Hazy Interactions: Behavioral and Neural Dysregulation of Social Decision-Making in Cannabis Users

by

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Abstract

Given the maladaptive relationship between cannabis use and social avoidance behavior, this study aimed to characterize behavioral and neural dysfunction during social decision-making in frequent cannabis users. For social decision-making, we used the social approach-avoidance conflict (SAAC) task, which measures approach-avoidance decisions to morphed facial expressions that systematically vary in happiness, anger, and co-occurring happiness and anger. During the SAAC task, electroencephalography (EEG) was used to measure midfrontal theta activity (FMθ), a neural marker of both cognitive conflict and approach-avoidance conflict. Participants (*N* = 31) included frequent cannabis users (*n* = 15) and infrequent cannabis users (*n* = 16). Contrary to hypotheses, frequent and infrequent cannabis users did not significantly differ in approach-avoidance ratings, reaction time, or midfrontal theta (FMθ) activity in response to social reward-threat conflict ($50\%_{Happy}/50\%_{Angry}$) that induce approach-avoidance conflict. Secondary analyses similarly revealed no significant cannabis-related differences in response to pure social reward ($100\%_{Happy}$) or social threat ($100\%_{Angry}$). Sensitivity analyses indicated that social anxiety severity was associated with social reward-threat conflict ratings, but did not account for cannabis group differences. Collectively, these findings indicate that frequent cannabis use was not associated with significant behavioral or neural responses during social approach-avoidance conflict in the current sample.

Artificial Intelligence (AI) Use Disclosure Statement

In the preparation of this thesis, no Artificial Intelligence (AI) tools were used.

Digital Accessibility Use Disclosure Statement

In the preparation of this thesis, the following digital accessibility tools were used to ensure this document complies with federal requirements: Microsoft Word. The author acknowledges full responsibility for the intellectual content of this work and has made a good faith effort to comply with digital accessibility requirements in publishing, wherein the nature of the content does not significantly change in order to do so. Furthermore, all content has been reviewed and revised to meet these requirements prior to final publication.

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List of Abbreviations

SAB	Social avoidance behavior
EEG	Electroencephalography
SAAC	Social Approach-Avoidance Conflict
SAD	Social anxiety disorder
CUD	Cannabis use disorder
FMθ	Midfrontal Theta
RT	Reaction time
MFC	Medial Frontal Cortex
ACC	Anterior Cingulate Cortex
AAC	Approach-Avoidance Conflict
MPS	Marijuana Problems Scale
THC	Tetrahydrocannabinol
QFVI	The Cahalan Quantity Frequency Variability Index
CBAS	The Cognitive Behavioral Avoidance Scale
CAST	Cannabis Abuse Screening Test
AUDIT	Alcohol Use Disorders Identification Test
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
DFAQ-CU	The Daily Sessions, Frequency, Age of Onset, and Quantity of Cannabis Use Inventory
EC-TLFB	The Enhanced Cannabis Timeline Follow-back
LSAS-SR	Liebowitz Social Anxiety Scale-Self Report

Introduction

Frequent cannabis use has been associated with social impairments such as social avoidance behavior (SAB), which may be attributable to disruptions in processing emotional stimuli and/or impaired conflict adaptation (Cougle et al., 2020; Hester et al., 2009, Walukevich-Dienst et al., 2023). SAB is a broad category of avoidance behaviors that can include premature withdrawal from social interactions or overt avoidance of social interactions, which may be exacerbated or maintained by cannabis use. Previous research suggests that the relationship between cannabis use and SAB may be particularly impairing in individuals who use cannabis to cope with social anxiety or discomfort in social situations (Buckner & Zvolensky, 2014). Therefore, is important to better understand SAB-relevant social decision-making processes in the context of cannabis use because these factors may reinforce one another over time, contributing to greater social isolation, increased psychiatric comorbidities, and reduced overall wellbeing (Cougle et al., 2020; Walukevich-Dienst et al., 2023). To the best of our knowledge, however, no research has empirically tested the motivational and neural mechanisms that may contribute to SAB in a cannabis using population, specifically. The present study seeks to bridge this gap by using a validated social approach-avoidance conflict (SAAC) task and electroencephalography (EEG) measures to characterize dysfunction in SAB-relevant motivational and neural processes among frequent cannabis users.

