NeuroRegulation

ISNR
INTERNATIONAL SOCIETY FOR
NEUROREGULATION & RESEARCH

EEG Signatures of Resilience Across Individuals With High and Low Anxiety

Sahen Gupta[1*] *and Jayasankara Reddy*[2]

[1]University of Portsmouth, School of Psychology, Sport & Health Sciences, Portsmouth, United Kingdom
[2]CHRIST (Deemed to be University), Department of Psychology, Bengaluru, India

Abstract

Background. Over the past decade, psychological resilience has become a key focus in psychological science. However, most research relies on self-report and psychosocial assessments to explore resilience across different populations and contexts. **Methods.** This two-phased study examined resilience using self-reported measures and EEG recordings. Phase 1 involved a cross-sectional analysis of resilience and anxiety in young adults using correlation and regression analysis. Phase 2 utilized a grouped experimental design with EEG resting-state recordings to compare high- and low-resilience individuals. EEG data were collected using a 64-channel Geodesic Sensor Net, NetAmps 400 Amplifiers, and NetStation Acquisition 5.0 Software. Spectral analysis was performed for group comparisons. **Results.** Significant EEG differences emerged between high- and low-resilience groups in the anterior midline, right frontal, right central, left parietal, and right parietal regions. Alpha band differences were predominantly frontal and right-sided, while beta band differences were posterior and left-sided. **Conclusions.** Results of the two phased study bridge the gap between psychosocial measures and electrophysiological measures in the study of resilience and anxiety. A conceptual model based on the findings is outlined to guide future research to investigate the mechanism between resilience and clinical presentations of anxiety and/or depression at the psychosocial and electrophysiological level.

Keywords: resilience; EEG; anxiety; neuropsychology; young adults

Citation: Gupta, S., & Reddy, J. (2025). EEG signatures of resilience across individuals with high and low anxiety. *NeuroRegulation, 12*(1), 12–28. https://doi.org/10.15540/nr.12.1.12

***Address correspondence to**: Sahen Gupta, Senior Lecturer, School of Psychology, Sport & Health Sciences, University of Portsmouth, Spinnaker Building, Cambridge Road, Portsmouth, United Kingdom (PO12EF). Email: sahen.guptaofficial@gmail.com

Copyright: © **2025**. Gupta and Reddy. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC-BY).

Edited by:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA

Reviewed by:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA
Randall Lyle, PhD, Mount Mercy University, Cedar Rapids, Iowa, USA

Introduction

Psychological science has examined cognitive, emotional, psychosocial, and behavioral indices of response to stress or adversity for nearly four decades to grapple with the question of what makes individuals successfully cope with and overcome many adversities across their lifetime (Southwick & Charney, 2018). Stress and anxiety in adulthood is detrimental to happiness and optimal functioning (Joëls et al., 2007). Stress is a condition or set of conditions that perturbs the psychological and physiological balance of the individual compromising homeostasis (Franklin et al., 2012). Psychological resilience is the individual's ability to engage metacognitive, emotional, behavioral resources to maintain a positive equilibrium and successfully adapt to adversity (Gupta & McCarthy, 2021; Prince-Embury, 2014). Simply put, collision with adversities in life causes significant stress and/or trauma and resilience is what helps one to adapt (Luthar et al., 2000).

Resilience has been extensively researched from behavioral and psychosocial perspectives (Bonanno, 2004; Bonanno & Diminich, 2013; Charney, 2004; Cicchetti, 2010; Feder et al., 2009; Holman, 2011; Masten, 2001). Evidence has identified states and protective factors associated with resilience (Fletcher & Sarkar, 2013). However, due to a lack of studies addressing both psychosocial and neuropsychological indices of resilience which constitutes a glaring gap in the knowledge base (Feder et al., 2009). From a psychobiological foundation, resilience, the dynamic process of responses to adversity, consists of short- and long-term responses that reduce allostatic load (Curtis & Cicchetti, 2007; Feder et al., 2009). Several anatomical loci and functional connectivity in specific networks of the brain have been highlighted as having a key role in stress resistance and/or vulnerability; for example, amygdala activation (Davidson & McEwen, 2012; Kim, 2011; Mahan & Ressler, 2012), the hippocamus-pituitary-adrenal (HPA) axis (de Kloet et al., 2005), the medial prefrontal cortex, and dorsal ralphe nucleus (Franklin et al., 2012).

There is only limited research using EEG and/or functional magnetic resonance imaging (fMRI) that examines the neuropsychological foundations of resilience in healthy populations. Waugh et al. (2008) using task-based fMRI found that, when facing threats, participants with high resilience had prolonged activity in the insula to only adverse stimuli; however, participants with low resilience had prolonged activity in the insula to neutral and adverse stimuli. This suggests that individuals with greater resilience effectively adjust emotional resources used based on the situation. Kim and Bell (2006) linked the development of regulatory behavior, a predictor of resilience, to frontal asymmetry. Resilience was positive correlated with left orbitofrontal cortex and right amygdala activation in fMRI when firefighters had a relaxation versus a trauma script, indicating emotional reactivity to stress plays a role in resilience (Reynaud et al., 2013). Kong et al. (2015) employed the regional homogeneity (ReHo) measure to explore neural correlates of trait resilience and discovered that higher ReHo in the anterior cingulate cortex (ACC) and the insula within salience network was associated with lowered trait resilience. The study, however, failed to find an association of resilience with other prefrontal cortex (PFC) regions such as the orbitofrontal cortex (OFC). Amyg-EFP-NF (amygdala activation guided neurofeedback training) reduces alexithymia and faster emotional Stroop indicating better resilience among soldiers (Keynan et al., 2019). This may be explained by the moderating influence of theta/beta ratio on the effects of stress on attention control biases (Putman et al., 2014). Using resting-state EEG measures from delta, alpha, and beta bands from healthy participants, Paban et al. (2019) have demonstrated a negative association between brain network flexibility and psychological resilience. A measure of autonomic response to emotion, the late positive potential (LPP) for negative pictures, was also reported to be negatively correlated with resilience, and this was seen to be driven primarily by optimism, a composite factor in resilience (Chen et al., 2018). However, a limitation of these studies is their focus on emotion processing. As such, except for Paban et al. (2019) who have examined flexibility of networks, no other study has examined if resilience affects the resting brain state in a holistic manner in order to generate markers of resilience.

This study uses the framework of the multisystem model of resilience (Liu et al., 2017) which conceptualizes psychological resilience to be comprised of three structures. First, the innermost layer (i.e., physiological and demographic profile); second, the intermediate layer (i.e., internal factors psychological makeup, personal experiences); and third, the outer later (i.e. external, environmental factors). However, except for a few studies (Kong et al., 2015; Paban et al., 2019; Reynaud et al., 2013; Waugh & Koster, 2015), none have focused solely on exploration of the biological component. To address this gap, we build upon extant evidence that hypothesized resilience to be linked to regions within the PFC ACC and medial PFC (mPFC; Liberzon & Sripada, 2007; Milad et al., 2009; Sekiguchi et al., 2015). The study is a two-staged study with psychosocial indices of resilience being confirmed in the sample before a pilot exploration of electrophysiological indices. In doing so, this study finds significance by combining self-reported psychosocial aspects of resilience with electrophysiological EEG markers to provide a holistic insight into psychological resilience. Resilience has an inverse relationship with anxiety in young adults (Chesak et al., 2019; Connor & Davidson, 2003; Roberts et al., 2021; Steinhardt & Dolbier, 2008), acting as a protective factor (Dray et al., 2017; Gupta & McCarthy, 2021, 2022; Shin & Choi, 2020; Song et al., 2021). Therefore, resilience to stress and anxiety provides fertile ground to investigate neural differences in resilience. Hence in the current study, the first phase measured resilience and anxiety levels and identified a group of individuals with high resilience–low anxiety and low resilience–high anxiety. Subsequently, a selected small sample from both groups underwent EEG recording with a 64-channel EEG system. This novel study reports on the relationship between resilience and anxiety and aims to formulate an understanding of an electrophysiological profile for a resilient individual and, in particular, seeks to establish markers in the EEG of individuals with high psychological resilience and low anxiety as compared to individuals with low psychological resilience and high anxiety.

Method

Recruitment and Screening (Phase 1)

Participants (*n* = 130) were recruited from population from young adults ($\text{Age}_{\text{range}}$ = 18–24). For Phase 1 (i.e., screening phase), purposive multi-stage sampling was conducted to ensure equal distribution of males and females based on sampling criteria. Individuals with diagnosed mental health disorders, learning disabilities, or sensory or motor deficits were excluded from the study since the goal was to understand EEG signature of resilience in healthy adults. Individuals with formal training in muscle relaxation, biofeedback or neurofeedback, and yoga were excluded to control again extraneous variables, since they act as a protective factor against anxiety. The study was reviewed and approved by the CHRIST (Deemed to be University) Ethics Committee (CU-RECEC-8/19). Participants were briefed on the procedures of the study, voluntary withdrawal rights and data protection protocols. Informed consent was obtained.

Procedure

Purposive sampling was undertaken for Phase 1 screening. Participants (*n* = 130) were briefed on the aims and objectives of the study and informed consent was obtained in line with the American Psychological Association code of ethics for psychologists. Participants were provided physical copies of the informed consent, demographic details questionnaire, and psychometrics. Identifying information was anonymized prior to screening analysis to mitigate potential bias. Psychometric measures were used to screen for psychological resilience, perceived stress, and anxiety.

