Abstract

This study investigated the relationship between perceived stress and frontal alpha asymmetry (FAA), exploring potential mediators such as emotion regulation and motivation. A sample of 110 participants completed measures of perceived stress, depression, emotion regulation, and motivation, along with EEG recordings to assess FAA. Results revealed that greater right frontal activity (lower right relative to left frontal alpha power) was associated with higher perceived stress levels, even after controlling for depressive symptoms. Perceived stress was found to mediate the relationship between FAA and difficulties in emotion regulation, highlighting the complex interplay between neural activity patterns and stress and emotion regulation. This study contributes to our understanding of the neural correlates of perceived stress and emphasizes the importance of considering individual differences in emotion regulation and motivation in stress-related outcomes. Further research should explore longitudinal designs to measure situational changes in stress and incorporate physiological stress responses to deepen our understanding of the neural and behavioral correlates of stress perception and inform potential interventions for improving emotional well-being.

Key Words: Perceived stress, frontal alpha asymmetry, emotion regulation

Decoding Stress: Frontal Alpha Asymmetry as a Biomarker and the Role of Emotion Regulation in Stress Perception

Perceived stress can be defined as the measure of one's feelings and thoughts about the degree of stress they feel in their individual experiences and daily life (Phillips, 2013). It is oftentimes associated with feelings of a lack of control and unpredictability (Wang et. al, 2019). An individual's perceived stress level is thought to be an intrinsic personality characteristic as opposed to one changed situationally, pointing to its significance as a predictor of physical and mental health outcomes (Cohen et. al, 1993; Wang et. al, 2019). Importantly, perceived stress is based on one's conception of stressors in an individual's life, as opposed to acute stress which focuses on the stressor itself rather than one's perception of the experience.

Perceived stress has been found to be important in individuals' coping abilities and mental well-being (e.g., Slimenn et. al, 2022). A cross-sectional study done by Slimenn and colleagues examined the effects that different types of stressors, such as academic, financial, and familial had on the mental well-being of undergraduate students. The researchers found that perceived stress had the strongest impact on students' mental well being, and was the greatest predictor of variance in mental well-being in their model, more so than academic, familial, or financial pressures (2022). They also found that perceived stress behaved as a mediating variable for the previously mentioned underlying stressors they examined, with individuals who were higher in perceived stress experiencing greater deficits to mental well-being when acute stressors were experienced (Slimenn et. al, 2022). Additionally, studies have linked depression and perceived stress in undergraduate students, and point towards the importance of emotional regulation strategies, specifically cognitive reappraisal, in modulating this relationship (Catabay et. al, 2019; Liu et. al, 2023).

It is important to clarify the differences between acute and chronic stress, and their relationships to perceived stress. According to Jamieson et al. (2013), acute stress can be defined as stress induced in a short-term situational manner, and that acute stress can be approached in one of two ways as proposed by the biopsychosocial model of challenge and threat. According to the model, if a stimulus is perceived as a challenge, personal resources exceed situational demands, whereas if a stimulus is perceived as a threat, it presents itself as the opposite, where demands exceed resources available (Jamieson et. al, 2013). Some researchers suggest that acute stress may increase cognitive flexibility and reduce negative affect (Jamieson et. al, 2013; Kohn et. al, 2017). Further, in regards to neural correlates, acute stress has been linked to decreased frontal alpha power and increased frontal beta power during tasks that require cognitive effort such as the Paced Auditory Serial Addition Task (PASAT) when compared to activity in the brain at rest (Erhardt et. al, 2021). This pattern of activity suggests that there is increased activity in frontal regions during tasks that require executive attention and logical thinking during acute stress.

In contrast, chronic stress relates to both the physiological and psychological responses that continued exposure to stress elicits (O'Connor et. al, 2021). Chronic stress is classified as stress that endures for large portions of the day over several weeks or months (Contrada & Baum, 2011). Physiologically, chronic stress exposure affects the body's regulation and response to cortisol, the primary hormone of the hypothalamic-adrenal-pituitary axis (HPA). The HPA is responsible for regulating the physical response to stress through changes such as increased heart and breathing rate, decreased digestion and blood flow, and pupil dilation (O'Connor et. al, 2021). Over long periods of stress exposure, sensitivity to cortisol diminishes, causing lasting detriments to the organ systems the HPA affects, such as the cardiovascular system and the digestive tract. Psychologically, chronic stress has been linked to the onset of depressive symptoms, as well as to increased rates of burnout and cognitive decline (Marin et. al, 2011). The deficits to cognition from chronic stress lay in stark contrast to acute stress's relationship with cognition, in which acute stress is associated with cognitive flexibility (Jamieson et. al, 2013; Kohn et. al, 2017; Erhardt et. al, 2021). The different effects on cognition from acute versus chronic stress highlight the importance of distinguishing the two constructs clearly.