Cannabis Use and Social Avoidance Behavior

Emerging research suggests a robust link between cannabis use and impaired social functioning such as SAB, particularly in individuals who use cannabis to cope with anxiety in social environments. Social anxiety, a key predictor of SAB, has been associated with increased risk for cannabis-related problems in individuals who meet criteria for social anxiety disorder (SAD; Buckner et al., 2011; Buckner & Zvolensky, 2014; Walukevich-Dienst et al., 2023). Consistently, the lifetime prevalence of cannabis dependence among individuals with SAD is approximately seven times greater that of the general population (Agosti et al., 2002; Buckner et al., 2008). Initially, cannabis use may serve as a coping mechanism to reduce anxiety in social situations. Over time, however, cannabis use ultimately maintains long-term anxiety in social situations, which can further facilitate SAB and exacerbate interpersonal dysfunction.

Consistent with this view, Buckner & Zvolensky (2014) demonstrated that individuals who used cannabis to cope with social anxiety, and those who avoid social interactions when cannabis is unavailable, tend to report higher levels of cannabis impairment. Similarly, Buckner et al. (2011) found that social avoidance, more than social fear, was a predictor of cannabis-related problems. Extending these findings to a more day-to-day level of functioning, Walukevich-Dienst et al. (2023) found that on days when young adults used cannabis to manage social anxiety symptoms, they experienced more negative cannabis-related consequences and were more likely to report avoiding other people. Together, these findings indicate a mutually reinforcing relationship between cannabis use and SAB, suggesting that behavioral avoidance may play an important role in maintaining and/or exacerbating cannabis use.

Moreover, previous research suggests that cannabis use may uniquely affect social behaviors even when compared to other types of substance use (Cougle et al., 2020). First, longitudinal studies demonstrate that individuals with anxiety disorders who continue to use cannabis are more likely to experience disrupted interpersonal relationships, school withdrawal, and reduced quality of life compared to non-user counterparts even after controlling for other types of substance use (Feingold et al., 2018). Second, individuals with cannabis use disorder (CUD) also tend to experience significantly lower levels of perceived social support compared to both non-users as well as compared to individuals with alcohol dependence (Cougle et al., 2020; Gliksberg et al., 2022). In particular, Gliksberg et al. (2022) found that the association between cannabis use, and social impairment is mediated by decreased social network size and diversity, which could suggest that cannabis use specifically diminishes opportunities for meaningful social interactions.

Collectively, these findings highlight a potential bidirectional model between cannabis use and social avoidance behavior. Impairments in interpersonal functioning are especially concerning given the high rates of psychiatric comorbidity of anxiety and mood disorders among individuals with cannabis dependence (Agosti et al., 2002). Therefore, examining the behavioral and neural mechanisms of social avoidance in cannabis users is critical for better understanding, and potentially treating, interpersonal consequences of frequent cannabis use.

Motivational Mechanisms Underlying Social Avoidance Behavior

Previous research demonstrates that perception of and motivational responses to affective facial expressions plays a key role in guiding social behavior. As humans, our social engagements are influenced by our ability to recognize and respond to social signals in our environment, especially signals conveyed by emotional facial expressions (Ambadar et al., 2005; Seidel et al., 2010). Research suggests that decision-making to approach or avoid another individual unfolds rapidly at the earliest stages of emotional perception, which serves as an evolutionary tool for evaluating social safety and threat in our environments (Ikeda, 2024; Frith, 2009). Thus, facial expressions engage multiple cognitive processes, including both the automatic processing of emotion signals as well as higher-order interpretation of social cues they convey (Ambadar et al., 2005; Frith, 2009).