Measures

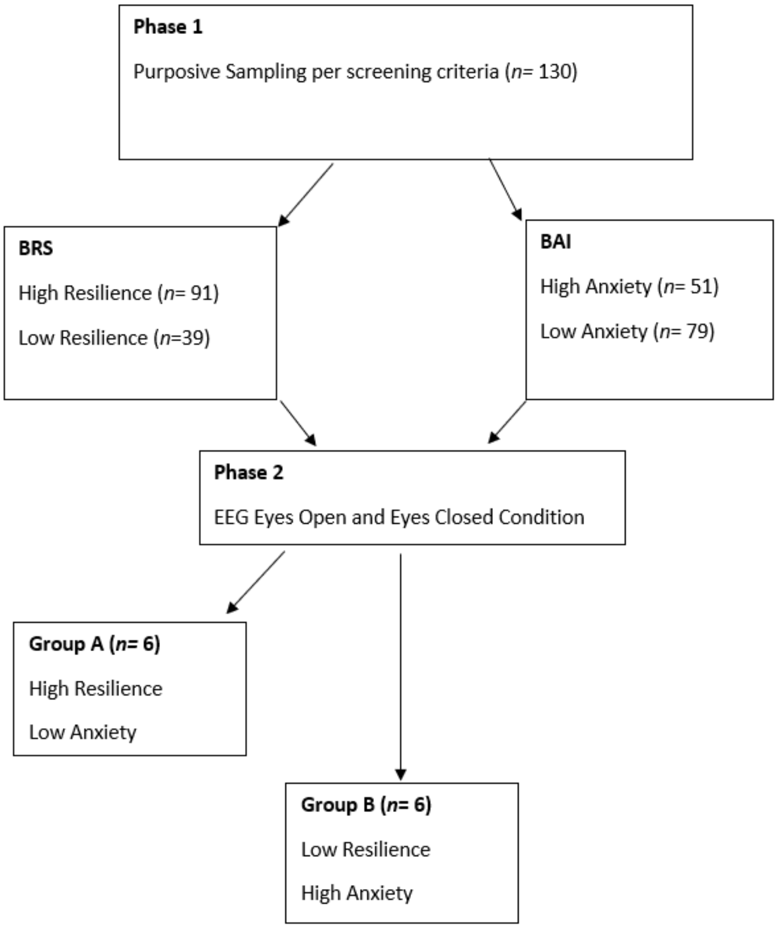
Brief Resilience Scale (BRS). The BRS developed by Smith et al. (2008) is a six-item measure of resilience to adapt and bounce back from stress and anxiety. BRS has been validated in young adults, cardiac patients, fibromyalgia, vocational rehabilitation adults, and among individuals with high anxiety and healthy controls (Jones et al., 2016; Kyriazos et al., 2018; Salah et al., 2021). It has adequate internal consistency across validation studies ranging from Cronbach’s α of 0.71 to 0.91.

Perceived Stress Scale (PSS). PSS developed by Cohen et al. (1994) is a widely validated instrument that measures the perception to stress (i.e., the degree to which situations are appraised as stressful). Items are designed to tap into how unpredictable, uncontrollable, and overloaded respondents find their lives via their cognitive and affective responses. Review evidence highlights the PSS-10 item questionnaire used in this study has consistency internal reliability across multiple studies Cronbach’s α greater than 0.70 (see Lee, 2012), which indicates adequate reliability.

Beck’s Anxiety Inventory (BAI). BAI (Steer et al., 1990) consists of 21 items which closely represent symptoms of severe anxiety. It measures the following factors: subjective anxiety, neuropsychological arousal, autonomic arousal, and panic (Beck et al., 1991) and has a high internal reliability (Cronbach’s α of 0.91) with a test–retest reliability of 0.75 (Beck et al., 1988). BAI has been evidence to be an effective screening measure of anxiety (Chapman et al., 2009; Leyfer et al., 2006) and has been used in nonclinical samples (Creamer et al., 1995).

Phase 1 Data Analysis. Data was scored according to the scoring instructions for each of the psychometric scales. Data was transferred to Microsoft Excel for sorting and scoring for Phase 1. Correlation and regression analysis was conducted using SPSS 20 to evaluate the relationship between resilience and anxiety in psychometric data obtained. In line with screening criteria, individuals at extreme valences scores of high resilience (4≥), high anxiety (30≥), low resilience (3≤), and low anxiety (21≤) were screened as eligible and were invited to participate in Phase 2 of the study. See Figure 1 for Phases of research.

Figure 1. *Procedural Research Phases Chart.*



Phase 2 Design and Participants

Study used an experimental design comparing EEG data of two groups on eyes-open and eyes-closed experimental conditions. Single-blind group assignment was conducted, and the EEG was recorded. Phase 1 screening rendered 30 potential participants meeting eligibility criteria. Potential participants were approached for voluntary participation in Phase 2 (i.e., EEG recording). Final study consisted of 12 study volunteers (18–24 years of age, 9 women and 3 men). Participants were assigned to groups in line with grouping criteria. Individuals with psychometric scores of high resilience and low anxiety were assigned to Group A. Individuals with psychometric scores of low resilience and high anxiety were assigned to Group B (see Table 1). The participants had no current or previous history of relevant physical illness (head injury, epilepsy) and they had not consumed any caffeinated beverage, drugs, or medication known to affect their EEG.

EEG Recording Sessions

The participants were seated comfortably in a dimly lit sound attenuated room. EEG data were recorded using a 64-channel Geodesic Sensor Net, NetAmps 400 Amplifiers, and NetStation Acquisition 5.0 Software (EGI, Inc., Eugene, OR). Scalp impedances were kept below 50 kΩ. The data was recorded as referenced to Cz with 250 Hz sampling rate. Data was viewed using 0.1 to 70 Hz band pass filter and a Notch filter at 50 Hz and monitored during the recording. All recordings were conducted in the afternoon (12:00 pm to 2:00 pm) or evening (4:00 pm to 6:00 pm). The participants were instructed to relax, and EEG was recorded for 3 min each for both eyes-open and eyes-closed conditions.

EEG Data Preprocessing and Editing

The data were imported offline into Matlab R2016b (The Matworks, Natick, MA, USA) environment using EEGLAB v 14.1.2b (Delorme & Makeig, 2004) and

Table 1
Demographic Information of Phase 2 Participants

Participant Code	Sex	Age	Electronic Devices (hr)	Handedness	Regular Exercise	Group	BRF	BAI
RE3006	F	21	3	88.25 (Right Handed)	YES	A	4.33	18
RE3034	M	24	3	100 (Right Handed)	NO	A	4.16	2
RE3001	F	22	4	100 (Right Handed)	NO	A	4.16	18
RE3003	F	20	5	100 (Right Handed)	YES	A	4	4
RE3004	F	21	2	100 (Right Handed)	NO	A	4.5	5
RE3005	F	21	8	100 (Right Handed)	NO	A	4.16	3
RE2007	F	19	3	100 (Right Handed)	YES	B	2.83	34
RE2006	F	21	4	100 (Right Handed)	YES	B	2.33	32
RE2002	F	19	5	100 (Right Handed)	YES	B	2.5	43
RE2005	F	21	5	100 (Right Handed)	NO	B	2.66	38
RE2004	F	20	3	100 (Right Handed)	YES	B	2	32
RE2003	M	18	5	100 (Right Handed)	NO	B	2.83	34

Note. RE3006, RE3033, RE3001, RE3003, RE3004, RE3005 are categorized as the high resilience group; and RE2007, RE2006, RE2002, RE2005, RE2004, RE2003 are classified as the low resilience group.

mffmatlabio2.02 (Pernet et al., 2019) importer for EGI files to preprocess the raw data. The data was first bandpass filtered between 0.1–45 Hz. Bad channels were identified after manual scanning of each file and subsequently these channels were excluded from the files. Hence, only some files did not contain data from F10, F9 and T9 channels. Eye electrode channels (61, 62, 63, and 64) were also excluded for all files.

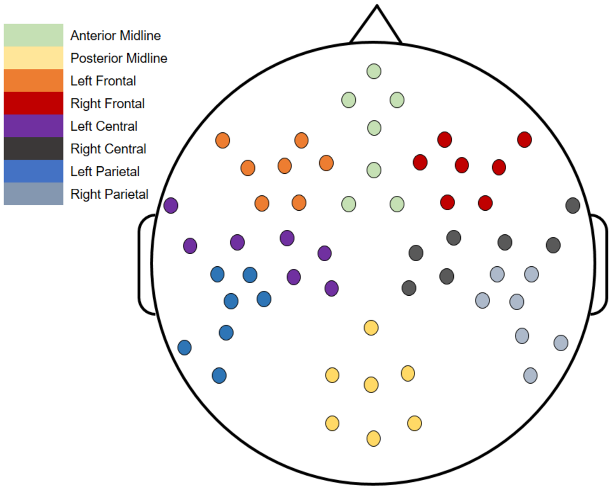
Next the data was segmented into 2-s epochs and the epochs with artifacts (eye blinks, EMG etc.) were rejected via visual inspection. All files with at least 90 s of good data were used. Four participants had only 46 s worth of good data for eyes-open condition. All data files were then rereferenced to average reference prior to the spectral analysis.

Spectral Analysis. Fast Fourier transform was applied using the Darbeliai plug-in (Baranauskas, 2009) for EEGLAB which uses the Welch's method to calculate FFT (window length = 1.996 s, no overlap). Absolute power was computed for all electrodes with good data for the following frequency bands: delta (1–3.5 Hz), theta (4–7.5 Hz), alpha1 (8–10 Hz), alpha2 (10–12 Hz), beta1 (13–15.5 Hz), beta2 (16–20.5 Hz), beta3 (21–30.5 Hz), and gamma (31–49.5 Hz). This was computed for both eyes-open and eyes-closed conditions.