While studies have examined the effects of acute stressors and chronic stress on physical health and emotional well-being, few have examined how one's perception of stress changes the influence of stress events on physical and mental health outcomes. It has been suggested that one's perception of life events is the driving force behind their behavioral and physiological responses to stress; an example is found in the relationship between perceived stress and depressive symptoms noted above (Catabay et. al, 2019, Wang et. al, 2019). Additionally, it has been demonstrated that perceived stress affects error processing, a key cognitive function, as seen by a study done utilizing Cohen's Perceived Stress Scale (PSS) and event-related-potentials (ERPs) to quantify error processing (Wu et. al, 2019). Participants in this study had their brain activity recorded with EEG as they completed the Go/NoGo task, a cognitive task used to measure response inhibition where participants are requested to respond (Go) to one stimulus and withhold response (No-Go) to another while their brain activity is recorded. Researchers observed that PSS scores were positively correlated with the late error-positivity component (Pe), which they interpreted to suggest that individuals with higher levels of perceived stress are more sensitive to previously-made errors, and dedicate more emotional and motivational resources to correcting these errors moving forward (Wu et. al, 2019).

A study completed by Knauft and colleagues demonstrated that perceived stress influenced the degree of cognitive flexibility during acute stress (Knauft et al., 2021). In their study, the researchers utilized the PSS to quantify perceived stress, the cold-pressor test (CPT) to induce acute stress, and the Wisconsin Card Sorting Task (WCST) to quantify perseveration, a reflection of reduced cognitive flexibility (2021). Knauft and colleagues consequently found that there was a negative relationship between acute stress and the amount of perseveration, and that perceived stress had a significant interaction effect with acute stress and cognitive flexibility. In this case, the level of perceived stress experienced by the participant affected the relationship between acute stress and the degree of perseveration, with individuals lower in perceived stress experiencing an increase in cognitive flexibility during acute stress, whereas individuals with higher perceived stress did not exhibit a significant change in cognitive flexibility following the addition of an acute stressor (Knauft et. al, 2021). The results of this study point towards the importance of distinguishing between perceived and acute stress, and the implication that while actual stress may influence an individual's physical and mental health, perceived stress may be the more important factor in determining outcomes.

As previously mentioned, the neural mechanisms of acute stress include decreased alpha and increased beta power over frontal regions, as well as changes in the posterior cingulate cortex and left and right precuneus (Erdhardt et. al, 2021; Vanhollebeke et. al, 2023). The posterior cingulate cortex and precuneus, have been linked heavily to effects of psychological stress due to their relationship with structures of the default mode network (DMN) and its function in emotion response and processing as well as memory retrieval (Soares et. al, 2013). However, the majority of existing research exploring the neural correlates of stress specifically examine differences in alpha power between the left and right frontal regions during acute stress exposure (e.g.,Berretz et. al, 2022; Erhardt et. al, 2021; Vanhollebeke et. al, 2023).

Hemispheric differences in brain activity is a vast area of research, in particular research examining differences between left and right frontal activity. This body of literature may be helpful in increasing our understanding of the neural correlates of perceived stress. Frontal alpha asymmetry is defined as the difference in relative left versus right frontal alpha power; greater alpha power is associated with cortical inactivity (Allen, Coan, & Nazarian, 2004). In terms of resting state EEG, the frequency band that displays the greatest amount of activity at rest is alpha (Allen, Coan, & Nazarian, 2004). Typically, frontal alpha asymmetry is calculated as the amount of right frontal alpha minus the amount of left frontal alpha. Consequently, higher frontal alpha asymmetry scores reflect greater left prefrontal activity when compared to right prefrontal activity. Studies examining frontal alpha symmetry often record brain activity during a resting state, when the participant is awake and alert, but not engaged in a specific task (Reznik & Allen, 2017).

Frontal alpha asymmetry has been shown to be predictive of the psychological well-being of individuals (Quadflieg et. al, 2015). For example, greater left relative to right frontal activity has been linked to greater flexibility in emotional regulation in addition to lower task-related cortisol release, pointing towards its potential importance in individuals' coping abilities in relation to stressors (Papousek et. al, 2011; Quaedflieg et. al, 2015). Inversely, greater right relative to left frontal alpha power is associated with a variety of psychopathological outcomes, most notably affective disorders such as depression and anxiety (Thibodeau Jorgensen, & Kim, 2006). Emotion regulation refers to one's ability to modulate their emotions, and can be done explicitly or implicitly; it can be measured through several dimensions, some of which include the strategies used in emotion regulation, such as cognitive reappraisal and emotional suppression (Gratz & Romer, 2008). Emotion regulation can also be measured through difficulty in regulating emotion, and difficulty in regulating emotion has been linked to greater right relative to left frontal activity (Zhang et.al, 2020). For example, Zhang et al. found that greater left frontal activation was associated with less difficulty in emotion regulation, specifically in relation to impulse control, consistent with previous findings that link increased emotion regulation capabilities with greater left frontal activation (e.g. Papousek et. al, 2016; Schweizer et. al, 2015).

