Resting state aperiodic slope predicts Research Domain Criteria Social Processes in young typically developing adults

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Abstract

Background: The aperiodic slope has been utilized to demonstrate differences in brain excitation-inhibition (E/I) in ageing, cognition, and neuro- and psycho-pathology. Furthermore, E/I imbalance has been associated with social communication difficulties in clinical and non-clinical groups. No work to date has explored the association between aperiodic activity and social communication difficulties.
Methods: A total of 40 typically developing young adults aged 18-24 (24 female; age mean=21.6, SD=1.9) each underwent 5 minutes each of eyes open and eyes closed resting state EEG using a 64-channel HydroCel Geodesic Sensor Net. Participants also completed Research Domain Criteria Social Processes measures: Social Responsiveness Scale (SRS), Reading the Mind in the Eyes task (RME), and Penn Emotional Recognition Task (PER).
Results: Sex differences in aperiodic slope and offset were observed, with steeper slope and greater offset observed in males, suggestive of increased inhibitory tone in this subgroup ($ps<.05$). Whole-brain aperiodic activity was not associated with SRS or RME scores, however better PER performance was differentially associated with left social brain slope and right social brain offset, with left slope decreasing (i.e., increasing E/I) and right offset increasing (i.e., decreasing E/I) with better performance ($ps<.05$).
Conclusions: These data show promise for supporting the notion that brain E/I is associated with social communication and processing difficulties, and this may extend to clinical groups (e.g., autism).

1. Introduction

Maintaining the equilibrium of excitatory and inhibitory synaptic membrane currents is essential for neural development, information processing, and memory storage (1). The brain's primary inhibitory neurotransmitter, gamma-aminobutyric acid (GABA), is responsible for regulating levels of excitatory glutamate, with disturbance to inhibitory tone leading to hyper-excitation. Likewise, disruption to excitatory glutamatergic processes can result in hyper-excitation depending on the location and nature of the disturbance (2). An imbalance in brain excitation/inhibition (E/I) ratios biased toward hyper-excitation has been associated with several psychopathologies and neurodevelopmental conditions, such as autism spectrum disorder (3–8), schizophrenia (9,10), and epilepsy (11,12).

Both animal and human studies point firmly toward E/I imbalance as a putative marker of social communication difficulties (13–16). Human neuroscientific studies support the role of brain E/I in social communication (17,18), with increased glutamate and/or reduced GABA levels associated with social communication difficulties in clinical (14,19–24) and non-clinical samples (22,25,26). Furthermore, psychopharmacological interventions that enhance brain inhibition, such as cannabidiol (CBD), riluzole, and R-Baclofen (STX209), have been shown to improve social functioning in children and adults with autism (27–33). In mice, optogenetic enhancement of excitation led to impairment in social behaviors, while systematically increasing inhibitory tone thereafter partially rescued these impairments (16). Similarly, low-frequency repetitive transcranial magnetic stimulation (TMS), which is known to inhibit neural activity, improved autism-like social and behavioral outcomes (34). Further, pharmacologically enhancing excitation reduces social behaviors in mice (13), while enhancing inhibition in autism mouse models improves social, cognitive, and behavioral outcomes (15,35).

Electroencephalography (EEG) has long been utilized as an accessible and affordable tool to probe the relationship between brain and behavior, particularly in relation to psychiatric and neurodevelopmental conditions (36). Putative markers of excitation and/or inhibition include mismatch negativity (37–39), functional E/I ratio (3), and oscillatory activity in delta, theta and gamma bands (40–44). Recent developments in resting state and task-related EEG data analysis have revealed that the broadband aperiodic signal, in contrast to periodic activity within a narrowband frequency range (i.e., neuronal oscillations), might be a more accurate reflection of E/I balance (45–47). Aperiodic activity is the background, scale-free activity that is represented on a 1/f-like power distribution, where spectral power decreases as frequency increases (45,48). The aperiodic signal, which is comprised of both the exponent (spectral slope) and offset (broadband shift in power across frequencies), is thought to reflect the integration of underlying synaptic currents (49). These currents have a double-exponential shape in the time domain, which produces the 1/f-like spectrum (45,46). Excitatory currents have a faster time constant and produce constant power at lower frequencies before rapid decay, while power decays more slowly as a function of frequency

for inhibitory currents. Thus, a smaller exponent (flatter 1/f-like slope) reflects more excitation relative to inhibition, while a larger exponent (steeper slope) reflects the converse (45,46). Given its utility for examining E/I balance across the cortex, and relative affordability and simple acquisition, the aperiodic slope has been utilized to demonstrate E/I differences in neuro- and psycho-pathology (50–53). The aperiodic offset (i.e., the y-intercept of the spectrum) represents the uniform shift of broadband power across frequencies (45,54), and is thought to reflect neuronal population spiking (55,56) and fMRI BOLD signal (57). Aperiodic offset has been associated with age (45,48,58,59), sex (59), and working memory (45,47), but not selective attention and executive control in children (59). No work to date has applied aperiodic activity analyses to explore differences in E/I social communication in a non-clinical sample.