Statistical Analysis. Absolute power data for both eyes-open and eyes-closed conditions was log transformed and subsequently analyzed for low anxiety versus high anxiety group differences using SPSS 20. For analysis, first log power data for each frequency band was aggregated into eight regional averages by grouping electrodes based on topographic contiguity. The regions were labelled as follows: anterior midline, posterior midline, left parietal, right parietal, left central, right central, left frontal, and right frontal (Figure 2). The regional averages were compared across groups (low resilience versus high resilience) using ANOVA.

Absolute power, in the eyes-open condition, for alpha1 (8–10 Hz) and alpha2 (10–12 Hz) for left frontal electrodes was subtracted from absolute power in the right frontal to create the frontal asymmetry score. Greater right frontal asymmetry values are positive and greater left frontal asymmetry values are negative.

Figure 2. *Head Plot Showing the Various Regional Electrode Groups.*



Note. Electrode grouping provided in Appendix A.

Ethical Considerations

Eligible participants for Phase 2 of the study were briefed on the EEG procedures and informed consent was obtained in line with the American Psychological Association code of ethics for psychologists. The study was reviewed and approved by the CHRIST (Deemed to be University) Ethics Committee (CU-RECEC-8/19). Participants were debriefed post-EEG recording. Identifying information such as legal name, address, and contact information data was anonymized with a participant code and stored in an encrypted drive with sole access for the research team in line with general data protection regulation (Voigt & von dem Bussche, 2017). Participants were informed of the voluntary nature of the study and their right to withdraw at any point.

Results

Phase 1 of the study aimed to assess the relationship between resilience and anxiety at obtained from psychometric self-report tests of the larger sample prescreening (*n* = 130). Shapiro-Wilk test of normality revealed data was not normally distributed (Resilience *W* = 0.026; Anxiety *W* = .000). Hence, Spearman's correlation was used, and results indicated a significant negative correlation between resilience and anxiety ($r = -0.392$, $p < .01$). Linear regression analysis indicated that increase in resilience significantly predicted a decrease in anxiety in this sample ($\beta = -6.778$, $p < .01$; see Table 2 below).

Table 2

Linear Regression Model Between Resilience and Anxiety in Phase 1 Sample (n = 130)

Predictor	Beta	*t*	R^2	ΔR^2	F	D-W
Resilience	−6.778	−4.800	0.154	0.147	23.038*	1.749

*$p < .01$.

Results (Phase 2)

From the subsample selected for EEG study, statistical analysis of EEG absolute power data from eyes-closed and eyes-open condition was conducted. ANOVA results revealed significant regional differences between the low resilience versus high resilience group only in the eyes-open EEG for high alpha and all beta bands (see Tables 3–5). Specifically, significant differences were identified between high resilience and low resilience groups in anterior midline region, $F(1, 10) = 5.031$, $p = .049$); right frontal region $F(1, 10) = 5.715$, $p = .038$); right central region, $F(1, 10) = 7.758$, $p = .019$); left parietal region, $F(1, 10) = 6.660$, $p = .027$); and right parietal region, $F(1, 10) = 5.440$, $p = .042$). The difference in EEG Alpha band showed a strong frontal and a right-sided preponderance while the beta band findings were more posterior and left, when comparing between high and low psychological resilience group.

Table 4 shows the comparison of means for all eight frequency bands for the high and low resilience groups in eyes-open condition. This table shows higher power in high alpha and lower power in beta 3 band in some regions for the high resilience group, which was not reflected in ANOVA analysis, perhaps owing to a very small sample size and high variability. Specifically, in high alpha band in eyes-open condition, right frontal area displayed a difference with high resilience group showing higher activation ($M = 11.25$, $SD = 13.62$) compared to low resilience group ($M = 1.94$, $SD = 0.65$). Similar difference was found in anterior midline area with higher activation seen in high resilience group ($M = 16.13$, $SD = 20.29$) compared to low resilience group

Table 3

ANOVA Between High and Low Resilience Groups in High Alpha (10–12 Hz), Beta 1 (13–15.5 Hz), Beta 2 (16–20.5 Hz), and Beta 3 (21–30.5 Hz) Absolute Power

	High Alpha (10–12 Hz) Absolute Power		**Beta 1 (13–15.5 Hz) Absolute Power**		**Beta 2 (16–20.5 Hz) Absolute Power**		**Beta 3 (21–30.5 Hz) Absolute Power**	
Region	F	Sig	F	Sig	F	Sig	F	Sig
Anterior Midlines	5.031	0.049*	0.536	0.481	0.195	0.668	0.000	0.985
Left Frontal	3.489	0.091	0.172	0.687	0.077	0.787	0.083	0.779
Right Frontal	5.715	0.038*	0.442	0.521	0.088	0.773	0.357	0.563
Left Central	4.469	0.061	2.503	0.145	3.276	0.100	5.036	0.049*
Right Central	7.758	0.019*	1.071	0.325	1.548	0.242	0.367	0.558
Left Parietal	6.660	0.027*	5.577	0.040*	5.347	0.043*	8.094	0.017*
Right Parietal	5.440	0.042*	1.524	0.245	0.817	0.387	1.767	0.213
Posterior Midlines	4.008	0.073	1.328	0.276	1.312	2.279	6.443	0.029*

Table 4

Mean and Standard Deviation of All Frequency Bands From the Eyes-Open Condition

		Delta	**Theta**	**Low Alpha**	**High Alpha**	**Beta1**	**Beta2**	**Beta3**
Left Frontal	LR*	7.67 (1.81)^	3.13 (1.72)	2.94 (1.69)	1.93 (1.00)	0.81 (0.48)	2.48 (3.28)	4.94 (5.90)
	HR**	7.67 (2.65)	3.20 (1.18)	3.31 (1.68)	8.95 (10.30)	0.84 (0.28)	1.34 (0.56)	2.59 (0.68)
Right Frontal	LR	7.28 (1.53)	3.19 (1.65)	3.07 (1.66)	1.94 (0.69)	0.88 (0.36)	2.33 (1.87)	7.69 (10.07)
	HR	10.03 (2.93)	3.94 (1.40)	3.42 (1.61)	11.25 (13.62)	1.02 (0.38)	1.66 (0.83)	2.64 (0.95)
Anterior Midline	LR	6.15 (1.44)	4.16 (2.95)	4.28 (2.48)	2.83 (1.44)	0.78 (0.54)	1.11 (0.46)	1.93 (1.45)
	HR	6.30 (1.5)	4.32 (2.43)	4.81 (3.19)	16.13 (20.29)	0.89 (0.36)	1.31 (0.75)	1.76 (0.92)
Left Central	LR	4.26 (1.41)	2.58 (2.35)	2.85 (2.27)	2.12 (1.32)	0.66 (0.46)	0.94 (0.50)	1.36 (0.72)
	HR	5.41 (1.10)	3.11 (1.07)	3.31 (2.00)	8.22 (8.13)	0.96 (0.34)	1.67 (0.92)	2.81 (1.57)
Right Central	LR	4.93 (1.91)	3.00 (2.36)	3.07 (2.40)	1.97 (1.00)	0.80 (0.51)	1.11 (0.49)	1.86 (0.70)
	HR	5.51 (1.23)	3.46 (1.48)	3.50 (1.87)	9.41 (8.50)	0.99 (0.35)	1.66 (0.91)	2.28 (1.30)
Left Parietal	LR	4.18 (1.05)	2.96 (2.58)	3.51 (2.00)	2.38 (0.88)	0.69 (0.32)	0.98 (0.50)	1.34 (0.51)
	HR	6.05 (1.96)	3.94 (1.48)	5.70 (4.42)	21.09 (28.06)	1.55 (0.75)	2.38 (1.36)	3.77 (2.28)
Right Parietal	LR	4.59 (1.53)	3.05 (2.28)	5.12 (2.70)	3.74 (2.30)	0.82 (0.46)	1.20 (0.22)	1.46 (0.50)
	HR	4.97 (1.05)	3.39 (1.48)	6.74 (4.50)	16.28 (10.27)	1.26 (0.53)	1.92 (1.28)	2.54 (1.62)
Posterior Midline	LR	7.48 (1.85)	3.80 (2.13)	7.34 (3.92)	5.26 (2.86)	1.21 (1.00)	2.33 (1.87)	1.29 (0.47)
	HR	7.81 (2.34)	4.32 (2.43)	8.32 (5.96)	39.05 (50.58)	1.75 (1.05)	1.66 (0.83)	3.06 (1.85)

*LR = Low Resilience; **HR = High Resilience; ^ = Mean (*SD*).

(*M* = 2.83, *SD* = 1.44). High resilience group showed higher activation in right central (*M* = 9.41, *SD* = 8.50) and right parietal areas (*M* = 16.28, *SD* = 10.07). Hypothesis H2 stating differences between high and low resilience groups in alpha band and hypothesis H4 stating differences between high and low resilience groups in beta band stands supported.

