Altered Connectivity in Autistic Adults during Complex Facial Emotion Recognition: A Study of EEG Imaginary Coherence

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***Abstract*— Difficulties in Facial Emotion Recognition (FER) are commonly associated with individuals diagnosed with Autism Spectrum Disorder (ASD). However, the mechanisms underlying these impairments remain inconclusive. While atypical cortical connectivity has been observed in autistic individuals, there is a paucity of investigation during cognitive tasks such as FER. It is possible that atypical cortical connectivity may underlie FER impairments in this population. Electroencephalography (EEG) Imaginary Coherence was examined in 22 autistic adults and 23 typically developing (TD) matched controls during a complex, dynamic FER task. Autistic adults demonstrated reduced coherence between both short and long range inter-hemispheric electrodes. By contrast, short range intra-hemispheric connectivity was increased in frontal and occipital regions during FER. These findings suggest altered network functioning in ASD**

I. Introduction

Difficulties in facial emotion recognition (FER) are commonly observed in individuals diagnosed with Autism Spectrum Disorder (ASD), a neurodevelopmental condition associated with alterations in social communication and interaction [1]. However, the mechanisms underlying these impairments in FER remain inconclusive [2]. As FER relies on the function of distributed networks within the brain [3], it is possible that deficits in FER may arise from more complex interactions within and between networks and may not be fully explained by dysfunction of individual structures.

Atypical cortical connectivity has been commonly observed in ASD [5]. Given that the integration and transfer of information between and within neural networks is essential for cognition, altered connectivity may be a mechanism contributing to the expression of the core diagnostic characteristics of ASD, including impairments in FER.

To date the majority of coherency investigations in individuals diagnosed with ASD have used resting state conditions, with a dearth of connectivity studies during cognitive tasks [4]. Further, drawing conclusions regarding atypical connectivity in ASD has been hindered by the use of differing tasks, participant groups and measures [5]. Some investigations of connectivity in ASD during FER using coherence and synchrony have found atypical connectivity in ASD, particularly in the theta band (typically 4-8 Hertz) [6-8]. Weaker theta/delta synchronization during the viewing of static basic emotions (such as happy, angry, fear, disgust, surprise, sadness) has been observed in autistic adolescents and adults [6] with similarly weaker theta synchronization found in autistic adults during the viewing of happy, angry and neutral faces [7]. Greater right frontal theta modulation has also been observed in autistic children during the recognition of static basic emotions [8].

Differences in alpha and beta frequencies have also been observed; however, they are less consistent [6,7]. These previous investigations have been limited to the use of stimuli which may not provide an ecologically valid assessment of FER in autistic adults. Given the developmental trajectory of FER [9], it is possible that the use of more complex emotions such as intimacy, jealousy, or guilt presented dynamically may provide a more socially-relevant assessment of FER for autistic adults.

The coherency of adults with and without a diagnosis of ASD was examined during the FER of complex, dynamic stimuli to determine if altered connectivity contributes to ASD-linked FER impairments during the processing of more socially relevant stimuli.

II. Methods

A. Participants

Data from twenty-two autistic adults and 23 typically developing (TD) adults were included in this study. Autistic adults were diagnosed with Autism Spectrum Disorder/High Functioning Autism (n=11) and Asperger Syndrome (n=11). Autistic adults and TD participants groups had a mean age of 25.2 (SD 9.0) years and 24.9 (SD 5.6) years respectively. Groups were matched on age ($p=0.69$), gender ($p=0.18$), verbal IQ ($p=0.77$), performance IQ ($p=0.85$) and full-scale IQ ($p=0.72$). Groups differed significantly on the map search subtests of the Test of Everyday Attention ($p=0.01$) and on autistic traits measured by the Social Responsive Scale – second edition ($p<0.01$).

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B. Measures

1) Facial Emotion Stimuli

The stimuli set consisted of 15 silent videos of adult actors expressing complex emotions derived from the Cambridge Mind Reading Face-Voice Battery [10]. Stimuli were between 3 to 5 seconds in length. All stimuli were presented for 5 seconds with images remaining static on the screen for the remaining 1-2 seconds if the videos were 3-4 seconds in length. Stimuli consisted of 4 positive (exonerated, empathic, vibrant, intimate), 9 negative (resentful, stern, grave, subservient, insincere, mortified) and 2 neutral (lured, appealing) emotions.