Due to the heterogeneity and spectrum nature of clinical conditions such as autism, it is important to investigate the extent to which brain processes relate to specific symptom domains relevant to specific conditions, rather than within the constraints of diagnostic boundaries. The broader autism phenotype reflects the notion that milder autistic traits are present in varying degrees across the non-clinical population globally (60,61), hence, extensive evidence supports the utility of non-clinical populations in investigating the behavioral and neurobiological characteristics of autism (25,62,63). The Research Domain Criteria (RDoC) highlight the limitations of diagnosis-specific research, and provides a rich framework for understanding psychiatric conditions in the context of varying degrees of symptomatology with neurobiological and/or genetic origins (64). Within the RDoC, the *social processes* domain includes social communication, affiliation and attachment with others, and perception and understanding of the self and others (65). Self-report measures of *social processes* recommended by RDoC include the Social Responsiveness Scale (SRS; 66), while objective measures include the Penn Emotion Recognition (PER; 67), and Reading the Mind in the Eyes (RME; 68) tasks. These measures have been utilized to assess social functioning in both clinical and non-clinical populations. Understanding the neurobiological mechanisms of *social processes*, at both clinical and non-clinical levels, is essential for broader global efforts to identify effective therapeutics to support those with social processing difficulties.

To that end, this study investigates the relationship between RDoC *social processes* and aperiodic activity in a young, non-clinical adults. It was hypothesized that *social processes* difficulties would be associated with a flatter aperiodic slope, indicating reduced global inhibitory tone (E<I). Given there has been no literature published to date on aperiodic activity and social difficulties, we also explored their relationship specifically in right and left temporo-parietal regions, which are known to be involved in social information processing (69–71).

2. Methods and Materials

2.1. Participants

A total of 40 young adults (24 female) aged 18-24 participated in this study (mean age=21.6 years, SD=1.9). Participants had an IQ>90 (mean=114.6, SD=10.15) and were excluded if they self-reported: a history of developmental, psychiatric genetic, or neurological conditions; a first-degree relative with a history of autism spectrum disorder, schizophrenia, bipolar disorder, or other psychiatric condition (not including depression and anxiety); a substance use disorder; regular smoking (> 1 cigarette/day); or taking any psychoactive medications. Participants were asked to abstain from caffeine and nicotine for 12 hours, and recreational drugs for 1 week, prior to testing; confirmation of compliance was made verbally on the day of testing. All participants provided written informed consent prior to any data collection for this study, and ethics approval was granted by Deakin University's Human Research Ethics Committee (2019-208) in accordance with the Declaration of Helsinki.

2.2. Psychometric and Behavioral Measures

Social Responsiveness Scale Version-2 (SRS; 72): The SRS is a 65-item measure of symptom severity across five autism symptom domains: Social Awareness (8 items), Social Motivation (11 items), Social Cognition (12 items), Social Communication (22 items), and Repetitive Behaviors/Restricted Interests (12 items). Responses are measured on a 4-point scale from 1 (*not true*) to 4 (*almost always true*). The psychometric properties of the adult self-report measure of the SRS were assessed by Ingersoll et al. (2011), with good reliabilities across subscales reported in an adult sample (SRS total α=.95, Social Awareness α=.64, Social Cognition α=.78, Social Communication α=.88, Social Motivation α=.81, and Repetitive Behaviors/Restricted Interests α=.81). Within the RDoC framework, the SRS is registered as a measure of Social Communication - reception and production of non-facial communication.

Reading the Mind in the Eyes Task (RME; 68): The RME is a 36-item measure of perception and understanding of conspecific mental states through the assessment an actor's eyes. The computerized task presents consecutive photos of actor's eyes in the center of the screen, and four words (one in each corner of the screen) that might describe the emotional state of the eye. Participants are to select the word that best describes the actor's emotion via mouse click. Accuracy on the RME is scored as the proportion of correct responses (from 0 to 1). Because participants are provided a dictionary of the emotional labels presented, reaction time data are not analyzed. Within the RDoC framework, the RME is a measure of Perception and Understanding of Others – understanding mental states.