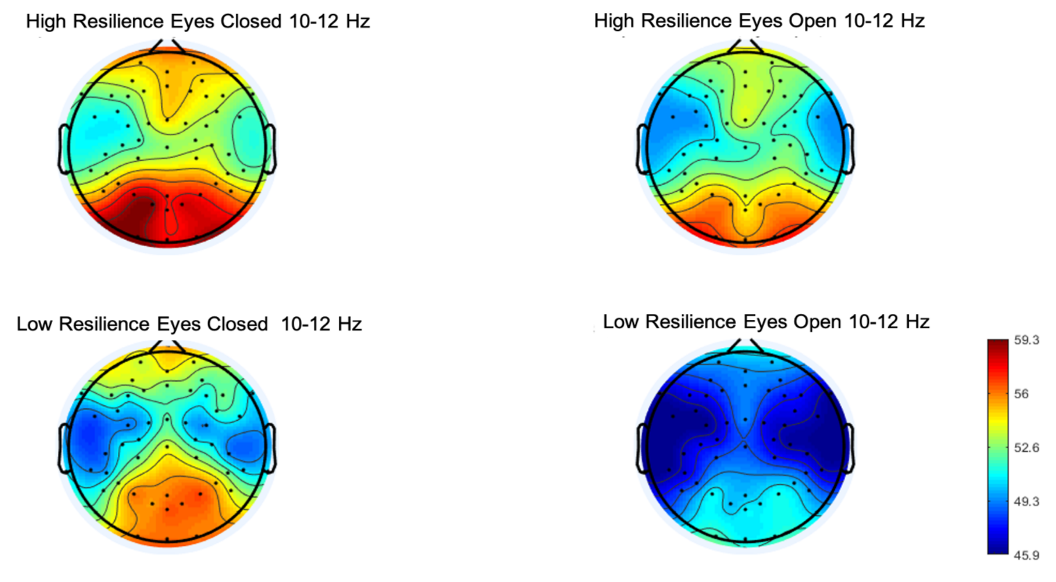
In eyes-closed condition (see Table 5), mean comparison of high resilience versus low resilience group revealed differences in the low alpha band A(8–10 Hz) in the left parietal area with high resilience group showing higher activation (*M* = 14.44, *SD* = 13.55) compared to low resilience group (*M* = 7.91, *SD* = 5.62). Many areas showed differences in high alpha band (10–12 Hz) between high resilience and low resilience groups. High resilience group showed higher activation of high alpha in right frontal (*M* = 14.65, *SD* = 13.60), anterior midline (*M* = 18.82, *SD* = 18.66), left central (*M* = 10.20, *SD* = 9.02), right central (*M* = 11.77, *SD* = 8.72), right parietal (*M* = 23.96, *SD* = 18.07), and posterior midline areas (*M* = 58.72, *SD* = 61.41). Therefore, hypothesis H3 stating differences between high and low resilience groups in delta band stands rejected.

Table 5
Mean and Standard Deviation of All Frequency Bands From the Eyes-Closed Condition

		Delta	Theta	Low Alpha	High Alpha	Beta1	Beta2	Beta3
Left Frontal	LR*	13.89 (5.53)^	5.49 (3.31)	6.84 (1.80)	5.43 (2.73)	3.16 (2.84)	2.78 (3.16)	3.16 (2.84)
	HR**	11.42 (2.05)	3.95 (1.40)	6.64 (4.29)	12.31 (12.19)	1.95 (0.66)	1.55 (0.79)	1.95 (0.66)
Right Frontal	LR	10.18 (3.38)	5.02 (2.98)	6.77 (1.78)	5.00 (2.22)	2.58 (1.69)	1.95 (1.33)	2.58 (1.69)
	HR	12.70 (4.66)	4.64 (1.54)	8.00 (4.94)	14.65 (13.60)	2.06 (0.77)	1.74 (0.84)	2.06 (0.77)
Anterior Midline	LR	9.48 (4.164)	6.09 (3.76)	9.96 (2.40)	7.62 (4.47)	1.69 (0.98)	1.67 (1.81)	1.69 (0.98)
	HR	10.31 (2.22)	5.36 (2.25)	11.66 (9.59)	18.82 (18.66)	1.78 (0.94)	1.77 (1.14)	1.78 (0.94)
Left Central	LR	7.75 (4.75)	4.87 (3.22)	5.71 (2.51)	4.09 (1.86)	1.69 (1.05)	1.45 (0.65)	1.69 (1.05)
	HR	6.34 (1.01)	3.90 (1.94)	6.20 (4.33)	10.20 (9.02)	2.18 (1.01)	1.74 (1.09)	2.18 (1.01)
Right Central	LR	8.92 (4.79)	5.90 (3.99)	6.25 (2.97)	4.30 (2.28)	1.89 (0.83)	1.49 (0.62)	1.89 (0.83)
	HR	7.06 (1.29)	4.41 (2.10)	7.32 (4.58)	11.77 (8.72)	2.14 (1.35)	1.95 (1.18)	2.14 (1.35)
Left Parietal	LR	6.69 (2.91)	5.05 (2.97)	7.91 (2.62)	5.09 (2.08)	1.80 (0.92)	1.59 (0.56)	1.80 (0.92)
	HR	8.79 (3.53)	5.80 (3.39)	14.44 (13.55)	25.02 (25.41)	3.42 (1.98)	3.14 (2.23)	3.42 (1.98)
Right Parietal	LR	8.39 (5.23)	6.37 (4.27)	14.99 (8.66)	9.85 (6.70)	1.72 (0.62)	1.87 (0.34)	1.72 (0.62)
	HR	7.78 (2.91)	5.32 (3.39)	14.70 (11.52)	23.96 (18.07)	2.44 (1.27)	2.59 (1.89)	2.44 (1.27)
Posterior Midline	LR	12.84 (7.28)	9.20 (6.23)	21.59 (6.74)	20.54 (14.87)	2.03 (1.08)	2.60 (1.22)	2.03 (1.08)
	HR	11.80 (5.99)	7.21 (5.43)	22.14 (17.73)	58.72 (61.41)	3.25 (1.81)	3.41 (2.57)	3.25 (1.81)

*LR = Low Resilience; **HR = High Resilience; ^ = Mean (*SD*).

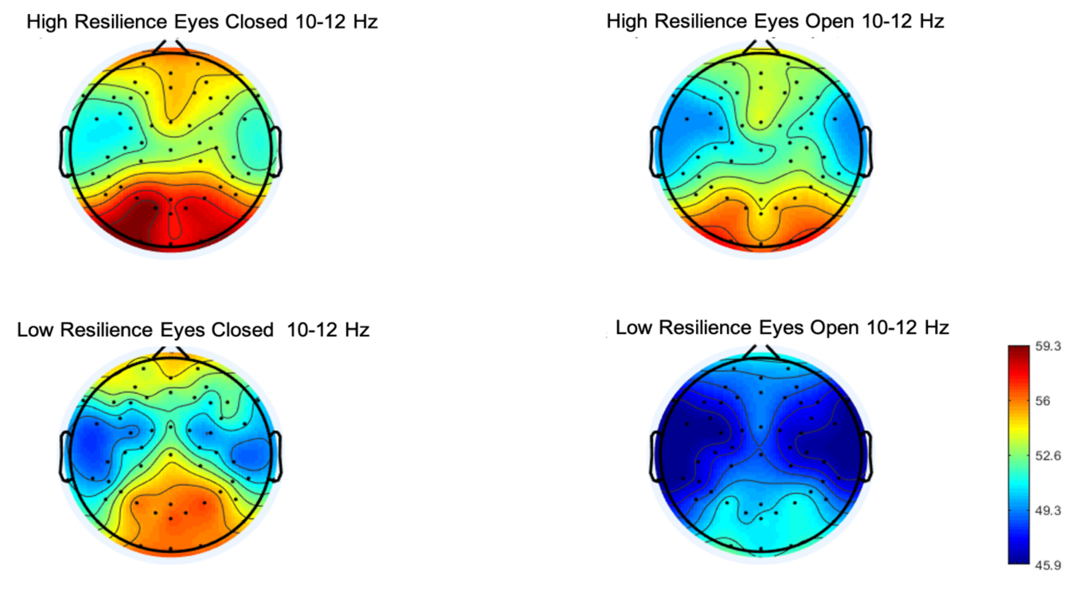
Figure 3. *Topographic Plots for High Alpha (10–12 Hz) Absolute Power.*



Note. Top row: Left - High Resilience Eyes Closed and Right - High Resilience Eyes Open.
Middle row: Left - Low Resilience Eyes Closed and Right - Low Resilience Anxiety Eyes Open.

Topographical plots indicate differences in neural activation between high resilience group and low resilience group in both eyes closed and eyes-open condition in high alpha band (10–12Hz; see Figure 3). Specifically, we observe differences in right and left frontal, orbitofrontal cortex, left and right parietal and right central areas in the eyes-closed condition. low resilience group shows minimal high alpha activity in eyes-open condition.

Figure 4. *Topographic Plots for Beta 3 (21–30.5 Hz) Absolute Power.*



Note. Top row: Left - High Resilience Eyes Closed and Right - High Resilience Eyes Open.
Middle row: Left - Low Resilience Eyes Closed and Right - Low Resilience Anxiety Eyes Open.

Table 6
Frontal Asymmetry Index in Alpha1 (8–10 Hz) and Alpha2 (10–12 Hz) Absolute Power

	Alpha1		Alpha2	
	LR	HR	LR	HR
Eyes Open	0.13	0.11	0.01	2.3
Eyes Closed	−0.07	1.36	−0.43	2.34

Note. LR = low resilience group; HR = high resilience group.

Topographical plots indicated marked differences in neural activation between high resilience group and low resilience group in both eyes-closed and eyes-open condition in beta 3 band (21–30.5 Hz; see Figure 4). In eyes-closed condition, differences between high and low resilience groups were observed in the left and right frontal, right central, and posterior midline areas. In eyes-open condition, low resilience group showed high activation in the left and right frontal areas in beta 3 band (21–30.5 Hz).

Frontal asymmetry index was computed as the difference of right minus the left hemisphere electrode values for six pairs of electrodes (AF4-AF3, F2-F1, F4-F3, F6-F5, F8-F7, F10-F9) and averaged to generate one measure for HR and LR. Positive values indicate greater right and negative values indicate a greater left balance. The analysis indicates high resilience group shows a stronger right frontal asymmetry in both eyes-open and eyes-closed condition in alpha 1 (8–10 Hz) and alpha 2 (10–12 Hz) bands. Low resilience group shows greater left frontal asymmetry in eyes closed condition in alpha 1 (8–10 Hz) and alpha 2 (10–12 Hz) bands.