Frontal alpha asymmetry has also been associated with motivational systems; greater left relative to right frontal activity is linked to approach based motivation for achieving goals and positive emotions, whereas greater right relative to left frontal activity is associated with inhibitory systems, meaning that individuals respond to negative behavioral stimuli by avoiding them (Coan, Allen, & McKnight, 2006). This is consistent with findings in recent research, which state that behavioral approach systems (BAS), specifically the impulsivity subscale, is related to greater left than right frontal activity, pointing towards its links to reward sensitivity theory (De Pascalis, Sommer, & Scacchia, 2018). In research conducted by De Pascalis et al. (2018), BAS was measured using Carver and White's BIS/BAS scale, which measures behavioral inhibition systems and three different subdimensions of behavioral approach systems: fun-seeking, drive, and reward-responsiveness (1994). It can be noted that both the behavioral approach system (BAS) and behavioral inhibition system (BIS) have been theorized to affect an individual's stress response. Additionally, Lacey et. al. found that affective emotion control drives greater right frontal activity as opposed to negative affect as a whole, and that while right frontal activity is related to motivation, it is linked to effortful control of motivation rather than withdrawn motivation (Lacey et. al, 2020). Research has demonstrated that for the subscales of BAS (drive, fun-seeking, & reward responsiveness), as well as BAS as a holistic score, there are significant interactions with negative stressful events on depression response (Toyoshima et. al, 2021). More specifically, BAS subscales have a negative moderating effect on the relationship between stressful life events and depressive symptoms; however, BIS scale was not a moderator in this relationship (Toyoshima et. al, 2021).

Few studies have directly examined the neural correlates of perceived stress (c.f., Saeed et al., 2020). A study performed by Saeed et al. found that frontal alpha asymmetry may be a potential biomarker of chronic stress, and may be particularly effective in predicting chronic stress when used in conjunction with existing self-report measures such as the perceived stress scale (PSS; Saeed et al., 2020). In their study, subjects had an initial EEG recording, completed both a psychological assessment of stress interview and the PSS, after which participants were assigned to either the control or stress condition. The results of their data collection pointed to alpha oscillations, specifically alpha asymmetry, being the most accurate predictor of stress level based machine learning models of stress (Saeed et. al, 2020). However, the team acknowledged their small sample size (N = 33) as well as their failure to measure other potential contributors to this relationship as limitations to their finding's applications. In the current study, I sought to investigate the neural correlates of perceived stress, specifically frontal alpha activity measured via frontal alpha asymmetry. Understanding the potential relationship that may exist between perceived stress and frontal alpha activity in the brain may play an important role in how clinicians examine and treat perceived stress. A particularly promising avenue that may benefit from this research is the use of neurofeedback, which has shown promising results in the treatment of anxiety and negative affect by targeting frontal alpha asymmetry patterns (Mennella et. al, 2017).

Hypotheses

Hypothesis 1: Frontal alpha asymmetry will be correlated with perceived stress levels; specifically, greater right frontal activity relative to left frontal activity (lower right frontal alpha power relative to left frontal power) will be associated with higher levels of perceived stress (Catabay et. al 2019; Liu et. al, 2021).

Hypothesis 2: Frontal alpha asymmetry will predict perceived stress levels, after controlling for effects from BDI scores, which are linked to FAA differences in prior research. After controlling for BDI scores, greater FAA scores reflecting greater right relative to left frontal activity (lower right relative to left frontal alpha power) will predict higher perceived stress scores (Saeed et. al, 2020).

Hypothesis 3: The relationship between perceived stress and frontal alpha asymmetry will be mediated by emotion regulation and motivation, with cognitive reappraisal and behavioral inhibition explaining some of the relationship between increased right relative to left frontal activity and higher perceived stress, due to each construct's individual previous links to perceived stress (Toyoshima et. al 202; Liu et. al, 2021).