2) Wechsler Abbreviated Scale of Intelligence – Second Edition

The WASI-2 [11] provided a measure of intelligence. The WASI-2 provides measures of verbal, performance and full-scale IQ based on four subtests (vocabulary, similarities, block design and matrix reasoning). The WASI-2 has been validated for use with individuals aged 6-89 years of age [11].

3) Social Responsiveness Scale – Second Edition

The SRS-2 provided a self-reported measure of autistic traits. The SRS-2 asks participants to rate statements relating to social communication and reciprocity on a 4-point Likert scale, providing a self-report measure of autism symptomatology [12].

4) Test of Everyday Attention

To provide a measure of attention in the groups, the Map Search and Elevator Counting subtests of the TEA were used to provide measures of selective and sustained attention [13].

C. Data Acquisition

Stimulus presentation and behavioral data acquisition were controlled via E-Prime software [14] with stimuli presented on a 106.7cm TV screen. A 40-channel Compumedics Neuroscan EEQ Quik Cap with Ag/AgCl electrodes and NeuroScan 4.5 Software [15] was used to record EEG data with a reference at Cz and virtual ground at AFz. EEG signals were recorded with an impedance of 5k Ohms or lower and sampled at 1000 Hertz. A NuAmps 40-channel amplifier was used to amplify the EEG signal with default internal hardware filters used for DC component removal and antialiasing. Vertical and horizontal electroculograms (EOGs) were recoded via electrodes placed on out outer canthi of each eye and above and below the left eye.

D. Procedure

The experimental procedures involving human subjects described in this paper were reviewed and approved by the Curtin University Human Ethics Research Committee. Written informed consent was obtained from participants. Vocabulary and similarities WASI-2 subtests were administered during preparation of the EEG. Participants were orientated to the FER task and were asked to complete two practice items followed by 15 FER test items. The FER stimuli were presented in a pseudo-randomized order. A fixation cross was presented for 1 second prior to the presentation of each stimulus. Following each stimulus, four complex emotion labels were presented on the screen with participants required to select one of the four labels they believed described the stimulus by indicating their answer on a keyboard.

E. Data Analysis

EEG data were initially processed to obtain the frequency bands. This process included an initial band pass filter (0.5 and 40 Hertz) and independent component analysis to subtract ocular artifacts. Analysis included 33 electrodes which were referenced to CZ. Data were baseline corrected to the last 500ms of fixation cross viewing prior to stimulus presentation. As stimuli were presented for 5 seconds, EEG data during the stimulus presentation were then segmented into 1000ms epochs relative to stimulus onset, with each stimulus providing 5 epochs.

As analysis were undertaken only when participants correctly identified the emotion, the number of segments of EEG data provided by each participant varied as a function of their accuracy. The EEG data for each participant was averaged for each condition (positive, negative) prior to calculating coherence. Calculations described in Almabruk, Iyer [16] were then used to estimate the imaginary part of coherency at alpha (8-15 Hz), beta (16-30 Hz) and theta (4-8 Hz) bands. As we aim to compare between the connectivity of ASD and TD per condition (e.g. ASD (positive) vs. TD (positive)), epoch counts were randomly matched. Therefore, 22 epochs were used in the analysis from each dataset.

Imaginary part of coherency between signals x and y as introduced in [17] is calculated by assessing their auto (s_xx,s_yy) and cross spectrum (s_xy) as shown in Eq. (1).

$$icoh_{xy}(f) = \text{imag}\left(\frac{\langle s_{xy}(\text{f})\rangle_n}{\sqrt{\langle s_{xx}(\text{f})\rangle_\text{n}\langle s_{yy}(\text{f})\rangle_n}}\right), \quad (1)$$

We extracted coherence matrices for each group (ASD, TD), frequency (alpha, beta, theta) and valence (positive, negative) resulting in 12 coherence matrices in total. These matrices presented EEG connectivity values for all possible electrode pairings, resulting in matrices with dimension of 33x33. Following the removal of diagonal features due to the symmetry of the matrices, each matrix resulted in 528 unique coherence values, with values in the range [-0.94, 0.93].