From a social motivational perspective, facial expressions act as important social signals that help inform and shape interpersonal interactions by activating fundamental approach and avoidance motivational systems (Frith, 2009; Gable & Gosnell, 2013). Specifically, perception of social threat such as anger cues typically activates avoidance motivation, whereas perception of social reward such as happiness cues typically activate approach motivation (Duijndam et al., 2020; Frith, 2009; Gable & Gosnell, 2013; Heuer et al., 2007). For example, happy expressions signal prosociality and typically communicate the possibility of a positive social interaction (Nikitin & Freund, 2019; Seidel et al., 2010). Consistently, research has shown that individuals respond faster with approach behaviors to happy faces compared to other facial expressions, indicating that happy faces may have a strong motivational effect on the decision to engage in social interactions (Duijndam et al., 2020; Nikitin & Freund, 2019). In contrast, angry expressions signal aggression and typically communicate the possibility of a negative social interaction. As a result, individuals typically respond to angry faces with avoidance behavior (Frith, 2009; Heuer et al., 2007; Ikeda, 2024; Seidel et al., 2010). Consistent with the close functional relationship between affective facial expressions and social motivation, SAB is associated with disrupted social motivational responses to affective facial expressions.

SAB is influenced by approach-avoidance responses to affective facial expressions that communicate more ambiguous social signals (Evans et al., 2024). Previous research demonstrates that affective facial expressions vary widely in both intensity and duration with some emotional expressions being intense and long-lasting, whereas others can be more subtle and fleeting (Ambadar et al., 2005). Thus, more ambiguous expressions are common in everyday life, as facial expressions are typically a blend of multiple, ambiguous social signals, which may be particularly relevant to SAB (Ambadar et al., 2005; Evans et al., 2024). Consistent with this view, SAB is associated with greater avoidance motivation and weaker approach motivation specifically when social reward and social threat co-occur (i.e., $50\%_{\text{Happy}} + 50\%_{\text{Angry}}$) to produce social reward-threat conflict (Evans et al, 2024). Moreover, emerging research suggests that these types of social reward-threat conflict signals elicit competing motivations to approach and avoid another individual (i.e., social approach-avoidance conflict; SAAC; Evans et al, 2024). Together, these findings suggest that SAB in frequent cannabis users may be facilitated by dysregulated social motivation during SAAC, which aligns with previously described disruptions in processing emotional stimuli and/or impaired conflict adaptation among frequent cannabis users (Cougle et al., 2020; Hester et al., 2009, Walukevich-Dienst et al., 2023).

However, no research to date has examined if frequent cannabis users exhibit SAAC-related dysfunction or characterized the neural processes that may contribute to SAAC-related dysfunction in frequent cannabis users. Understanding whether frequent cannabis users show altered behavioral and neural responses during SAAC is critical for clarifying how cannabis use may contribute to real-world social impairment. Given that social interactions involve interpreting conflicting emotional signals, disruptions in these processes could interfere with the ability to form or maintain meaningful social relationships. Investigating the neural mechanisms underlying SAAC, particularly areas involved in conflict monitoring, may provide insight into the cognitive processes that drive maladaptive social behaviors in a cannabis using population.

Neural Mechanisms of Social Approach-Avoidance Conflict

Using EEG, previous research demonstrates that cognitive and motivational conflict elicit Midfrontal Theta (FMθ) activity. Traditionally, FMθ activity is elicited in stimulus-response tasks, such as a Flanker task, which induce cognitive conflict via competition of behavioral responses to task-relevant and task-irrelevant stimuli (Lange et al., 2022, (Nigbur et al., 2011). At the neural level, FMθ reflects activity in the medial frontal cortex (MFC), a region involved in performance monitoring and conflict processing (Cavanagh & Shackman, 2015; Lange et al., 2022). Cavanagh & Shackman (2015) argue that FMθ activity represents a neurophysiological mechanism for adjusting behavior when environmental information is ambiguous and/or conflicting, which frequently induces states of high arousal and anxiety. Consistent with this conceptualization, FMθ activity is also elicited in the context of approach-avoidance conflict (AAC), which involves competition between reward and threat. For example, Lange et al. (2022) found that FMθ activity increased during high-conflict decision-making where participants had to accept or reject outcomes with varying rewards or punishments. Demonstrating specificity to AAC, rather than ambiguity more generally, the strongest FMθ activity occurred when AAC was maximal (i.e., trials with both 50% reward and 50% punishment outcome probabilities). Moreover, this study did not observe a correlation between FMθ activity elicited by cognitive conflict (Flanker task) and FMθ activity elicited by AAC (reward/threat task). This suggests that FMθ activity during AAC can also represent motivational conflict specifically, rather than decisional conflict more generally. Therefore, there is growing evidence that FMθ is a neural mechanism of motivational conflict, which makes it a highly relevant towards better understanding SAB in frequent cannabis users.