Discussion

One of the results which evaluated the self-reported resilience and anxiety levels indicate a significant relationship between resilience and anxiety, with higher resilience inversely predicting anxiety in the regression model. The finding reflects extant literature across cultural contexts indicating resilience acts as a protective factor against anxiety (Jefferies et al., 2021; Song et al., 2021). Framing this finding with the multisystem model of resilience (Liu et al., 2017), this is the intermediate layer (i.e., internal factors psychological makeup, personal experiences) and outer later (i.e., external, environmental factors) of resilience. In selected participants for Phase 2 of the study, high resilience individuals reported low to moderate perceived stress and anxiety (see Table 1). This finds support in multiple types of evidence in literature which outlined how moderately stressful and anxiety-provoking events (perceived as tolerable) increase resilience levels often through stress inoculation, steeling, and anxiety-driven resilience (Cathomas et al., 2019; Crane et al., 2019; Dooley et al., 2017; Feder et al., 2019; Jefferies et al., 2021; Malhi et al., 2019).

Phase 2 study results indicate a robust difference in the scalp resting electrical patterns of high and low resilience groups (as measured by psychometric testing) in the eyes-open state as measured using noninvasive brain recordings (EEG) in eyes-open and eyes-closed condition (resting-states only). Our results indicate that high resilience group had greater high alpha band power in the right central, right and left parietal regions. High resilience group also had higher beta 3 power in left central, left parietal and posterior midline regions, suggesting a left and posterior preponderance. Functional neuroimaging studies associated with resilience are limited with most studies focused on clinical patient populations such as depression, trauma, PTSD, and anxiety disorder, where there are alterations present in emotion and stress regulation brain circuitry (van der Werff et al., 2013). Interestingly, our result suggesting resting-state changes may be in line with the findings of Kong et al. (2015) who reported that resilience has a significant negative correlation with rs-fMRI signals in bilateral insula, and rostral anterior cingulate cortex. The insula may be key to the resilience process due to its importance in human emotional processes (Uddin et al., 2017), while the ACC is linked to affect regulation (Stevens et al., 2011) which is a key component of resilience. Figure 5 below outlines a preliminary model on the operation of psychological resilience based on the findings of this pilot study and the trends highlighted during literature review.

Paban et al. (2019) used a dynamic network analysis of EEG data to identify key regions belonging to the "core functional network" outlined by van den Heuvel et al. (2009) as characteristics of high psychological resilience. This network includes regions involved in the cognitive processes of top-down attentional control (superior parietal cortex; Sestieri et al., 2017), decision-making in the OFC (Schuck et al., 2018) and cognitive-behavioral regulation (Bush et al., 2000) which oscillates in a fast-frequency beta band linked to reflect aspects of sensory information processes (Hong et al., 2008). Results from our study supports the conclusions drawn by Paban et al. (2019) indicating that high resilience group have higher beta activation in the left parietal, left central, and posterior midline regions. Topographical plots show a more frontal distribution of beta 3 (21–30 Hz) band (see Figure 4) also indicate regulated OFC and frontal cortex activation in beta 3 band (see Figure 4). Review evidence on the neurobiology of resilience have noted the importance of the PFC and limbic connection (Bolsinger et al., 2018; Feder et al., 2019; Holz et al., 2020; Ioannidis et al., 2020; Malhi et al., 2019). Activation of the PFC is crucial in cognitive and emotional inhibition, reducing amygdala reactivity to stressors and adversity. The findings of this preliminary pilot indicate that higher resilience individuals have greater prefrontal beta wave for cognitive and emotional regulation in response to stressors.

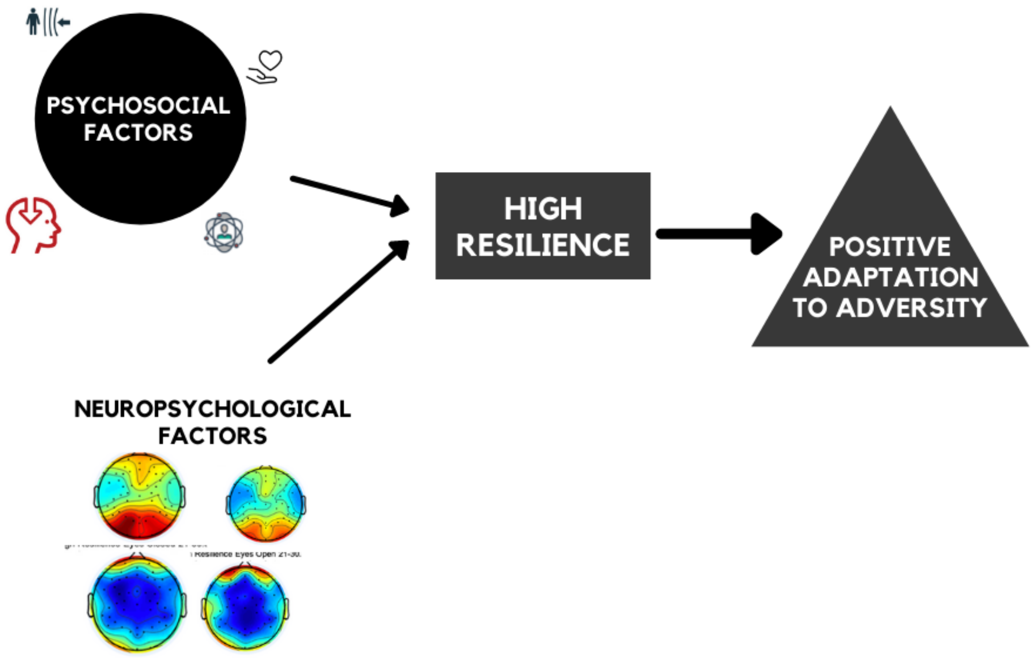
ANOVA results also indicate high resilience groups having greater activation in the right frontal, right central and parietal region in high alpha band and left central region in beta 3 band. The high alpha results have a right side and anterior preponderance while the beta 3 power results have a left posterior preponderance. High alpha band activation in the right frontal region is associated with less cognitive demands (Miyake et al., 2000). This could potentially point to the fact that high resilience individuals have lesser cognitive demands when responding to stressors and adversity. EEG resting state in high resilience children who had adapted to maltreatment, showed greater relative left central activity in the alpha band, in the eyes-open state (Curtis & Cicchetti, 2007). High and low resilience groups have also shown consistent differences over left parietal scalp regions in the high alpha, beta 1, beta 2, and beta 3 bands, with high resilience groups showing greater activation. A recent study (Kahl et al., 2020) found that greater resilience was associated with significant increase in cortical thickness in areas in right hemisphere cluster that included the lateral occipital cortex, the fusiform gyrus, the inferior parietal cortex, as well as the middle and inferior temporal cortex. The authors report that these anatomical areas are known to be involved in the processing of emotional visual input.

These findings provide support to models of adaptive regulation enhances resilience post adversity. Some examples are the coping circumplex model, systematic self-reflection model, cognitive appraisal of resilience, cognitive growth, and trajectory models (Bonanno et al., 2013; Crane et al., 2019; Stanisławski, 2019; Tedeschi & Calhoun, 2004; Yao & Hsieh, 2019). These models theorize aspects of cognitive flexibility in situational challenge appraisal, benefit finding, self-reflection, and regulation for resilient responses. Based on the findings of this study and review of literature, the interface between psychosocial and neuropsychological markers that contribute to high resilience are outlined in Figure 5 below.

A key driver of high resilience is the mastery motivation system which includes the ability to recall previous experiences where the individual overcame adversity resiliently (Masten, 2015). Our results indicate that the high resilience group shows higher beta 3 activation in the posterior midline region in addition to the higher left parietal activation. This region (specifically the lateral posterior parietal cortex and posterior midline region) has been linked to activation during demanding cognitive tasks and episodic memory retrieval (Daselaar et al., 2009). The combined findings highlight the importance of the psychological characteristics of resilience in addition to the neural markers indicating different brain region activation for high and low resilience individuals as theoretically underlined by Gupta (2021). Additionally, higher orbitofrontal, frontal, parietal, and central activations are a feature of the high resilience group. However, this activation merely indicates greater episodic retrieval of events and flexible cognitive reflections of it. The psychological makeup of the individual determines the nature of the episodic ruminations. They can be deliberate reflections which are structured thoughts to better understand the event and how to maximize mastery motivation to cope with event or it can lead to intrusive ruminations which lead to negative automatic thoughts and worries reinforced by past negative experiences which increases distress (Luca, 2019).