Analyses on these matrices were conducted with the aim of identifying coherency differences between ASD and TD adults during FER of positive and negative emotion in the three frequency bands. For each frequency band and valence, the TD matrix was subtracted from the ASD matrix to obtain a difference matrix (dif). Prior to subtracting the coherency matrices, imaginary coherence values were normalized.

Trivial connectivity differences were then omitted by applying thresholds known as coherence deviation. Calculating these thresholds as shown in Eq. (2) depends on the epoch counts and frequency counts in each band.

$$\sigma = \frac{1}{\sqrt{(\text{number of epochs}) * (\text{number of frequencies})}} \quad (2)$$

Coherency values above threshold of the difference matrices were visualized in figures labelled with their electrode pairs (Fig.1 (a)). Green pixels refer to an increase in the coherency of the ASD compared to the TD group which means that $dif(x,y) > \sigma$ (i.e. ASD ($icohxy$) -TD ($icohxy$) > σ).

While red pixels refer to decrease in the coherency of ASD group compared to TD group, which means that $dif(x,y)$<- σ (i.e. ASD ($icohxy$) -TD ($icohxy$) $<-\sigma$). These green and red pixels were then depicted in topography figures (Fig 1(b)).

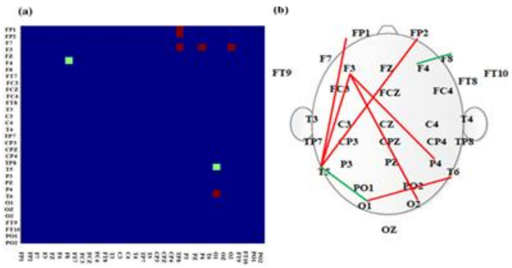

Figure 1. (a) Green pixels represent increment in the EEG electrode connectivity of the ASD compared to the TD group while red pixels represent decrements in the connectivity of the ASD compared to the TD group. (b) topography figure for the electrode pairs being identified in (a)

III. Results

A. Positive Emotion

Figure 2 displays the topographical representation of the imaginary coherency differences between ASD and TD adults during FER. Autistic adults had reduced short range inter-hemispheric coherency in frontal regions in theta (FP1/F8, F7/F8 and F3/F8) and alpha (FP1/F8, F7/F8, F3/F4, F3/F8) frequencies. In the beta frequency, reduced short range and mid-range inter-hemispheric coherency was found in in parietal (P3/P4) and parietal-temporal regions (P3/T6). Across frequency spectra, autistic adults demonstrated reduced anterior-posterior connectivity between inter-hemispheric (Theta: F4/P3, Beta; F8/T5, F4/T5, F4/O1, FP1/P4, F3/P4, FP1/T6, F3/T6, F7/T4, F7/T6) and intra-hemispheric pairs (Theta: F4/O2, F4/P4; Alpha; F7/PO1, Beta; F8/T6, Fp2/T4, Fp2/T6, F4/P4, F4/T6). Autistic adults had greater short and mid-range intra-hemispheric connectivity in posterior regions in all frequencies: theta (P3/O1, P4/O2), beta (O2/P4, O2/T6) and alpha (O2/T6).

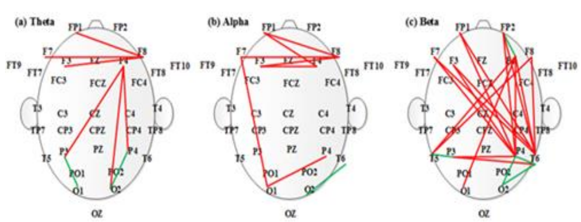

Figure 2. Topographical representation of electrode connectivity between ASD and TD adults during positive FER.