Penn Emotion Recognition Task (PER; Gur et al., 2002): The PER task includes 40 color photographs of static faces expressing 4 basic emotions (happiness, sadness, anger, or fear) and neutral expressions. Stimuli are balanced for poser's gender, age, and ethnicity, and for

each emotion category. Four high-intensity and four low-intensity expressions are included. Participants view one image at a time and choose the correct emotion label for each face via mouse click. A composite measure of accuracy and reaction time, the linear integrated speed-accuracy score (LISAS), is calculated according to the following formula: LISAS = RT + (S_{RT} / S_{PE}) x PE, where RT is participant mean reaction time, PE is participant mean proportion of errors, S_{RT} is the standard deviation of the reaction time, and S_{PE} is the standard deviation of the proportion or errors (73). PER LISAS will be referred to as "PER performance" hereafter, with higher scores indicating better performance. Within the RDoC framework, the PER task is a measure of Social Communication – reception of facial communication.

2.3. Electroencephalography data acquisition

EEG data were recorded using a 64-channel HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc, USA) containing silver/silver-chloride (Ag/AgCl) electrodes surrounded by electrolyte-wetted sponges. Electrical Geodesics Net Station EEG software (version 5.0) was used to acquire the data via a Net Amps 400 amplifier using a sampling rate of 1 KHz. Data were referenced online to electrode Cz, and electrode impedances were checked to ensure they were < 50 KOhms prior to data collection. Participants were seated in a quiet, dimly lit room and asked to sit still with their eyes open while looking at a fixation cross for 5 minutes, and then eyes closed for 5 minutes, while resting state data were collected. Electrode impedances were checked between eyes open and eyes closed blocks to ensure they remained < 50 KOhms. One participant withdrew from the study and did not undergo EEG.

2.4. EEG Pre-processing

EEG data were pre-processed in MATLAB (R2021a; The Mathworks, Massachusetts, USA) incorporating the EEGLAB toolbox (v2023.0; 74) and custom scripts. The Reduction of Electroencephalographic Artifacts (RELAX; v1.1.2) software (75,76) was used to clean each EEG dataset. The fully automated RELAX pipeline uses empirical approaches to identify and reduce non-neural artifacts, and includes the use of both multi-channel Wiener filters and wavelet enhanced independent component analysis (ICA). As part of the RELAX pipeline, the data were bandpass filtered between 0.5 and 80 Hz (fourth-order zero-phase Butterworth filter). A notch filter (47-53 Hz) was then applied to remove any line noise. Any bad channels were removed using a multi-step process incorporating the 'findNoisyChannels' function (PREP pipeline; 77). Multi-channel Wiener filtering (78) was used to initially clean blinks, muscle activity, and horizontal eye movement, followed by robust average re-referencing (77), and wavelet-enhanced ICA (78), with components for cleaning identified using the automated independent component (IC) classifier IClabel (79). Any rejected electrodes were then interpolated back into the data using spherical interpolation and all pre-processed data files were visually inspected prior to further analysis.

2.5. Electroencephalography data analysis

All pre-processed resting state data were visually inspected for quality assurance prior to inclusion in statistical analyses. Two participants were excluded from the study due to excessive line noise for both eyes open and eyes closed conditions, and an additional two participants' eyes open data were excluded due to excessive line noise. The power spectral density of the EEG signal was calculated using Welch's method (2-second Hamming window, 50% overlap) for all electrodes across all participants for both the eyes-open and eyes-closed datasets. The FOOOF toolbox (version 1.0.0; https://fooof-tools.github.io/fooof/; 45) was then used to parameterize the spectral data through separation of the periodic and aperiodic components of the signal. The aperiodic exponent and offset were extracted across 1 to 40 Hz using the 'fixed' aperiodic mode. Spectral parameterization settings for the algorithm were: peak width limits=[1, 12], maximum number of peaks=8, peak threshold=2, minimum peak height=0.05.

The performance of the FOOOF algorithm for fitting the data was assessed using two "goodness of fit" measures: R^2, explained variance; and mean absolute error (MAE), total error of the model fit (45,51). Model fits for both eyes open and eyes closed data were good (eyes open: R^2=.99, MAE=.047; eyes closed: R^2=.99, MAE=.054. Complete fit statistics are presented in the Supplementary Material). There was no difference in mean R^2 between eyes open and eyes closed conditions (t(64.13)=-.30, p=.765), while MAE for eyes open was significantly lower compared to eyes closed (t(69.44)=2.19, p=.032). Aperiodic exponent (slope) was significantly larger for eyes closed condition (t(69.65)=2.82, p=.006), indicating a steeper slope than for eyes open. Similarly, the offset (intercept) was larger for eyes closed than eyes open condition (t(69.97)=3.0, p=.004). There were strong, positive correlations between exponent and offset for eyes open (*rho*=.73, p<.001) and eyes closed (*rho*=.80, p<.001), and between eyes open and closed exponent (*rho*=.73, p>.001) and eyes open and closed offset (*rho*=.78, p<.001).