Methods

Participants

Sampling was done through SONA, an online psychology research portal utilized by Stockton University. Students were compensated through credits that are used for either course requirements or extra credit. Inclusionary criteria included strong right handedness, with EHI scores of 80 or greater, normal or corrected to normal vision, and no history of traumatic brain injury, as per the standard for EEG research studies. Participants taking medications for the treatments of mental health disorders were also excluded. After applying inclusionary criteria, the sample size for the study was 110. The sample consisted of 18.2% male participants (*n* = 20), and 81.8% female participants (*n* = 90), with an average age of 20.69 years (*SD* = 3.28, *min* = 17 years, *max* = 46 years). For more information on participants, see **Table 1** and **Table 2.**

Materials

Edinburgh Handedness Inventory *(EHI; Oldfield, 1971)*

The EHI is a 10-item scale that asks participants to indicate their hand preference (always left, usually left, no preference, usually right, always right) in a variety of tasks (e.g., writing, using scissors, throwing a ball Oldfield, 1971). The EHI is a standard and reliable method for measuring handedness in a variety of studies, and has demonstrated strong test-retest reliability in prior research (Ransil & Schacter, 1994). Responses are scored by assigning values to each response, ranging from -10 to 10 (always left (-10), usually left (-5), no preference (0), usually right (5), always right(10), and summed to obtain a final handedness score. In the current study, scores of 80 or higher were used to confirm that participants are consistently right handed and participants with lower scores were excluded from analyses.

Perceived Stress Scale *(PSS; Cohen et. al, 1983)*

The PSS is a 10-item perceived stress scale that uses a 5 point Likert scale, with scores ranging from 0 (never) to 4 (very often). Example items include: (1) “In the last month, how often have you been upset because of something that happened unexpectedly?”, (4) “In the last month, how often have you felt confident about your ability to handle your personal problems?” Scores are calculated by first reverse scoring questions 4, 5, 7, and 8, then summing the scores of the 10 individual items, with higher scores denoting higher perceived stress levels. Scores ranging from 0-13 would be considered low stress, scores ranging from 14-26 would be considered moderate stress, and scores ranging from 27-40 would be considered high perceived stress. The PSS had an associated Chronbach's alpha value of 0.379.

Beck Depression Inventory-Short Form (BDI-SF; Beck & Beck, 1972)

The BDI-SF is a 13-item assessment scored on a 4-point scale ranging from 0-3. Example items scored from 0-"I don't feel disappointed in myself", 1-"I am disappointed in myself", 2-"I am disgusted in myself", and 3-"I hate myself". The total scores will range from 0-39, 0-4 corresponding with minimal to no depression, 5-7 being mild depression, 8-15 being moderate depression, and scores of 16 or higher corresponding to severe depression. This measure was found to have the same level of internal consistency as the 21-item BDI long form, making it an acceptable substitution measure (Beck & Beck, 1972). The Beck Depression Inventory scale had an associated Cronbach's alpha value of 0.845.

BIS/BAS Scale *(Carver & White, 1994)*

The BIS/BAS scale, developed by Carver and White (1994), measures the two main motivation systems that have been proposed to drive behaviors: the behavioral approach system (BAS) which regulates desire based motives, and behavioral inhibition system (BIS) which regulates aversive motives. The scale consists of 24 items measured on a 4-point Likert scale with responses ranging from "very true for me" (1) to "very false for me" (4). All but items #2 and #22 are reversed scored, and the questionnaire is broken down into the following subscales: BAS drive (3, 9, 12, 21), BAS fun-seeking (5, 10, 15, 20), BAS reward-responsiveness (4, 7, 14, 18, 23), and BIS (2, 8, 13, 16, 19, 22, 24). Example items for each include: (3)"I go out of my way to get things I want", (5) "I'm always willing to try something new if I think it will be fun", (4) "When I'm doing well at something, I love to keep at it", and (8) "Criticism or scolding hurts me quite a bit." The BIS subscale had an associated Cronbach's alpha value of 0.784, the BAS Reward Responsiveness subscale had an associated Cronbach's alpha value of 0.779, the BAS Drive subscale had an associated Cronbach's alpha value of 0.602, and the BAS Fun Seeking subscale had an associated Cronbach's alpha value of 0.627.

Emotion Regulation Questionnaire *(ERQ; Gross & John, 2003)*

The ERQ, devised by Gross and John (2003), measures two main subcomponents of emotion regulation: cognitive reappraisal and emotion suppression. It is a 10-item scale measured on a 7 point Likert scale, with responses ranging from "strongly disagree" (1) to "strongly agree" (7). Items 1, 3, 5, 7, 8, and 10 are linked to reappraisal, and items 2, 4, 6, and 9 are linked to suppression. Example items for each include: (1) "When I want to feel more positive emotion (such as joy or amusement), I change what I'm thinking about", (2) "I keep my emotions to myself." The reappraisal subscale of the ERQ had an associated Cronbach's alpha value of 0.832, and the suppression subscale had an associated Cronbach's alpha value of 0.651 (McDonald's Omega value of 0.818).