Results from the asymmetry analysis indicates high resilience group to have greater right frontal asymmetry in eyes-open and eyes-closed condition in the alpha 1 (8–10 Hz) band. This finding is in contrast to Curtis and Cicchetti's (2007) study on resilience related resting-state EEG differences

Figure 5. *Interface Between Psychosocial and Neuropsychological Markers Leading to High Resilience.*



where low resilience in children was associated with greater right alpha hemispherical activity in eyes-open condition. The findings of our study indicate that low resilience group has greater left frontal asymmetry in eyes-closed condition in alpha 1 (8–10 Hz) and alpha 2 (10–12 Hz) bands. The difference in findings of the current study and Curtis and Cicchetti (2007) can be linked to the eyes-open and eyes-closed conditions. Another explanation of the divergent results can be traced to the fact that self-reported anxiety was also a variable that may have played a role (e.g., low resilience group had high self-reported anxiety). Negative spontaneous mood (e.g., anxiety, perceived stress, tension) decreases when frontopolar activation asymmetry shifts to the right (Papousek & Schulter, 2002). Therefore, resilience individuals with greater right frontal activation not only self-report lesser anxiety and perceived stress but also have neural markers of the same. Greater right frontal activity reflects withdrawal related motivational states and traits of sadness (Coan & Allen, 2004), empathy (Tullet et al., 2012), with right-lateralized brain activity in the frontal region linked to the ability to exert sustained cognitive control (Ambrosini & Vallesi, 2016; Çiçek & Nalçacı, 2001). This is reflected at the psychosocial level where highly resilience individuals do show greater acceptance of negative emotions after adversity and can sustain cognitive control to facilitate adaptation (Hoorelbeke et al., 2016; Joorman et al., 2014). Wacker et al. (2010) found that greater right frontal asymmetry was associated with behavioural inhibition sensitivity during no-go trials on the go/no-go task which ties into the self-regulation ability that high resilience individuals have. In a 2003 experimental study with anger approach (fight) or anger-withdrawal (flight), Wacker et al. (2003) found that greater right frontal asymmetry was associated with fear-approach. This is supported by the fact that at the behavioral level, resilient individuals do not engage in avoidance coping when exposed to adversity or stressors (Campbell-Sills et al., 2006; Gupta & McCarthy, 2021). However, in-depth research is needed to explain this mechanism since other studies have linked increased rightward frontal alpha asymmetry to anxiety disorders and depression (Coan & Allen, 2004; Thibodeau et al., 2006).

Limitations

The sample size of Phase 2 of the current study is a limitation to generalizability as a pilot study. Data collection was initiated pre-COVID but had to be paused due to health and safety concerns. Participants' unavailability from Phase 1 screened sample led to the comparatively lesser sample size in group A and B. The limited source localization conducted in this study is another limitation which future research can address.

Future Directions

Future research can improve upon the sample size of this study and implement longitudinal designs with multistage EEG recordings. This would provide data into the stability of the EEG markers of resilience. There is also a need to distinguish between resilience and stress resistance (Fleshner et al., 2011). Future studies could conduct source localization to extend the precision of current findings. fMRI based designs could provide further insight into the EEG markers by testing the replicability of the regions associated with resilience in this study.

Author Acknowledgements

The authors would like to acknowledge Ms. Satya G. (Research Associate), for her invaluable support in the EEG recording and spectral analysis and the NeuroCognition Laboratory, Christ University, for the use of the EEG Facilities.

Author Disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. No artificial intelligence or generative AI was used during the study.

References

Ambrosini, E., & Vallesi, A. (2016). Asymmetry in prefrontal resting-state EEG spectral power underlies individual differences in phasic and sustained cognitive control. *NeuroImage, 124*(Part A), 843–857. https://doi.org/10.1016/j.neuroimage.2015.09.035

Baranauskas, M. C. C. (2009). Socially aware computing. In *ICECE 2009: VI International conference on engineering and computer education* (pp. 1–5).

Beck, A. T., Brown, G., Steer, R. A., & Weissman, A. N. (1991). Factor analysis of the Dysfunctional Attitude Scale in a clinical population. *Psychological Assessment: A Journal of Consulting and Clinical Psychology, 3*(3), 478–483. https://doi.org/10.1037/1040-3590.3.3.478

Beck, A. T., Steer, R. A., & Carbin, M. G. (1988). Psychometric properties of the Beck Depression Inventory: Twenty-five years of evaluation. *Clinical Psychology Review, 8*(1), 77–100. https://doi.org/10.1016/0272-7358(88)90050-5

Bolsinger, J., Seifritz, E., Kleim, B., & Manoliu, A. (2018). Neuroimaging correlates of resilience to traumatic events—A comprehensive review. *Frontiers in Psychiatry, 9*, Article 693. https://doi.org/10.3389/fpsyt.2018.00693

Bonanno, G. A. (2004). Loss, trauma, and human resilience: Have we underestimated the human capacity to thrive after extremely aversive events? *American Psychologist, 59*(1), 20–28. https://doi.org/10.1037/0003-066X.59.1.20

Bonanno, G. A., & Diminich, E. D. (2013). Annual research review: Positive adjustment to adversity—Trajectories of minimal–Impact resilience and emergent resilience. *Journal of Child Psychology and Psychiatry, 54*(4), 378–401. https://doi.org/10.1111/jcpp.12021

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*(6), 215–222. https://doi.org/10.1016/S1364-6613(00)01483-2

Campbell-Sills, L., Cohan, S. L., & Stein, M. B. (2006). Relationship of resilience to personality, coping, and psychiatric symptoms in young adults. *Behaviour Research and Therapy, 44*(4), 585–599. https://doi.org/10.1016/j.brat.2005.05.001

Cathomas, F., Murrough, J. W., Nestler, E. J., Han, M.-H., & Russo, S. J. (2019). Neurobiology of resilience: Interface between mind and body. *Biological Psychiatry, 86*(6), 410–420. https://doi.org/10.1016/j.biopsych.2019.04.011

Chapman, L. K., Williams, S. R., Mast, B. T., & Woodruff-Borden, J. (2009). A confirmatory factor analysis of the Beck Anxiety Inventory in African American and European American young adults. *Journal of Anxiety Disorders, 23*(3), 387–392. https://doi.org/10.1016/j.janxdis.2008.12.003

Charney, D. S. (2004). Psychobiological mechanisms of resilience and vulnerability: Implications for successful adaptation to extreme stress. *American Journal of Psychiatry, 161*, 195–216. https://doi.org/10.1176/appi.ajp.161.2.195

Chen, D., Wu, J., Yao, Z., Lei, K., Luo, Y., & Li, Z. (2018). Negative association between resilience and event-related potentials evoked by negative emotion. *Scientific Reports, 8*, Article 7149. https://doi.org/10.1038/s41598-018-25555-w

Chesak, S. S., Khalsa, T. K., Bhagra, A., Jenkins, S. M., Bauer, B. A., & Sood, A. (2019). Stress management and resiliency training for public school teachers and staff: A novel intervention to enhance resilience and positively impact student interactions. *Complementary Therapies in Clinical Practice, 37*, 32–38. https://doi.org/10.1016/j.ctcp.2019.08.001

Cicchetti, D. (2010). Resilience under conditions of extreme stress: A multilevel perspective. *World Psychiatry, 9*(3), 145–154. https://doi.org/10.1002/j.2051-5545.2010.tb00297.x

Çiçek, M., & Nalçacı, E. (2001). Interhemispheric asymmetry of EEG alpha activity at rest and during the Wisconsin Card Sorting Test: Relations with performance. *Biological Psychology, 58*(1), 75–88. https://doi.org/10.1016/S0301-0511(01)00103-X

Coan, J. A., & Allen, J. J. B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology, 67*(1–2), 7–50. https://doi.org/10.1016/j.biopsycho.2004.03.002

Cohen, S., Kamarck, T., & Mermelstein, R. (1994). Perceived stress scale. *Measuring stress: A guide for health and social scientists, 10*(2), 1–2.

Connor, K. M., & Davidson, J. R. (2003). Development of a new resilience scale: The Connor-Davidson Resilience Scale (CD-RISC). *Depression and Anxiety, 18*(2), 76–82. https://doi.org/10.1002/da.10113

Crane, M. F., Searle, B. J., Kangas, M., & Nwiran, Y. (2019). How resilience is strengthened by exposure to stressors: The systematic self-reflection model of resilience strengthening. *Anxiety, Stress, & Coping, 32*(1), 1–17. https://doi.org/10.1080/10615806.2018.1506640

Creamer, M., Foran, J., & Bell, R. (1995). The Beck Anxiety Inventory in a non-clinical sample. *Behaviour Research and Therapy, 33*(4), 477–485. https://doi.org/10.1016/0005-7967(94)00082-U

Curtis, W. J., & Cicchetti, D. (2007). Emotion and resilience: A multilevel investigation of hemispheric electroencephalogram asymmetry and emotion regulation in maltreated and normally treated children. *Developmental Psychopathology, 19*(3), 811–840. https://doi.org/10.1017/S0954579407000405

Daselaar, S. M., Prince, S. E., Dennis, N. A., Hayes, S. M., Kim, H., & Cabeza, R. (2009). Posterior midline and ventral parietal activity is associated with retrieval success and encoding failure. *Frontiers in Human Neuroscience, 3*, Article 13. https://doi.org/10.3389/neuro.09.013.2009

Davidson, R. J., & McEwen, B. S. (2012). Social influences on neuroplasticity: Stress and interventions to promote well-being. *Nature Neuroscience, 15*(5), 689–695. https://doi.org/10.1038/nn.3093

de Kloet, E. R., Joëls, M., & Holsboer, F. (2005). Stress and the brain: From adaptation to disease. *Nature Reviews Neuroscience, 6*(6), 463–475. https://doi.org/10.1038/nrn1683

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Dooley, L. N., Slavich, G. M., Moreno, P. I., & Bower, J. E. (2017). Strength through adversity: Moderate lifetime stress exposure is associated with psychological resilience in breast cancer survivors. *Stress and Health, 33*(5), 549–557. https://doi.org/10.1002/smi.2739

Dray, J., Bowman, J., Campbell, E., Freund, M., Wolfenden, L., Hodder, R. K., McElwaine, K., Tremain, D., Bartlem, K., Bailey, J., Small, T., Palazzi, K., Oldmeadow, C., & Wiggers, J. (2017). Systematic review of universal resilience-focused interventions targeting child and adolescent mental health in the school setting. *Journal of the American Academy of Child & Adolescent Psychiatry, 56*(10), 813–824. https://doi.org/10.1016/j.jaac.2017.07.780

Feder, A., Fred-Torres, S., Southwick, S. M., & Charney, D. S. (2019). The biology of human resilience: Opportunities for enhancing resilience across the life span. *Biological Psychiatry, 86*(6), 443–453. https://doi.org/10.1016/j.biopsych.2019.07.012

Feder, A., Nestler, E. J., & Charney, D. S. (2009). Psychobiology and molecular genetics of resilience. *National Review Neuroscience, 10*(6), 446–457. https://doi.org/10.1038/nrn2649

Fleshner, M., Maier, S. F., Lyons, D. M., & Raskind, M. A. (2011). The neurobiology of the stress-resistant brain. *Stress, 14*(5), 498–502. https://doi.org/10.3109/10253890.2011.596865

Fletcher, D., & Sarkar, M. (2013). Psychological resilience: A review and critique of definitions, concepts, and theory. *European Psychologist, 18*(1), 12–23. https://doi.org/10.1027/1016-9040/a000124

Franklin, T. B., Saab, B. J., & Mansuy, I. M. (2012). Neural mechanisms of stress resilience and vulnerability. *Neuron*, *75*(5), 747–761. https://doi.org/10.1016/j.neuron.2012.08.016

Gupta, S. (2021). Bouncing back! Clinical intersections of resilience, cognitive behavioural neuropsychology, and psychoneuroimmunology (PNI): An introduction. *Resilience, psychoneuroimmunology, neuropsychology: Applications in clinical settings.* Google Books.