In short, FMθ dysfunction during SAAC may play a particularly important role in SAB among frequent cannabis users. As noted previously, SAB is more generally associated with dysregulated motivational responses during SAAC and cannabis use is associated with deficits in conflict adaptation (Evans et al., 2024; Hester et al., 2009). These findings converge to suggest that FMθ activity dysfunction may contribute to maladaptive conflict adaptation during SAAC, which facilitates engagement in SAB. While research remains limited in cannabis using populations, Hester et al. (2009) found that chronic cannabis users showed reduced activity during a stimulus-response task in the anterior cingulate cortex (ACC), a core neural region recruited during conflict processing and commonly reflected in the FMθ. In this study, cannabis users were also less aware of performance errors, which could suggest impairments in conflict processing. Therefore, it seems plausible that cannabis users may exhibit blunted FMθ activity during SAAC. Identifying blunted FMθ activity in frequent cannabis users during SAAC offers important implications for understanding the mechanisms that contribute to SAB, which may ultimately yield insights into novel treatment targets in this population.

Present Study

Therefore, the proposed study aimed to compare motivational and neural measures of SAAC between frequent cannabis users compared to infrequent cannabis users. The proposed study builds on prior research using the Social Approach-Avoidance Conflict (SAAC) task to robustly elicit and measure SAAC, which has demonstrated strong psychometric properties for clinical research (Evans et al., 2024; Evans et al., 2026). During the SAAC task, EEG data will be concurrently collected to measure FMθ activity, a neural mechanism of AAC (Lange et al., 2022). In addition to providing a measure of FMθ, EEG was selected due to its excellent temporal resolution (Louis & Frey, 2016), which allows for precise, millisecond-level measurement of cortical activity during decision-making. Using this approach, the current study characterized social decision-making and neural dysfunction during SAAC in frequent cannabis users.

Hypotheses

Hypothesis 1a

At the behavioral level, we hypothesized that frequent cannabis users would exhibit more avoidance selections and fewer approach selections during SAAC ($50\%_{Happy}$ / $50\%_{Angry}$ faces), compared to infrequent cannabis users. No group differences were expected in response to $100\%_{Happy}$ faces or $100\%_{Angry}$ faces, which do not induce SAAC.

Hypothesis 1b

At the behavioral level, we hypothesized that frequent cannabis users would exhibit slower reaction time (RT) during SAAC ($50\%_{Happy}$ / $50\%_{Angry}$ faces) compared to infrequent cannabis users. No group differences were expected in response to $100\%_{Happy}$ faces or $100\%_{Angry}$ faces, which do not induce SAAC.

Hypothesis 2

At the neural level, we hypothesized that frequent cannabis users would exhibit reduced FMθ activity during SAAC ($50\%_{Happy}$ / $50\%_{Angry}$ faces) compared to infrequent users. No group differences were expected in response to $100\%_{Happy}$ faces or $100\%_{Angry}$ faces, which do not induce SAAC.

Method

Sample

The final sample consisted of 31 individuals recruited from a southeastern university and surrounding community (*M* = 30.16 years, *SD* = 11.14; 61.30% female, 38.70% male). The sample was predominantly White (77.4%), with 9.7% identifying as Black, 9.7% as Hispanic, and 3.2% as Other or Multiracial. Additional demographic characteristics stratified by cannabis use group are presented in Table 1.

Of the final sample, 16 participants (51.6%) were infrequent cannabis users, and 15 participants (48.4%) were frequent cannabis users. Infrequent cannabis users were required to report no cannabis use during the past month and fewer than 20 lifetime cannabis use occasions. To minimize substance-related confounds, infrequent cannabis users were also required to report no more than 3 standard drinks per week for women and 7 standard drinks per week for males, with 0 occasions of binge drinking in the past year. Non-drinkers were also eligible for the infrequent cannabis use group. Comparatively, frequent cannabis users reported cannabis use on four or more days per week during the past month. To further reduce potential confounding effects of alcohol use, frequent cannabis users were required to report no more than 7 standard drinks per week for women or 14 standard drinks per week for men during the past year, with fewer than six binge-drinking episodes (CDC, 2023). Individuals reporting regular or recent use of other illicit substances were excluded. All participants were compensated through either course credit or monetary compensation.