Difficulties in Emotion Regulation Scale *(DERS; Gratz & Romer, 2004)*

The DERS, developed by Gratz and Romer (2004), is a 36 item questionnaire that measures issues with emotion regulation, and includes the following subdimensions: non acceptance of emotional response, difficulty in engaging in goal directed behavior, difficulty with impulse control, lack of emotional awareness, limited access to emotion regulation strategies, and lack of emotional clarity. The questions are scored on a 1-5 Likert scale, with responses ranging from "almost always" (1) to "almost never" (5); these responses are then summed for each subscale, as well as summed as a total score for difficulties in emotion regulation. Example items include: "When I'm upset, I become angry with myself for feeling that way", "When I'm upset, I have difficulty getting work done", "I experience my emotions as overwhelming and out of control", "I pay attention to how I feel" (reverse scored), "When I am upset, I believe I will remain that way for a long time", and "I am clear about my feelings" (reverse scored). The subscales of the DERS had associated Cronbach's alpha values ranging from 0.753 to 0.919. The total DERS had an associated Cronbach's alpha value of 0.878.

EEG

EEG data were recorded using a HydroCel Geodesic Sensor Net, with Cz reference (Electrical Geodesics, Inc., 2020). Sensor impedance levels were kept below 50 kΩ , appropriate for use with the Net Amps 400 high-impedance amplifier. Data were sampled at 500 Hz, and filtered using an analog .1 – 100 Hz bandpass filter. Three minutes of eyes-open data followed by three minutes of eyes-closed data were recorded from each participant using Net Station 5.4 software (Electrical Geodesics, Inc., 2020)

Procedure

The procedure for the project was approved by Stockton University's IRB. Participants were first welcomed into the lab (G-226) and their informed consent obtained. The participant then completed a basic demographics form as well as the EHI. After completing these measures, the EEG net was applied. They then engaged in a 3 minute eyes-open recording block, followed by a 3 minute eyes-closed recording block. Once the recording was complete, the net was removed and the participant completed a series of self-report measures, detailed above, on the lab computer using the Qualtrics platform. Measures included the BDI-SF, the PSS, the BIS/BAS scale, the DERS, and the ERQ. All measures were administered in a randomized order for each participant. They were then thanked for their participation and their SONA credits granted.

EEG Data Reduction

EEG data were processed offline using EEGLAB 2022.1 (Delorme & Makeig, 2004), supplemented by MATLAB scripts, run using Matlab 2021a (Mathworks, Natick, MA, USA). The data were filtered in EEGLAB using a band-pass filter (0.2 - 50 Hz) and then segmented into 2-second epochs. Files were visually inspected to remove bad channels and epochs containing gross artifacts. Files were then subject to independent component analysis and the resulting components were processed for artifact using IC Label (Pion-Tonachini et al., 2019), a plug-in available for use on the EEGLAB platform. Components identified as artifacts were removed from the data and the files were visually inspected a second time to ensure no artifact remained. After final visual review, missing channels were interpolated from neighboring channels and the data were re-referenced to average reference before undergoing baseline correction.

Absolute power was estimated using MATLAB's Fast Fourier Transformation function. Power was estimated for the alpha frequency band (8 Hz - 13 Hz) and log transformed. FAA was calculated at frontal electrode pairs (e.g electrodes F7 and F8) so that positive FAA scores indicate greater right relative to left frontal alpha power, or greater left relative to right frontal activity. FAA was calculated for electrode pairs F3 and F4 as well as F7 and F8 to compare activity at medial and lateral frontal locations.

Results

Analysis Overview

Prior to analyses, data was screened for univariate and multivariate outliers and none were identified; the variables of interest were found to be normally distributed and did not violate the assumption of homoscedasticity (see **Table 2** for descriptive statistics). Correlation and regression analyses were utilized to analyze the data. To examine the first hypothesis, relationships between frontal alpha asymmetry and perceived stress scores were explored with an expected outcome of a negative correlation between left frontal alpha activity and perceived stress scores. To examine the second and third hypotheses, regression analyses were performed in order to determine the predictive capabilities of FAA in relation to perceived stress. An initial standard multiple regression was performed utilizing exploring the effectiveness of FAA in predicting perceived stress after controlling for BDI. A follow-up backwards regression analysis was then conducted to determine the best model for predicting stress from FAA, the BIS/BAS subscales,and emotional regulation measures. Based on results from this regression, mediation analyses were then conducted utilizing cognitive reappraisal, DERS total scores, and BIS motivation as potential mediating variables for the relationship between FAA and perceived stress while controlling for BDI. All analyses were performed using a 95% confidence interval and at the $p < 0.05$ significance level.