2.6. Statistical analyses

Statistical analyses were conducted in R (version 4.1.0). Multivariate linear models (MLMs) were designed to assess the extent to which aperiodic slope and offset with eyes open and eyes closed predicted *social processes* outcomes (SRS total, PER IES, and RME accuracy). Separate models were defined for exponent and offset (i.e., model 1 predictors included eyes open exponent and eyes closed exponent, model 2 included eyes open offset and eyes closed offset; see Supplementary material for full model deigns). Assumptions for all MLMs were assessed using the *olsrr* and *MVN* packages in R (80,81), including normality, linearity, homoscedasticity, and multicollinearity. All assumptions were met, except for a significant skew in RME and PER LISAS scores, which was subsequently normalized using the Yeo-Johnson transform in R (VGAM package; 82).

Exploratory MLMs were also designed to investigate the extent to which left and right social brain aperiodic activity predicted *social processes* outcomes. To calculate aperiodic slope and offset in social brain regions, electrodes over left and right temporo-parietal regions were averaged separately (left: P5 CP5 TP9 TP7 C5 T7 T9; right: P6 CP6 TP10 TP8 C6 T8 T10; see Figure 1). These electrodes cover brain regions including the superior, middle, and inferior temporal gyrus, supramarginal gyrus, and angular gyrus, all known to be involved in social information processing (69–71). False discovery rate was corrected for using the Benjamin Hochberg method in R (stats package; 83).

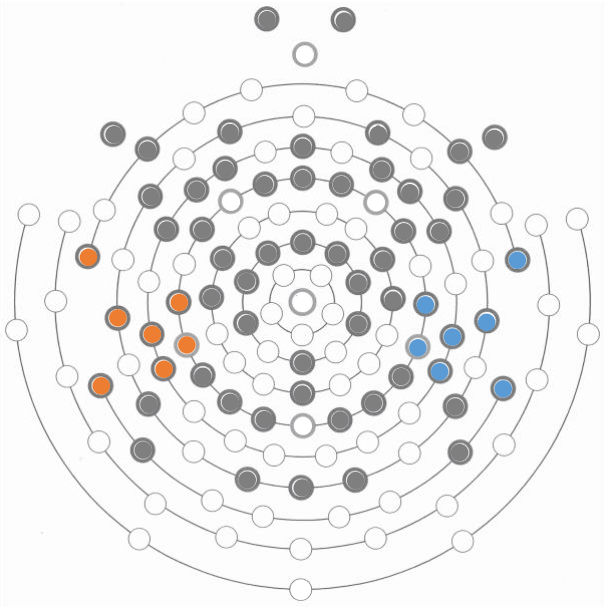

Figure 1: Electroencephalograph electrode placement. 64-channel Geodesic Sensor Net electrode placement (dark circles), with the cluster of electrodes selected to represent left (blue) and right (orange) social brain highlighted.

3. Results

3.1. Descriptive statistics

Descriptive statistics for final participant sample characteristics (n=37), *social processes* outcomes, and aperiodic activity metrics are presented in Table 1. There were no significant age or biological sex effects on *social processes* measures (ps>.05), and no significant correlations between age and aperiodic activity outcomes (ps>.05). However, males compared to females had a significantly steeper exponent ($t(24.20)=-2.56$, $p=.017$, $p_{FDR}=.033$) and higher offset ($t(29.20)=-2.08$, $p=.047$, $p_{FDR}=.047$) during eyes open, as well as a steeper exponent ($t(33.76)=-2.83$, $p=.008$, $p_{FDR}=.032$) and higher offset during eyes closed ($t(34.90)=-2.34$, $p=.025$, $p_{FDR}=.033$; Figure 2).

Table 1: Descriptive statistics of psychometric, behavioral, and aperiodic activity measures