Frequent and infrequent cannabis users did not significantly differ in age, $t(29) = -0.40$, $p = 0.69$, $d = -0.14$, biological sex, $\chi^2(1) = 0.02$, $p = 0.89$. Additionally, frequent and infrequent cannabis users did not significantly differ in estimated weekly alcohol consumption $t(29) = 0.05$ $p = 0.97$, $d = 0.20$. Self-report and behavioral data were available for all participants. However, midfrontal theta data for four individuals were discarded due to poor data quality associated with excessive EEG signal artifacts (Infrequent cannabis users: $n = 2$; Frequent cannabis users: $n = 2$). Therefore, EEG analyses were conducted on a final sample of $N = 31$ participants, including $n = 16$ infrequent cannabis users and $n = 15$ frequent cannabis users.

Self-Report Measures

Marijuana Problems Scale (MPS; Stephens et al., 2000)

The MPS is a self-report questionnaire that identified areas of an individual's life affected by marijuana use in the past three months. It contained 19 items that represented potential negative effects of marijuana on social relationships, self-esteem, motivation, productivity, work and finances, physical health, memory impairment, and legal problems. Participants rated each item based on the extent to which it had been a problem for them using a three-point scale (0= No Problem, 1= Minor Problem, or 2= Serious Problem). Responses were summed into a total score ranging from 0-38, with a higher score reflecting greater cannabis-related problem severity. The MPS has demonstrated good psychometric properties with particularly strong internal consistency (Buckner et al., 2007; Hodgins & Stea, 2018). In the present study, the MPS demonstrated good internal consistency (α = 0.88).

The Daily Sessions, Frequency, Age of Onset, and Quantity of Cannabis Use Inventory (DFAQ-CU; Cuttler & Spradlin, 2017)

The DFAQ-CU is a self-report questionnaire that measured frequency, age of onset, and quantity of cannabis use. It contained pictures of marijuana that assisted with the measurement of the quantity of marijuana used, as well as questions that assessed the method of cannabis use (e.g., concentrates, flower, edibles), the methods of administering cannabis (e.g., joints, pipes, pens), and THC levels. This measure helped capture an individual's frequency, quantity, and age of onset of cannabis use. The DFAQ-CU has demonstrated strong psychometric properties as a measure of cannabis use patterns (Cuttler & Spradlin, 2017). Reliability is excellent for assessing frequency (α = 0.95), good for age of onset and marijuana quantity (α = 0.81 and 0.88), and acceptable for marijuana concentrate quantity and daily sessions (α = 0.76 and 0.69). The DFAQ-CU also demonstrated strong convergent and predictive validity with established measures of cannabis use and problems (i.e., Cannabis Abuse Screening Test [CAST]), and acceptable discriminant validity with alcohol use measures (i.e., Alcohol Use Disorders Identification Test [AUDIT]). The DFAQ-CU served as a descriptive measure of cannabis use characteristics and was not used in inferential analyses; therefore, internal consistency was not calculated in the present sample.

The Enhanced Cannabis Timeline Follow-back (EC-TLFB; Petrilli et al., 2024)

The EC-TLFB is an interview and self-report questionnaire that was used to calculate frequency of cannabis use, method of administration, and types of cannabis product used, including potential co-administration of cannabis and tobacco. The EC-TLFB also collected detailed information regarding any alcohol or other drug use (if applicable). To enhance accuracy, visual aids, rating scales, and a calendar were used to assist in estimating the types and quantities of the products used. The EC-TLFB has demonstrated excellent concordance between self-reported cannabis use and urinalysis-confirmed cannabis use (Petrilli et al., 2024).