B. Negative Emotion

As shown in Figure 3, autistic adults showed reduced long range inter-hemispheric coherency in frontal-parietal (theta: FP1/P3, FP2/P4, alpha: FP2/P3), frontal-occipital (theta: FP2/O2, F4/O2, F8/O2, alpha: FP1/O2, beta: F3/O2) and frontal temporal (theta: F8/T6, alpha: F7/T6, FP1/T6, F8/T5, F4/T5) electrode pairs. Reduced mid and long-range intra-hemispheric coherency was also found across frequencies. In the theta frequency, this was characterized by reduced coherency in frontal-occipital (F7/O2, FP1/O2, F8/O1), frontal parietal (FP2/P3, F8/T5, F8/P3) and frontal-central (F4/C4) electrodes. In alpha, reduced coherency was observed between frontal-temporal (F7/T5, FP1/T5, F3/T5, FP2/T6, F4/T6), frontal-occipital (FP2/O2, F4/O2) and parietal-occipital (O1/P4, P3/O2) electrode pairs. In beta, reduced intra-hemispheric coherency was restricted to frontal-temporal (FP1-T5, F3/T5) electrode pairs. Greater coherency in autistic adults was observed in parietal-occipital electrode pairs in the theta frequency (P3/O1), temporal-parietal electrode pairs (T5/P3) in the alpha frequency and temporal-occipital (T5/01) pairs in the alpha and beta frequencies. Increased short range intra-hemispheric coherency was also found in the frontal regions (theta: FP2/F8, F8/FP2, alpha; FP2/P4, beta; F8/F4).

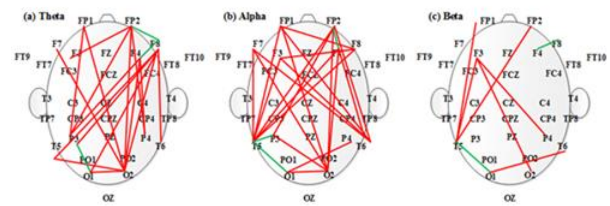

Figure 3. Topographical representation of electrode connectivity between ASD and TD groups during negative FER.

IV. Discussion

Autistic adults demonstrated reduced long range global coherency with concurrent coherency increases in short range frontal and occipital regions during FER, supporting the hypothesis that altered network function contributes to ASD-linked FER impairment. An effect of stimulus valence on coherency differences between groups was evident. Autistic adults showed reduced coherency primarily in alpha and theta bands during negative FER, with reduced coherency during positive FER being more evident in the beta frequency. This may indicate that while connectivity in autistic adults is altered during FER generally, the mechanisms contributing to FER impairment may vary in accordance with emotional valence.

Decreased coherency in all frequency bands in autistic adults was characterized by reduced coherency between anterior and posterior electrode pairs. It is possible that this pattern of reduced coherency indicates atypicalities in the transfer of information between posterior visual processing areas with higher order affective and decision-making networks in frontal regions, required for FER processes [3]. Similar patterns of reduced anterior-posterior coherency have been found in theory of mind tasks in individuals diagnosed with ASD [18], postulated to reflect increased autonomy of posterior networks in an attempt to remediate the lack of input from frontal regions [18]. The notion that autistic adults had reduced input from anterior regions, resulting in greater autonomy of posterior networks may be further supported by the observations of increased parietal-occipital and occipital-temporal connections in autistic adults during FER. In this case, autistic adults may place a greater reliance on visual spatial processes to visually mediate deficits in networks involved in higher order FER processes [19].

Reduced anterior-posterior beta coherency has also been associated with greater emotional involvement during emotion stimulation paradigms, perhaps indicating decreased involvement of the prefrontal cortex when evaluating emotional information [20]. It is possible that reduced beta coherency represents hyper-reactivity to the emotional stimuli in autistic adults with less prefrontal involvement to control this response [20]. Decreased alpha coherency with increased right theta coherency during negative FER was also observed, possibly suggesting that autistic adults had atypicalities in the modulation of attention [6] and greater voluntary control of emotion processing during negative FER [7].

While this study provides insights into the mechanisms of FER processing in ASD, a number of limitations must be noted. While the accuracy of coherence measures may be questioned, in extracting the imaginary part of coherency, issues related to volume conduction associated with traditional coherency calculations are effectively resolved [17]. Further, while findings of altered connectivity in autistic adults differed as a function of emotional valence, providing intriguing insights into the mechanisms of FER in autistic adults, these findings were based on a limited number of stimuli. Future research may benefit from more thorough investigation of these potential valence-linked differences in connectivity.

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