	Total (N=37)		Female (n=22)	Male (n=15)
	Mean (SD)	Min-Max	Mean (SD)	Mean (SD)
Age	22 (1.9)	18 – 25	21 (1.9)	22 (1.9)
IQ	115 (9.8)	91 – 148	114 (8.2)	117 (12)
Social Processes				
SRS total	52 (6.8)	42 – 69	51 (5.8)	54 (8.4)
SRS SCI	53 (6.9)	42 – 71	52 (5.6)	54 (8.6)
SRS RRB	53 (8.4)	40 – 73	51 (7.2)	55 (10)
RME accuracy	.81 (.08)	.64 – .94	.83 (.08)	.78 (.08)
PER RT	2.9 (.69)	2.0 – 4.9	2.8 (.48)	3.0 (.94)
PER accuracy	.89 (.05)	.78 – .97	.90 (.04)	.86 (.05)
PER performance	3.3 (.97)	2.2 – 7.0	3.1 (.65)	3.5 (1.3)
Aperiodic activity				
Whole brain				
EO exponent	1.2 (.17)	.96 – 1.7	1.2 (.14)	1.3 (.19)
EC exponent	1.3 (.17)	.95 – 1.7	1.3 (.17)	1.4 (.14)
EO offset	.21 (.38)	-.47 – 1.4	.10 (.36)	.36 (.38)
EC offset	.49 (.41)	-.63 – 1.3	.37 (.44)	.66 (.31)
Left social brain				
EO exponent	1.2 (.19)	.96 – 1.7	1.2 (.15)	1.3 (.21)
EC exponent	1.3 (.20)	.86 – 1.7	1.3 (.20)	1.4 (.15)
EO offset	.16 (.41)	-.50 – 1.5	.014 (.34)	.35 (.43)
EC offset	.42 (.45)	-.67 – 1.3	.25 (.45)	.66 (.35)
Right social brain				
EO exponent	1.2 (.20)	.67 – 1.7	1.2 (.18)	1.3 (.19)
EC exponent	1.3 (.20)	.77 – 1.6	1.2 (.21)	1.4 (.13)
EO offset	.18 (.42)	-.84 – 1.3	.026 (.37)	.38 (.41)
EC offset	.43 (.48)	-1.0 – 1.2	.26 (.50)	.67 (.34)

Notes: SD=standard deviation, SRS=Social Responsiveness Scale, SCI=Social Communication Index, RRB=Restricted Repetitive Behaviors, RME=Reading the Mind in the Eyes, PER=Penn Emotion Recognition Task, RT=reaction time, performance=linear integrated speed-accuracy score (LISAS), EO=eyes open, EC=eyes closed.

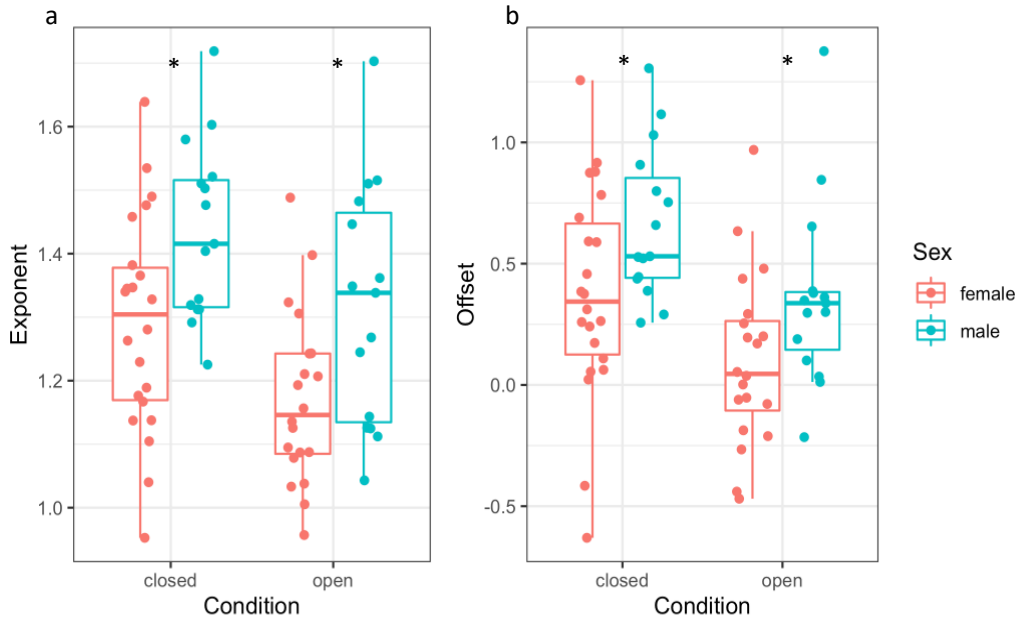

Figure 2: Sex differences in aperiodic activity. Sex differences in exponent (a) and offset (b) for eyes open and eyes closed conditions. *p_{FDR}<.05

3.2. Social processes outcomes

Spearman's rho correlations were conducted to test the relationship between the three *social processes* measures. There were no significant relationships between SRS total scores and RME accuracy or PER performance (*ps*>.05). The relationship between PER performance and RME accuracy was significant, with PER performance increasing with RME accuracy as would be expected (*rho*=.391, *p*=.018, p_{FDR}=.026).