The Cahalan Quantity Frequency Variability Index (QFVI; Cahalan et al., 1969)

The Cahalan Quantity Frequency Variability Index (QFVI) was an interview used to confirm drinking behavior and verify group eligibility. Participants were pre-screened for alcohol use using a REDCap questionnaire prior to the lab visit to ensure preliminary eligibility, and the QFVI was administered during the lab session to confirm final group placement (e.g., infrequent users vs. frequent cannabis users). Participants reported both frequency of alcohol consumption (i.e., daily, weekly, monthly, or yearly) and the average number of drinks consumed per drinking occasion. Weekly alcohol use was estimated by converting reported drinking frequency to a weekly rate using a 31-day month and a 365-day year when applicable, to get the average number of drinks consumed per occasion. When participants reported ranges for drinking frequency or number of drinks consumed, the midpoint of the reported range was used in the calculation.

The Cognitive Behavioral Avoidance Scale (CBAS; Ottenbreit & Dobson, 2004)

The Cognitive Behavioral Avoidance Scale (CBAS) is a 31 item self-report questionnaire that assessed avoidance behaviors across four subdomains reflecting combinations of cognitive/behavioral and social/nonsocial dimensions. For the present study, we focused on the 8 items that assessed behavioral social avoidance. Items were rated on a 5-point Likert scale ranging (1= Not at all true of me to 5= Extremely true for me) with higher scores indicating greater behavioral social avoidance tendencies. The behavioral social avoidance subscale has demonstrated good internal consistency (α = 0.86), and the total scale showed excellent reliability (α = 0.91). In the present sample, the behavioral social avoidance subscale demonstrated excellent internal consistency (α = 0.91).

The Severity Measure for Social Anxiety Disorder (Social Phobia; Craske et al., 2013)

The Severity Measure for Social Anxiety Disorder is a self-report questionnaire that assessed the severity of social anxiety symptoms in individuals who are aged 18 and older. Each item asked individuals to rate the severity of their social anxiety disorder for the past 7 days. The Severity Measure for Social Anxiety Disorder items were rated on a 4-point scale (0= Never to 4= All of the time). Total scores ranged from 0-40, where a higher score was indicative of higher levels of social anxiety disorder (social phobia). The Severity Measure for Social Anxiety Disorder has exhibited good psychometric properties, including internal consistency, convergent validity, and divergent validity (LeBeau et al., 2016). It shows high internal consistency (α = 0.86) and strong convergent validity, correlating significantly with clinically related fear and avoidance scores and other established self-report measures of social anxiety (i.e., Liebowitz

Social Anxiety Scale-Self Report [LSAS-SR]). Discriminant validity was supported by a non-significant correlation with depressive symptoms, indicating that the scale specifically assesses social anxiety. The Severity Measure for Social Anxiety Disorder demonstrated excellent internal consistency in the present study (α = 0.92).

Social Approach-Avoidance Conflict (SAAC) Task

The Social Approach-Avoidance Conflict (SAAC) parametrically modulates social signal intensity using morphed facial expressions (Evans et al., 2024). Specifically, morphed facial expressions parametrically varied in social reward (Happiness), social threat (Anger), or social reward-threat conflict (co-occurring happiness and anger). To create morphed facial expressions, facial landmarks were mapped for neutral, happy, and angry faces, which allowed faces to be linearly interpolated in 50% increments to modulate conveyed emotional intensity. For example, social reward was parametrically modulated by linearly interpolating a neutral face ($0\%_{Happy}$) with a happy face ($100\%_{Happy}$) to create a $50\%_{Happy}$ facial expression of the same individual. As shown in Figure 1, a total of 9 levels of morphed facial expressions were used in the SAAC that vary in social reward ($0\%_{Happy}$, $50\%_{Happy}$, $100\%_{Happy}$), social threat ($0\%_{Angry}$, $50\%_{Angry}$, $100\%_{Angry}$), or social reward-threat conflict ($100\%_{Happy}$, $50\%_{Happy}$ + $50\%_{Angry}$, and $100\%_{Angry}$). Participants completed 64 trials for each facial expression, resulting in 576 trials across the nine face morph conditions.