Gupta, S., & McCarthy, P. J. (2021). Sporting resilience during COVID-19: What is the nature of this adversity and how are competitive elite athletes adapting? *Frontiers in Psychology, 12*, Article 611261. https://doi.org/10.3389/fpsyg.2021.611261

Gupta, S., & McCarthy, P. J. (2022). The sporting resilience model: A systematic review of resilience in sport performers. *Frontiers in Psychology, 13*, 1003053. https://doi.org/10.3389/fpsyg.2022.1003053

Holman, E. A., Lucas-Thompson, R. G., & Lu, T. (2011). Social constraints, genetic vulnerability, and mental health following collective stress. *Journal of Trauma and Stress, 24,* 497–505. https://doi.org/10.1002/jts.20671

Holz, N. E., Tost, H., & Meyer-Lindenberg, A. (2020). Resilience and the brain: A key role for regulatory circuits linked to social stress and support. *Molecular Psychiatry, 25*(2), 379–396. https://doi.org/10.1038/s41380-019-0551-9

Hong, L. E., Buchanan, R. W., Thaker, G. K., Shepard, P. D., & Summerfelt, A. (2008). Beta (~16 Hz) frequency neural oscillations mediate auditory sensory gating in humans. *Psychophysiology, 45*(2), 197–204 https://doi.org/10.1111/j.1469-8986.2007.00624.x

Hoorelbeke, K., Koster, E. H., Demeyer, I., Loeys, T., & Vanderhasselt, M.-A. (2016). Effects of cognitive control training on the dynamics of (mal)adaptive emotion regulation in daily life. *Emotion, 16*(7), 945. https://doi.org/10.1037/emo0000169

Ioannidis, K., Askelund, A. D., Kievit, R. A., & van Harmelen, A.-L. (2020). The complex neurobiology of resilient functioning after childhood maltreatment. *BMC Medicine, 18*(1), Article 32. https://doi.org/10.1186/s12916-020-1490-7

Jefferies, P., Höltge, J., & Ungar, M. (2021). Social anxiety and resilience: Associations vary by country and sex. *Adversity and Resilience Science, 2*(1), 51–62 https://doi.org/10.1007/s42844-020-00026-2

Joëls, M., Karst, H., Krugers, H. J., & Lucassen, P. J. (2007). Chronic stress: Implications for neuronal morphology, function, and neurogenesis. *Frontiers in Neuroendocrinology, 28*(2–3), 72–96. https://doi.org/10.1016/j.yfrne.2007.04.001

Jones, H. J., Stergiakouli, E., Tansey, K. E., Hubbard, L., Heron, J., Cannon, M., Holmans, P., Lewis, G., Linden, D. E. J., Jones, P. B., Davey Smith, G., O'Donovan, M. C., Owen, M. J., Walters, J. T., & Zammit, S. (2016). Phenotypic manifestation of genetic risk for schizophrenia during adolescence in the general population. *JAMA Psychiatry, 73*(3), 221–228. https://doi.org/10.1001/jamapsychiatry.2015.3058

Joormann, J., & Vanderlind, W. M. (2014). Emotion regulation in depression: The role of biased cognition and reduced cognitive control. *Clinical Psychological Science, 2*(4), 402–421 https://doi.org/10.1177%2F2167702614536163

Kahl, M., Wagner, G., de la Cruz, F., Köhler, S., & Schultz, C. C. (2020). Resilience and cortical thickness: A MRI study. *European Archives of Psychiatry and Clinical Neuroscience,* 270(5), 533–539. https://doi.org/10.1007/s00406-018-0963-6

Keynan, J. N., Cohen, A., Jackont, G., Green, N., Goldway, N., Davidov, A., Meir-Hasson, Y., Raz, G., Intrator, N., Fruchter, E., Ginat, K., Laska, E., Cavazza, M., & Hendler, T. (2019). Electrical fingerprint of the amygdala guides neurofeedback training for stress resilience. *Nature Human Behaviour, 3*(1), 63–73. https://doi.org/10.1038/s41562-018-0484-3

Kim, K. J., & Bell, M. A. (2006). Frontal EEG asymmetry and regulation during childhood. *Annals of the New York Academy of Sciences, 1094*(1), 308–312. https://doi.org/10.1196/annals.1376.040

Kim, M. J. Loucks, R. A., Palmer, A. L., Brown, A. C., Solomon, K. M., Marchante, A. N., & Whalen, P. J. (2011). The structural and functional connectivity of the amygdala: From normal emotion to pathological anxiety. *Behavioural Brain Research, 223*(2)*,* 403–410. https://doi.org/10.1016/j.bbr.2011.04.025

Kong, F., Hu, S., Wang, X., Song, Y., & Liu, J. (2015). Neural correlates of the happy life: The amplitude of spontaneous low frequency fluctuations predicts subjective well-being. *NeuroImage, 107,* 136–145. https://doi.org/10.1016/j.neuroimage.2014.11.033

Kyriazos, T. A., Stalikas, A., Prassa, K., Galanakis, M., Yotsidi, V., & Lakioti, A. (2018). Psychometric evidence of the Brief Resilience Scale (BRS) and modeling distinctiveness of resilience from depression and stress. *Psychology, 9*(7), 1828–1857. https://doi.org/10.4236/psych.2018.97107

Lee, E.-H. (2012). Review of the psychometric evidence of the perceived stress scale. *Asian Nursing Research, 6*(4), 121–127. https://doi.org/10.1016/j.anr.2012.08.004

Leyfer, O. T., Ruberg, J. L., & Woodruff-Borden, J. (2006). Examination of the utility of the Beck Anxiety Inventory and its factors as a screener for anxiety disorders. *Journal of Anxiety Disorders, 20*(4), 444–458. https://doi.org/10.1016/j.janxdis.2005.05.004

Liberzon I., & Sripada C. S. (2007). The functional neuroanatomy of PTSD: A critical review. *Progress in Brain Research, 167*, 151–169. https://doi.org/10.1016/S0079-6123(07)67011-3

Liu, J. J. W., Reed, M., & Girard, T. A. (2017). Advancing resilience: An integrative, multi-system model of resilience. *Personality and Individual Differences, 111*, 111–118. https://doi.org/10.1016/j.paid.2017.02.007

Luca, M. (2019). Maladaptive rumination as a transdiagnostic mediator of vulnerability and outcome in psychopathology. *Journal of Clinical Medicine, 8*(3), Article 314. https://doi.org/10.3390/jcm8030314

Luthar, S. S., Cicchetti, D., & Becker, B. (2000). Research on resilience: Response to commentaries. *Child Development, 71*(3), 573–575. https://doi.org/10.1111/1467-8624.00168

Mahan, A. L., & Ressler, K. J. (2012). Fear conditioning, synaptic plasticity and the amygdala: Implications for posttraumatic stress disorder. *Trends in Neuroscience, 35*(1)*,* 24–35. https://doi.org/10.1016/j.tins.2011.06.007

Malhi, G. S., Das, P., Bell, E., Mattingly, G., & Mannie, Z. (2019). Modelling resilience in adolescence and adversity: A novel framework to inform research and practice. *Translational Psychiatry, 9*(1), Article 316. https://doi.org/10.1038/s41398-019-0651-y

Masten, A. S. (2001). Ordinary magic. Resilience processes in development. *American Psychologist, 56*(3)*,* 227–238 https://doi.org/10.1037/0003-066X.56.3.227

Masten, A. S. (2015). *Ordinary magic: Resilience in development*. Guilford Publications.