3.3. Whole-brain aperiodic activity MLMs

Multivariate linear models were designed to test the extent to which aperiodic exponent and offset predicted *social processes* outcomes of SRS scores, RME accuracy, and PER performance. In the first model, the exponent values for both eyes open and eyes closed conditions were entered as predictors, however, these were not significant predictors of SRS total score (R^2_{adj}=.058, *F*(2,31)=2.01, *p*=.150), PER performance (R^2_{adj}=-.057, *F*(2,31)=.12, *p*=.885), or RME accuracy (R^2_{adj}=.032, *F*(2,31)=1.55, *p*=.228; Figure 3). In the second model, the offset values for both eyes open and eyes closed conditions were entered into the model as predictors of *social processes* outcomes. Again, offset was not a significant predictor of SRS total score (R^2_{adj}=-.013, *F*(2,31)=.80, *p*=.460), PER performance (R^2_{adj}=-.044, *F*(2,31)=.31, *p*=.738), or RME accuracy (R^2_{adj}=.065, *F*(2,31)=2.14, *p*=.134; Figure 3).

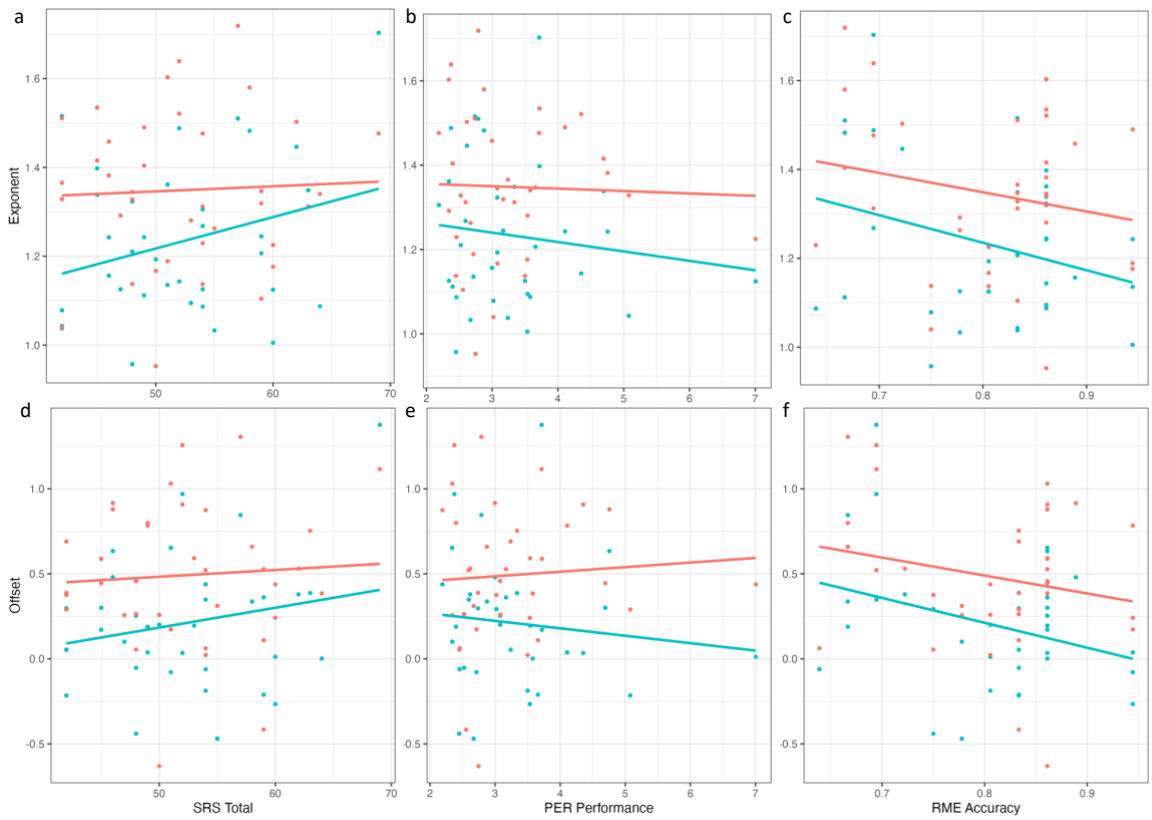

Figure 3: Scatter plots of aperiodic activity and Social Processes outcomes. Scatter plots of exponent (top[a-c]; model 1) and offset (bottom[d-e]; model 2) versus SRS total score (left[a,d]), PER performance (middle[b,e]) and RME accuracy (right[c,f]), in eyes open (green) and eyes closed (red) conditions.