Frontal Alpha Asymmetry and Perceived Stress

No significant relationships were found for perceived stress and FAA at F3_F4 or F7_F8 electrode locations (see **Table 3**). However, after controlling for BDI score, a significant negative correlation was found between perceived stress and FAA at F8-F7, $r = -0.24$, $p = 0.01$, meaning that greater activity over the right hemisphere was associated with greater perceived stress. No significant relationships for FAA at F4-F3 were present after controlling for BDI (**Table 4**).

Frontal Alpha Asymmetry as a Predictor of Perceived Stress

A standard multiple regression was conducted using FAA at F7_F8 as an independent variable and perceived stress as the outcome variable, after controlling for BDI scores. The model was significant, $F(2, 107) = 41.84$, $p < 0.001$, $R^2 = 0.439$. BDI accounted for 42.7% of the variance in perceived stress ($p < 0.001$) and FAA at F8-F7 accounted for 3.35% of the variance in perceived stress ($p = 0.013$). See **Table 5** for a complete summary of the results.

FAA, Motivation, Emotion Regulation, and Perceived Stress

A backwards linear regression was utilized to identify the best model of perceived stress out of the following candidate variables: BDI, DERS total score, cognitive reappraisal, suppression, BIS, BAS, and FAA at F8-F7 (**Table 6**). The final model identified BDI ($\beta = 0.455$, $t = 6.228$, $p < 0.001$), BAS fun-seeking ($\beta = 0.201$, $t = 3.162$, $p < 0.05$), DERS total ($\beta = 0.376$, $t = 5.094$, $p < 0.001$), cognitive reappraisal ($\beta = -0.144$, $t = -2.215$, $p < 0.05$), and FAA at F8-F7 ($\beta = -0.173$, $t = -2.760$, $p < 0.05$) as having the greatest degree of predictability, and was found to be statistically significant, $F(5, 104) = 32.118$, $p < 0.001$. The adjusted R^2 value (0.588) suggests that 58.8% of the variance in perceived stress can be accounted for by the model.

To test the third hypothesis, a mediation analysis was conducted to examine whether cognitive reappraisal or DERS total scores behaved as mediators in the relationship between FAA and perceived stress, while controlling for BDI. In these models, the independent variable was perceived stress, the dependent variable was FAA at F8-F7, and the possible mediators were DERS total, a measure of emotion regulation difficulty, and cognitive reappraisal; BDI was included as a covariate in the analysis. For DERS total scores, the overall model was significant, $F(3, 106) = 44.992$, $p < 0.001$. The direct effect of FAA at F8-F7 on stress was significant, $c' = -13.82$, $p = 0.019$. However, there was no significant indirect effect between FAA at F8-F7 and stress through DERS total, $ab = - 2.521$, LLCI: -9.899, ULCI; 4.473. For cognitive reappraisal, the overall model was also significant, $F(3, 106) = 30.631$, $p < 0.001$. The direct effect of FAA at F8-F7 was significant, $c' = -15.601$, $p = 0.016$. However, there was no significant indirect effect between FAA at F8-F7 and stress through cognitive reappraisal, *ab* = -0.737, LLCI: -4.278, ULCI: 2.824.

A second mediation analysis was conducted, this time using stress as a potential mediator of the relationship between FAA at F8-F7 and DERS total, including BDI as a covariate as in the previous model. The purpose of this analysis was to examine if the directionality of the relationship may be different than previously hypothesized, with stress perception behaving as a mediator for emotion regulation difficulties and FAA. The overall model was significant, $F(2,107) = 20.54$, $p < .001$. In this case, there was a significant indirect effect between FAA at F8-F7 and DERS total through stress (ab = 16.99, LLCI: -30.4655, ULCI: -4.1233), with higher FAA associated with lower stress and higher stress resulting in higher emotion regulation difficulties, reflected in DERS total scores (see **Figure 1**). The direct effect between FAA and DERS total was not significant, c' = 4.86, $p = .71$

Discussion

This study explored the intricate relationship between frontal alpha asymmetry (FAA), perceived stress, and various psychological constructs such as emotion regulation and motivation. The findings shed light on how individual differences in neural activity patterns may influence an individual's perceived stress levels and, subsequently, their emotional well-being.

