ms before auditory stimuli. Face stimuli remained until end of auditory presentation.	Fear, Happy	ASD N170 and P100 = TD. ASD N200 amplitude to fear voice < happy voice when presented with fear face. TD N200 amplitude to fear voice > happy voice when presented with fear faces.	**83% (20/24).** Sample size small. Analytic method partially described. Limited discussion of source of participant and discussion of limitations.
Magnee et al., 2011	HFA	23	22.7 (3.8)	TD	24	22.7 (1.9)	CA, WAIS III (Dutch) Gender	Implicit	**Static**, Congruent and Incongruent Visual and Auditory Pairs. Face stimuli exposure time 100ms, auditory stimuli	Fear, Happy	No differences in N170 to visual stimuli. TD had significant congruency effects for N170 amplitude for divided attention condition (both auditory and visual input) in left hemisphere but not ASD group.	**88% (21/24).** Limited discussion of participant source. Analytic method partially described. Limitations partially described.

									presented for 500ms.			
O'Connor et al., 2007	AS	15	23.5(5.2)	TD	15	23.8 (4.4)	CA	Labelling	**Static**, photographs, stimuli exposure time 600ms.	Neutral, Sad	ASD N170 amplitude = TD. ASD N170 latency to eyes and mouth > than TD. ASD latency to faces > TD. ASD N170 latency to faces = objects. TD N170 latency to faces shorter than to objects. ASD P100 = TD.	**92% (22/24).** Sample size small. Participants matched on CA.
O'Connor et al., 2005	AS	15	24.6 (8.8)	TD	15	: 23.8 (8.7)	CA, Gender	Labelling	**Static,** photographs, Stimuli 1s exposure time.	Happy, Sad, Anger, Fear	ASD P100 amplitude = TD. ASD P100 and N170 latencies > than TD. ASD N170 amplitude < than TD. ASD P200 = TD.	**92% (22/24).** Sample size small. Participants matched on CA.
Cooper et al., 2013	High AQ	10	25.4 (for both groups)	Low AQ	10	25.4 (for both grou ps)	N/A	Implicit	**Dynamic**, video of faces with hand movement. Stimuli exposure time 3s.	Happy, Anger, Neutral	High AQ greater low beta event related desynchronization to angry compared to happy. No group differences in alpha. Low AQ greater low beta event related desynchronization to happy compared to angry and neutral; low AQ had greater low beta event related desynchronization to happy compared to high AQ.	**83% (20/24).** Sample size small. Limited discussion of participant source or participant characteristics. Group matching procedure unclear.
Fujita et al., 2013	Autism, AS, PDD-NOS	9	31.5	TD	10	26.8	CA	Implicit	**Static**, photographs, upright and inverted. 20 ms exposure time.	Fear, Neutral	ASD N100 amplitude for upright and inverted faces = upright and inverted objects. TD N100 amplitude to fear in upright > objects in upright.No subliminal face effect in ASD (object – fear or neutral). TD subliminal face effect with N100 amplitude for upright fear > inverted fear. ASD N100 amplitude subliminal face effect < TD for upright condition. ASD P300 = TD.	**88% (21/24).** Sample size small. Participants matched on CA.

Abbreviations: LFAS Low functioning Autism; TD; Typically developing, CA; Chronological age, RCPM; Ravens Coloured Progressive Matrices, AS; Asperger Syndrome, WASI; Wechsler Abbreviated Scales of Intelligence, HFA; High Functioning Autism, WAIS; Wechsler Adult Intelligence Scales, MWT; Mehrfachwahl-Wortschatztest (Multiple Choice Vocabulary Test), DTVP; Developmental Test of Visual Perception, AQ; Autism Quotient. N/A denotes areas where sufficient information was not provided by study.

Appendix a. Search Terms Used for Each Database

Database	Date of Search	Results returned	MeSH Terms or key words*
ProQuest	27 January, 2016	15	"Autistic Disorder "Child Development Disorders, Pervasive" "Autism Spectrum Disorder" "Evoked Potentials" "Electroencephalography" "eye movements" "fixation, ocular" "Emotions" "expressed emotion" "affect"
Medline	27 January, 2016	171	'Autistic Disorder" "Child Development Disorders, Pervasive" "Autism Spectrum Disorder" "Asperger Syndrome" "Electroencephalography" "evoked potentials" "evoked potentials, visual" "eye movements" "eye movements, measurements" "fixation, ocular" "Emotions" "facial expression" "social perception" "Affect"
PsychInfo	20 January, 2016	118	"autism" "pervasive developmental disorder"

			"Aspergers syndrome" "Evoked Potentials" "Electroencephalography" "eye movements" "eye fixation" "visual perception" "visual tracking" "visual search" "emotions" "emotional states" "expressed emotion" "social perception"
Scopus	27 January, 2016	211	"autistic disorder" "child development disorders pervasive" "autism spectrum disorder" "Asperger" "evoked potential" "EEG" "Electroencephalography" "eye tracking" "eye movement" "fixation, ocular" "eye fixation" "visual tracking" "emotion" "expressed emotion" "social perception"
CINAHL	27 January, 2016	40	"Autistic Disorder" "Child Development Disorders, Pervasive" "Electroencephalography" "Evoked Potentials, Visual" "Evoked Potentials"

Embase	27 January, 2016	189	“Eye movements”, Eye Movement Measurements” “Emotions” “Affect” “Facial Expression” “autism” “Asperger syndrome” “childhood disintegrative disorder” “pervasive developmental disorder not otherwise specified” “electroencephalography” “eye movement” “eye tracking” “eye fixation” “emotion” “facial expression” “affect”

Appendix B. Criteria from the Kmet Form for Quantitative Analysis Used to Assess Methodological Quality of Included Studies.

	Criteria	Yes (2)	Partial (1)	No (0)
1	Question / objective sufficiently described?			
2	Study design evident and appropriate?			
3	Method of subject/comparison group selection *or* source of Information/input variables described and appropriate?			

4	Subject (and comparison group, if applicable) characteristics sufficiently described?
5	If interventional and random allocation was possible, was it described
6	Outcome and (if applicable) exposure measure(s) well defined and robust to measurement / misclassification bias? Means of assessment reported?
7	Sample size appropriate?
8	Analytic methods described/justified and appropriate?
9	Some estimate of variance is reported for the main results?
10	Controlled for confounding?
11	Results reported in sufficient detail?
12	Conclusions supported by the results?