3.4. Social brain aperiodic activity MLMs

Exploratory analyses were conducted to investigate whether aperiodic activity in social brain regions specifically might predict *social processes* outcomes (SRS, PER performance, RME accuracy). Therefore, measures of exponent and offset for both eyes open (EO) and eyes closed (EC) conditions were averaged over temporo-parietal clusters in right and left hemisphere (Figure 4), and two models were defined for exponent and offset separately with four predictors each (i.e., left STS EO, left STS EC, right STS EO, right STS EC) (see Supplementary material for models). None of the overall models for SRS, PER performance, and RME accuracy for both exponent and offset predictors were significant (*p*s>.1). When looking at the individual predictors in the models, left STS exponent (β=-.042, t=-2.18, p=.037), and right STS offset (β=.025, t=2.06, p=.049) predicted PER performance in the eyes closed condition (Figure 4). That is, when participants had their eyes closed, right offset increased (i.e., decreased E/I ratio) with increasing PER performance, while left STS exponent decreased with better performance (i.e., increased E/I ratio).

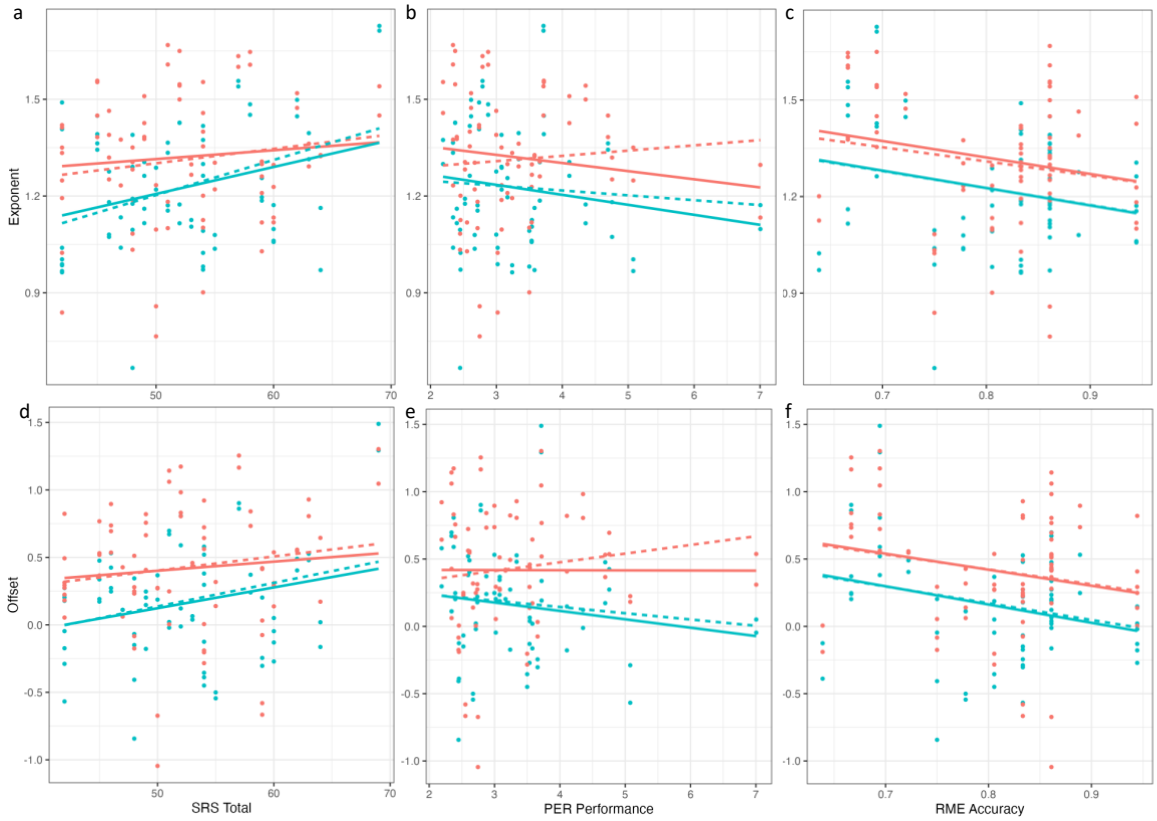

Figure 4: Scatter plots of aperiodic activity by hemisphere and Social Processes outcomes. Scatter plots of exponent (top[a-c]; model 1) and offset (bottom[d-f]; model 2) versus SRS total score (left[a,d]), PER performance (middle[b,e]) and RME accuracy (right[c,f]), in eyes open (green) and eyes closed (red) conditions from the left (solid line) and right (dotted line) social brain regions.

4. Discussion

Investigations of aperiodic activity (exponent and offset) are increasingly reported across neurodevelopmental, cognitive, and psychiatric datasets as a putative measure of brain E/I ratios (50–53,84), with a steeper exponent (slope) indicating more brain inhibition (i.e., reduced E/I). This study was the first, to our knowledge, to investigate the extent to which resting state aperiodic activity predicts RDoC *social processes* outcomes in non-clinical young adults.