The results revealed that higher levels of perceived stress were associated with greater right frontal activity (lower right frontal alpha power), indicating diminished left relative to right frontal activity. This aligns with previous research suggesting that increased right frontal activity is linked to affective disorders such as depression and anxiety (Thibodeau Jorgensen, & Kim, 2006). Moreover, the study demonstrated that FAA at F8-F7 independently accounted for a significant portion of the variance in perceived stress levels, even after controlling for depressive symptoms. Frontolateral asymmetry has been seen as increasingly important in predicting risk and severity of depressive symptoms in fMRI studies (Pizzagalli, 2011; Gotlib & Hamilton, 2014). Glier and colleagues explored similar findings in their 2022 paper, which examined acute stress and trait anxiety in relation to FAA calculated at F8-F7; the study found increased right hemispheric activation for individuals high in trait anxiety following acute stress induction (Glier et. al, 2022). It is important to highlight this particular finding due to the larger volume of studies that explore asymmetry using F3 and F4 electrodes, which are more medial locations over the frontal regions. F3-F4 electrode pairs were not significant in the analyses performed in the present research. The present findings underscore the potential utility of frontolateral alpha asymmetry as a neurobiological marker for assessing perceived stress.

The results of the regression analyses revealed compelling insights into the relationship between frontal alpha asymmetry (FAA) and perceived stress. Consistent with prior literature, FAA emerged as a significant predictor of perceived stress, even after accounting for the influence of depressive symptoms (BDI scores) (Saeed et al., 2020). Specifically, greater right frontal activity relative to left frontal activity (lower right relative to left frontal alpha power) was associated with higher perceived stress levels, supporting previous findings (Catabay et al., 2019; Liu et al., 2021). These results align with the broader theoretical framework suggesting frontal alpha asymmetry as a potential biomarker of stress and its utility in predicting stress levels (Saeed et al., 2020). The regression findings also underscore the importance of considering individual differences in coping mechanisms and motivational systems when examining the relationship between FAA and perceived stress. Specifically, the study found that the reward subscale of the BAS was a significant predictors of perceived stress, in line with previous literature suggesting a link between BAS and stress response (Toyoshima et al., 2021). This highlights the need for further exploration into the nuanced interactions between motivational systems, neural activity patterns, and perceived stress. Additionally, while BIS was relevant to perceived stress, it did not emerge as a significant predictor in the final regression model. While previous studies have linked the BIS/BAS scale and FAA, others have found no significant relationship between the constructs as it pertains to healthy adolescents (Scheinder et. al, 2016; Day et. al, 2019).

Furthermore, the study explored potential mediators in the relationship between FAA and perceived stress, focusing on emotion regulation and motivation. While cognitive reappraisal and emotion regulation difficulties did not emerge as significant mediators, stress itself was found to mediate the relationship between FAA and emotion regulation difficulties. This suggests a complex interplay between neural activity patterns, perceived stress, and emotion regulation, wherein higher levels of perceived stress may exacerbate difficulties in regulating emotions, leading to greater emotional dysregulation (Epel et. al, 2018; Thayer, Mather, & Koenig, 2021).

It is important to note that within the present study, a few limitations do exist, and further research needs to be done to address them. Firstly, the study's reliance on a convenience sample recruited through an online psychology research portal may introduce selection bias, limiting the generalizability of the findings beyond the university student population. Moreover, the exclusion of participants taking medications for mental health disorders may have inadvertently excluded individuals with clinically significant levels of stress, potentially skewing the sample towards lower stress levels. Additionally, the study's cross-sectional design precludes causal inference, limiting the ability to ascertain the directionality of the observed relationships between FAA, perceived stress, and other psychological constructs. Lastly, the reliance on self-report measures for assessing perceived stress, emotion regulation, and motivation introduces the possibility of common method bias, as participants may respond in a socially desirable manner or may not accurately reflect their true experiences. Future research employing objective measures of stress could provide more robust evidence regarding the complex interplay between neural activity patterns and psychological functioning.

Overall, this study contributes to our understanding of the neural correlates of perceived stress and emphasizes the importance of considering individual differences in emotion regulation and motivation when assessing stress-related outcomes. Future research could benefit from examining the temporal dynamics of these relationships and explore potential interventions targeting neural activity patterns to mitigate perceived stress and improve emotional well-being. Additionally, incorporating measures of physiological stress responses, such as cortisol levels, and current life events checklists, could provide further insights into the underlying mechanisms linking neural activity to perceived stress.