In response to each facial expression, participants were instructed to indicate between *approaching* OR *avoiding* the individual as if they were in a social situation. Specifically, they were told that selecting *approach* indicated that they would prefer to initiate interaction with the individual, whereas selecting *avoid* indicated they would prefer to prevent interacting with the individual in a social situation. Participants were instructed to use the left and right arrow key to make their selection, and to respond within 2 seconds (2000ms) on every trial. Before beginning the task, participants were asked whether they understood the task instructions and were given the opportunity to ask questions and receive clarification as needed. On each trial, approach-avoidance selection and reaction time required to make a selection were recorded. Previous research has recently validated that $50\%_{\text{Happy}}$ + $50\%_{\text{Angry}}$ facial expressions robustly elicit SAAC as evidenced by more intermediate approach-avoidance selections and longer decision-making RTs compared to $100\%_{\text{Happy}}$ or $100\%_{\text{Angry}}$ faces that do not induce SAAC (Evans et al., 2026).

As mentioned above, for each trial in the SAAC task, participants were provided 2000ms to make a selection and instructed to make a selection in all trials (i.e., non-responses are considered invalid). To control for laterality effects, the sides of the screen that present approach and avoid were counterbalanced across participants. The SAAC task was presented in four 7-minute blocks with breaks provided between each block to manage participant fatigue. The SAAC task was approximately forty-seven minutes in total duration.

In the current study, we analyzed two behavioral measures derived from the SAAC task. Our two behavioral measures included the proportion of approach-avoidance selections for each face morph type (0 = Approach; 1 = Avoid) as well as RTs to make approach-avoidance selections. Together, these measures served as behavioral measures of social decision-making. Importantly, the SAAC task produced measures with strong psychometric properties for characterizing individual differences in SAAC (Evans et al., 2024; 2026). Across the three facial morph conditions, the internal consistency was excellent for approach-avoidance choices (ρs > 0.90) with reaction time also showing acceptable or approaching acceptable internal consistency (ρs > 0.66). For these measures, we excluded trials with RTs shorter than 200ms given that such rapid responses are not sufficient to represent complex decision making about facial identification and processing. This process resulted in very minimal behavioral data loss in the SAAC task (0.07% of all Happy-Angry task trials).

Psychophysiological EEG Data Collection and Data Processing

EEG data was used to assess FMθ activity in response to facial expressions during the SAAC, which is putatively a neural marker of approach-avoidance conflict. EEG data was sampled at 1000hz and collected using a 32-channel cap following the 10-20-system (Acticap, Brain Products GmbH), and the ActiCHamp amplifier system (Brain Products GmbH). FCz was placed as the reference electrode, with a ground electrode placed at AFz. We aimed to keep all electrode impedances below 10 kΩ to optimize EEG data quality. Four additional electrooculography electrodes were placed above/below the left eye to measure vertical eye movement, and on each side of the participant’s outer eye to measure horizontal eye movement. Participants were instructed to look straight at the monitor when placing the electrodes to ensure EOG electrodes were aligned with the pupil.

EEG data was processed using the BrainVision Analyzer software (Brain Products GmbH). Raw data was down sampled to 250Hz and referenced to the average mastoids (TP9/TP10), which are less electrically active due to distance from cortical tissue and are distal from the midfrontal region of interest, thereby minimizing the risk of subtracting relevant brain activity from the primary midfrontal area of interest. A 60 Hz notch filter was applied, followed by a high-pass filter at 0.10 Hz. As done previously by Gratton et al. (1983), ocular artifacts were corrected using a regression-based method. Artifacts were removed using a modified version of the FASTER algorithm, and then trained research assistants conducted a visual inspection to manually validate automated algorithm-flagged segments. Following artifact rejection, 92.68% of FCz epochs were retained across all social reward-threat conditions ($100\%_{Happy}$, $50\%_{Happy}/50\%_{Angry}$, $100\%_{Angry}$). Moreover, FCz retention rates were similar between cannabis groups, which ranged from 92.09% - 92.58% for infrequent cannabis users and 92.65% - 92.74% for frequent cannabis users across the social reward-threat conditions.