Given a shift in E/I towards increased excitation has been associated with social communication difficulties in clinical, non-clinical, and animal studies (13–15,25), it was predicted that reduced (i.e., flatter) aperiodic slope would be associated with more social communication and processing difficulties. Contrary to expectations, the aperiodic slope averaged across all electrodes (i.e., whole brain) did not predict *social processes* outcomes in either the eyes open or eyes closed condition. This may indicate that: 1) predictive power of exponent and offset is possibly region-specific, thus including all electrodes introduces substantial noise that effectively drowns out any signal; 2) there was insufficient power to

detect an effect; and/or 3) E/I measured by aperiodic brain activity does not predict the RDoC *social processes* measures utilized here.

To explore the regional specificity of aperiodic activity to social processes, two 'social brain' clusters were created left and right hemisphere that localized to superior, middle, and inferior temporal gyrus, supramarginal gyrus, and angular gyrus (71). These regions are known to be involved in social information processing (69,70). Results of the regression models suggested that aperiodic activity within these left and right social brain regions overall did not predict social processes outcomes in our non-clinical sample. When inspecting the individual regression coefficients within each model, however, there was some indication that better facial emotion recognition (PER performance) was associated with a flatter exponent (i.e., higher E/I ratio) in left social brain. In contrast, in right social brain, higher offset (i.e., shift in broadband power across frequencies) was associated with better facial emotion recognition. It is important to note that these effect sizes were very small and should therefore be interpreted cautiously.

Further investigations with larger samples are essential to support this finding, particularly given the relationship is in the opposite direction to what would be expected. Previous research suggests that social communication difficulties are associated with an increase in E/I (8,16), implying increased excitation and/or reduced inhibition. However, more recent research has suggested that the nature of the E/I imbalance, that is increased excitation or increased inhibition, is region specific (7,17,18), and regional specificity of increased inhibitory tone has been reported in mouse models (85). The increased inhibitory tone in social brain regions in conjunction with more social communication difficulties observed in this study may reflect underlying neurobiological mechanisms.

In line with previous literature, males had a significantly higher aperiodic offset and steeper slope than females in both eyes open and eyes closed conditions (48,59). Sex differences in a prior adolescent sample were thought to reflect an advanced neurophysiological maturity in females (86), which may be the case in this young adult sample as neurodevelopment continues into early adulthood for both males and females (87). Contrary to previous reports (45,48,58,59), exponent and offset were not associated with age, which may reflect that aperiodic activity is relatively stable between 18 and 25 years, or that the age range of the sample was too narrow to detect age effects. Also, in line with previous research in children and adolescents, steeper exponent and higher offset were recorded in the eyes closed compared to eyes open condition (48,59). This reflects a reduction in E/I when eyes are closed, which could be explained by the lack of visual stimulation, attention, and arousal, compared to when participants' eyes were open (88).

There were no significant relationships between RDoC *social processes* self-report (SRS) and behavioral (RME, PER) outcomes in this study. This was somewhat unexpected and possibly

problematic given the three measures, SRS, RME and PER, are proposed by the RDoC as gold standard measures of the *social processes* constructs. Although they appear to index different aspects of social processes, namely social communication (reception of facial communication [PER], and reception and production of non-facial [SRS]), and perception and understanding of others (understanding mental states [RME]), it is reasonable to expect that they would be related. The lack of interrelationship in this study may reflect the limited spread in performance/difficulties in the tasks in this non-clinical sample, insufficient data, or that the measures have poor construct validity, potentially due to poor insight when completing self-report measures.

The main limitations for this study were the modest sample size (N=37) and narrow spread of social processes difficulties, particularly for SRS scores. These issues combined may have been a significant contributor to the lack of statistically significant findings, given the small effect sizes reported herein. A more diverse spread of abilities within the sample, for example including clinical participants, may have revealed more compelling relationships between aperiodic activity and social processing abilities. Furthermore, EEG is limited in its ability to examine social brain areas specifically due to its relatively poor spatial resolution. Source localization using magnetoencephalography (MEG) and concurrent participant structural brain scans would allow for a more accurate analysis of social brain and social processes abilities.

Despite these limitations, this preliminary data shows promise for supporting the notion of an imbalance in brain E/I associated with social communication processing difficulties across clinical and non-clinical groups. Aperiodic exponent and offset were moderately associated with emotion recognition abilities, particularly in the left and right social brain regions. Future work should seek to examine this relationship in a larger sample across clinical and non-clinical populations. Furthermore, studies involving pharmacological interventions that modulate excitatory and/or inhibitory processes would provide valuable insights into the utility of the aperiodic slope as a putative neurobiomarker of social processes abilities.

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