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Table 1: Demographics

Variable		**Frequency**	**Percentage**
Gender	**Male**	20	18.20
	Female	90	81.80
Race/Ethnicity	**American Indian/Alaska Native**	1	0.90
	Asian	11	10.00
	Black	3	2.70
	White	63	57.30
	Multi-racial	3	2.70
	Latinx	29	26.40
Mental Health Dx	**Yes**	23	20.90
	No	87	79.10

Table 2: Descriptives

Variable	N	Min	Max	M	SD
Age	110	17	46	20.69	3.281
Handedness	110	80	100	94.864	6.755
Stress	110	2	33	20.29	6.380
BDI	110	0	18	5.82	4.528
Cognitive Reappraisal	110	10	42	27.37	6.956
Emotion Suppression	110	4	28	15.51	5.583
DERS Total	110	18	75	43.92	12.578
BAS Drive	110	4	16	11.01	2.543
BAS Fun-seeking	110	5	16	12.12	2.204
BAS Reward	110	13	20	17.64	1.765
BIS	110	8	28	22.26	3.748
FAA at F4-F3	110	-0.24	0.10	-0.036	0.070
FAA at F8-F7	110	-0.28	0.20	-0.019	0.072
FAA at Fp2-Fp1	110	-0.18	0.06	-0.006	0.039

Table 3: Correlations between stress & variables of interest. * denotes significance at the 0.05 level, and ** denotes significance at the 0.01 level.

Variable	Stress	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.BDI	0.637**	—									
2.Cognitive Reappraisal	-0.245**	-0.121	—								
3.Emotion Suppression	0.220*	0.298**	0.120	—							
4.DERS Total	0.641**	0.522**	-0.227*	0.342**	—						
5.BAS Drive	-0.104	-0.113	0.159	-0.215*	-0.140	—					
6.BAS Fun-seeking	0.116	-0.053	0.227*	-0.052	-0.028	0.412**	—				
7.BAS Reward	0.043	-0.031	0.350**	-0.093	-0.057	0.473**	0.381**	—			
8..BIS	0.380**	0.307**	-0.179	-0.054	0.371**	-0.078	-0.025	0.163	—		
9.FAA at F4-F3	-0.026	0.120	0.128	0.187	0.021	0.063	-0.019	0.114	-0.222*	—	
10.FAA at F8-F7	-0.105	0.120	0.036	0.053	-0.005	0.080	0.101	0.056	-0.208*	0.680**	—
11.FAA at Fp2-Fp1	0.035	0.047	-0.038	0.006	0.076	0.036	0.075	-0.033	-0.049	0.339**	0.446**

Table 4: Correlations between stress & variables of interest, controlling for BDI. * denotes significance at the 0.05 level, and ** denotes significance at the 0.01 level.

Variable	Stress	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.Cognitive Reappraisal	-0.219*	—								
2.Emotion Suppression	0.041	0.164	—							
3.DERS Total	0.469**	-0.194*	0.229*	—						
4.BAS Drive	-0.042	0.147	-0.192*	-0.095	—					
5.BAS Fun-seeking	0.195*	0.222*	-0.038	-0.001	0.409**	—				
6.BAS Reward	0.082	0.349**	-0.087	-0.048	0.473**	0.381**	—			
7.BIS	0.251**	-0.151	-0.161	0.259**	-0.046	-0.009	0.182	—		
8.FAA at F4-F3	-0.134	0.145	0.160	-0.049	0.078	-0.013	0.119	-0.274**	—	
9.FAA at F8-F7	-0.237**	0.052	0.019	-0.081	0.095	0.108	0.061	-0.259**	0.675**	—
10.FAA at Fp2-Fp1	0.006	-0.033	-0.009	0.061	0.042	0.078	-0.013	-0.067	0.336**	0.4

Table 5: Standard linear regression predicting perceived stress.

Variable	B	95% CI [LL,UL]	*β*	*t*	*p*
(Constant)	14.581	[13.043, 16.118]		18.796	<0.001
BDI	0.928	[0.725, 1.132]	0.659	9.032	<0.001
FAA at F8-F7	-16.338	[-29.173, -3.504]	-0.184	-2.524	0.013

Table 6: Backwards linear regression predicting perceived stress

Model		B	95% CI [LL, UL]	*β*	*t*	*p*
5	**(Constant)**	4.461	[-1.509, 10.432]		1.482	0.141
	BDI	0.641	[0.437, 0.844]	0.455	6.228	<0.001
	FAA at F8-F7	-15.311	[-26.311, -4.311]	-0.173	-2.760	0.007
	BAS Fun-seeking	0.582	[0.217, 0.946]	0.201	3.162	0.002
	Cognitive Reappraisal	-0.132	[-0.250, -0.014]	-0.144	-2.215	0.029
	DERS total	0.191	[0.116, 0.265]	0.376	5.094	<0.001

Figure 1: Depiction of mediating role of perceived stress between FAA at F8-F7 and DERS.