Milad, M. R., Pitman, R. K., Ellis, C. B., Gold, A. L., Shin, L. M., Lasko, N. B., Zeidan, M. A., Handwerger, K., Orr, S. P., & Rauch, S. L. (2009). Neurobiological basis of failure to recall extinction memory in posttraumatic stress disorder. *Biological Psychiatry, 66*(12), 1075–1082. https://doi.org/10.1016/j.biopsych.2009.06.026

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Paban, V., Modolo, J., Mheich, A., & Hassan, M. (2019). Psychological resilience correlates with EEG source-space brain network flexibility. *Network Neuroscience, 3*(2), 539–550. https://doi.org/10.1162/netn_a_00079

Papousek, I., & Schulter, G. (2002) Covariations of EEG asymmetries and emotional states indicate that activity at frontopolar locations is particularly affected by state factors. *Psychophysiology, 39*(3), 350–360. https://doi.org/10.1017/S0048577201393083

Pernet, C. R., Appelhoff, S., Gorgolewski, K. J., Flandin, G., Phillips, C., Delorme, A., & Oostenveld, R. (2019). EEG-BIDS, an extension to the brain imaging data structure for electroencephalography. *Scientific Data, 6*(1), Article 103. https://doi.org/10.1038/s41597-019-0104-8

Prince-Embury, S. (2014). Three-factor model of personal resiliency and related interventions. In S. Prince-Embury & D. Saklofske (Eds.), *Resilience interventions for youth in diverse populations* (pp. 25–57). Springer. https://doi.org/10.1007/978-1-4939-0542-3_3

Putman, P., Verkuil, B., Arias-Garcia, E., Pantazi, I., & van Schie, C. (2014). EEG theta/beta ratio as a potential biomarker for attentional control and resilience against deleterious effects of stress on attention. *Cognitive, Affective, & Behavioral Neuroscience, 14*(2), 782–791. https://doi.org/10.3758/s13415-013-0238-7

Reynaud, E., Guedj, E., Souville, M., Trousselard, M., Zendjidjian, X., El Khoury-Malhame, M., Fakra, E., Nazarian, B., Blin, O., Canini, F., & Khalfa, S. (2013). Relationship between emotional experience and resilience: An fMRI study in firefighters. *Neuropsychologia, 51*(5), 845–849. https://doi.org/10.1016/j.neuropsychologia.2013.01.007

Roberts, N. J., McAloney-Kocaman, K., Lippiett, K., Ray, E., Welch, L., & Kelly, C. (2021). Levels of resilience, anxiety and depression in nurses working in respiratory clinical areas during the COVID pandemic. *Respiratory Medicine, 176*, Article 106219. https://doi.org/10.1016/j.rmed.2020.106219

Salah, H. M., Al'Aref, S. J., Khan, M. S., Al-Hawwas, M., Vallurupalli, S., Mehta, J. L., Mounsey, J. P., Greene, S. J., McGuire, D. K., Lopes, R. D., & Fudim, M. (2021). Effect of sodium-glucose cotransporter 2 inhibitors on cardiovascular and kidney outcomes—Systematic review and meta-analysis of randomized placebo-controlled trials. *American Heart Journal, 232*, 10–22. https://doi.org/10.1016/j.ahj.2020.10.064

Schuck, N. W., Wilson, R., & Niv, Y. (2018). A state representation for reinforcement learning and decision-making in the orbitofrontal cortex. In R. Morris, A. Bornstein, & A. Shenhav, *Goal-directed decision making* (pp. 259–278). Academic Press. https://doi.org/10.1016/B978-0-12-812098-9.00012-7

Sekiguchi, A., Kotozaki, Y., Sugiura, M., Nouchi, R., Takeuchi, H., Hanawa, S., Nakagawa, S., Miyauchi, C. M., Araki, T., Sakuma, A., Taki, Y., & Kawashima, R. (2015). Resilience after 3/11: Structural brain changes 1 year after the Japanese earthquake. *Molecular Psychiatry, 20*(5), 553–554. https://doi.org/10.1038/mp.2014.28

Sestieri, C., Shulman, G. L., & Corbetta, M. (2017). The contribution of the human posterior parietal cortex to episodic memory. *Nature Reviews Neuroscience, 18*(3), 183–192. https://doi.org/10.1038/nrn.2017.6

Shin, J. Y., & Choi, S. W. (2020). Interventions to promote caregiver resilience. *Current Opinion in Supportive and Palliative Care, 14*(1), 60–66. https://doi.org/10.1097/SPC.0000000000000481

Smith, B. W., Dalen, J., Wiggins, K., Tooley, E., Christopher, P., & Bernard, J. (2008). The brief resilience scale: Assessing the ability to bounce back. *International Journal of Behavioral Medicine, 15*(3), 194–200. https://doi.org/10.1080/10705500802222972

Song, J., Fogarty, K., Suk, R., & Gillen, M. (2021). Behavioral and mental health problems in adolescents with ADHD: Exploring the role of family resilience. *Journal of Affective Disorders, 294*, 450–458. https://doi.org/10.1016/j.jad.2021.07.073

Southwick, S. M., & Charney, D. S. (2018). *Resilience: The science of mastering life's greatest challenges*. Cambridge University Press.

Stanisławski, K. (2019). The coping circumplex model: An integrative model of the structure of coping with stress. *Frontiers in Psychology, 10*, Article 694. https://doi.org/10.3389/fpsyg.2019.00694

Steer, R. A., Scholl, T. O., & Beck, A. T. (1990). Revised Beck Depression Inventory scores of inner-city adolescents: Pre- and postpartum. *Psychological Reports, 66*(1), 315–320. https://doi.org/10.2466%2Fpr0.1990.66.1.315

Steinhardt, M., & Dolbier, C. (2008). Evaluation of a resilience intervention to enhance coping strategies and protective factors and decrease symptomatology. *Journal of American College Health, 56*(4), 445–453. https://doi.org/10.3200/JACH.56.44.445-454

Stevens, F. L., Hurley, R. A., & Taber, K. H. (2011). Anterior cingulate cortex: Unique role in cognition and emotion. *The Journal of Neuropsychiatry and Clinical Neurosciences, 23*(2), 121–125.

Tedeschi, R. G., & Calhoun, L. G. (2004). Posttraumatic growth: Conceptual foundations and empirical evidence. *Psychological Inquiry, 15*(1), 1–18. https://doi.org/10.1207/s15327965pli1501_01

Thibodeau, R., Jorgensen, R. S., & Kim, S. (2006). Depression, anxiety, and resting frontal EEG asymmetry: A meta-analytic review. *Journal of Abnormal Psychology, 115*, 715–729. https://doi.org/10.1037/0021-843x.115.4.715

Tullett, A. M., Harmon-Jones, E., & Inzlicht, M. (2012). Right frontal cortical asymmetry predicts empathic reactions: Support for a link between withdrawal motivation and empathy. *Psychophysiology, 49*(8), 1145–1153. https://doi.org/10.1111/j.1469-8986.2012.01395.x

Uddin, L. Q., Nomi, J. S., Hébert-Seropian, B., Ghaziri, J., & Boucher, O. (2017). Structure and function of the human insula. *Journal of Clinical Neurophysiology, 34*(4), 300–306. https://doi.org/10.1097/WNP.0000000000000377

van den Heuvel, M. P., Mandl, R. C., Kahn, R. S., & Hulshoff Pol, H. E. (2009). Functionally linked resting-state networks reflect the underlying structural connectivity architecture of the human brain. *Human Brain Mapping, 30*(10), 3127–3141. https://doi.org/10.1002/hbm.20737

van der Werff, S. J. A., van den Berg, S. M., Pannekoek, J. N., Elzinga, B. M., & van der Wee, N. J. (2013). Neuroimaging resilience to stress: A review. *Frontiers in Behavioral Neuroscience, 7*, Article 39. https://doi.org/10.3389/fnbeh.2013.00039

Voigt, P., & von dem Bussche, A. (2017). *The EU general data protection regulation (GDPR): A practical guide* (1st ed.). Springer International Publishing. https://doi.org/10.1007/978-3-319-57959-7

Wacker, J., Chavanon, M. L., Leue, A., & Stemmler, G. (2010). Trait BIS predicts alpha asymmetry and P300 in a Go/No-Go task. *European Journal of Personality, 24*(2), 85–105. https://doi.org/10.1002%2Fper.740

Wacker, J., Heldmann, M., & Stemmler, G. (2003). Separating emotion and motivational direction in fear and anger: Effects on frontal asymmetry. *Emotion, 3*(2), 167–193. https://doi.org/10.1037/1528-3542.3.2.167

Waugh, C. E., & Koster, E. H. W. (2015). A resilience framework for promoting stable remission from depression. *Clinical Psychology Review, 41*, 49–60. https://doi.org/10.1016/j.cpr.2014.05.004

Waugh, C. E., Wager, T. D., Fredrickson, B. L., Noll, D. C., & Taylor, S. F. (2008). The neural correlates of trait resilience when anticipating and recovering from threat. *Social Cognitive and Affective Neuroscience, 3*(4), 322–332. https://doi.org/10.1093/scan/nsn024

Yao, Z.-F., & Hsieh, S. (2019). Neurocognitive mechanism of human resilience: A conceptual framework and empirical review. *International Journal of Environmental Research and Public Health, 16*(24), Article 5123. https://doi.org/10.3390/ijerph16245123

Received: September 07, 2024
Accepted: October 14, 2024
Published: March 24, 2025

Appendix A

Figure 1A. *Electrode Grouping for the EGI 64-Channel Sensor Layout.*

Anterior Midline (AFz_A + F1_A + F2_A + Fz_A + FC1_A + FCz_A + FC2_A)/7.

Posterior Midline (Pz_A + PO3_A + POz_A + PO4_A + O1_A + Oz_A + O2_A)/7.

Left Parietal (LM_A + P9_A + P7_A + P5_A + TP7_A + CP5_A + P3_A)/7.

Right Parietal (RM_A + P10_A + P8_A + P6_A + TP8_A + CP6_A + P4_A)/7.

Left Central (CP1_A + C1_A + FC3_A + C3_A + C5_A + T7_A + T9_A)/7.

Right Central (CP2_A + C2_A + FC4_A + C4_A + C6_A + T8_A + T10_A)/7.

Left Frontal (AF3_A + F3_A + F5_A + FC5_A + FT7_A + F7_A + F9_A)/7.

Right Frontal (AF4_A + F4_A + F6_A + FC6_A + FT8_A + F8_A + F10_A)/7.

Montage used EGI 64-channel HydroCel Geodesic Sensor Net
(https://www.egi.com/research-division/geodesic-sensor-net