Computing Midfrontal Theta (FMθ)

Time frequency analyses were conducted to extract midfrontal theta (FMθ) power in the 4-8 Hz range, consistent with prior research on approach-avoidance conflict (Lange et al., 2022). FMθ activity was extracted from electrode FCz, which has been commonly utilized in previous research studying conflict-related midfrontal activity. Theta power was decibel (dB) transformed relative to a pre-stimulus baseline from -800 ms to -300 ms averaged across all task trials. A similar dB transformation was applied to other frequency bands (e.g., alpha and beta) using an identical procedure. This pre-stimulus window was selected to avoid edge artifacts when removing pre-stimulus activity from post-stimulus activity.

Following procedures used by Lange et al. (2022), we used 30 complex Morlet wavelets spaced logarithmically between 1 and 30 Hz, using 3 wavelet cycles to provide a balance between temporal precision and frequency precision, which was utilized in our analyses. The SAAC task was optimized for this purpose by including a longer minimum inter-trial interval (ITI) duration of 1800 ms to facilitate utilization of longer pre-stimulus windows for dB normalization.

For quantifying FMθ activity, we selected an early (146 – 434 ms) and late (436 – 724 ms) post-stimulus window based on findings from Lange et al. (2022). Specifically, this study identified a significant cluster of theta activity during AAC at approximately 300-800 ms post-stimulus, with peak AAC-related FMθ activity observed in the 400-700 ms range.

To identify FMθ activity during the SAAC task, we used a personalized window selection process. First, average time frequency plots across all task trials were computed in BrainVision Analyzer software (Brain Products GmbH) for both an early and late post-stimulus window defined above by Lange et al. (2022). Within each of these time windows, the peak theta response was separately identified for each participant by locating the average wavelet peak demonstrating the highest decibel (dB) power within the theta band range. Once the peak was identified for a given participant, a 100-ms window was constructed around this peak, which ranged from 50ms before to 50ms after the personalized peak value. Theta power was then extracted for these personalized 100-ms windows for each participant and morph condition. Specifically, FMθ was extracted from wavelet layers 11-18 (i.e., 3.23 Hz – 7.34 Hz), which corresponded to midfrontal theta activity for each participant, time window, and morph condition.

Data Analytic Strategy

In the current study, we quantified between-group differences in SAAC effects using the same analytic strategy for both behavioral and neural measures derived from the SAAC task. To quantify between-group differences in SAAC effects, we used mixed-design Repeated Measures ANOVAs (RM-ANOVAs) that test a 2 (Group: Frequent vs. Infrequent cannabis users) × 3 (Morph: $100\%_{Happy}$ vs. $50\%_{Happy}$ + $50\%_{Angry}$ vs. $100\%_{Angry}$) design. Specifically, we examined whether the effect of Morph on SAAC task responses differed by Group, with a focus on the $50\%_{Happy}$ + $50\%_{Angry}$ faces that elicit social approach-avoidance conflict. In this way, task measures in response to co-occurring social reward and social threat were directly compared across groups relative to responses to unambiguous social reward ($100\%_{Happy}$) and unambiguous social threat ($100\%_{Angry}$). Bonferroni-adjusted pairwise comparisons of the estimated marginal means were conducted to examine between-group differences for each facial morph condition, separately. To further characterize any group differences across morph conditions, parameter estimates were examined to assess between-group differences at each morph level.

To control for ambiguity more generally, exploratory analyses were conducted using the social reward (Neutral–Happy) and social threat (Neutral–Angry) morph sets. For each morph set, similar mixed-design RM-ANOVAs were conducted using a 2 (Group: Frequent vs. Infrequent cannabis users) × 3 (Morph) design. The social reward analysis included the $100\%_{Neutral}$ vs. $50\%_{Neutral}$ + $50\%_{Happy}$ vs. $100\%_{Happy}$ face morph conditions, whereas the social threat analysis included the $100\%_{Neutral}$ vs. $50\%_{Neutral}$ + $50\%_{Angry}$ vs. $100\%_{Angry}$ face morph conditions. Lastly, to control for social anxiety symptoms, an additional sensitivity analysis was conducted to determine whether the observed findings remained when accounting for individual differences in social anxiety. Specifically, mixed-design RM-ANOVAs were conducted using a 2 (Group: Frequent vs. Infrequent cannabis users) × 3 (Morph: $100\%_{Happy}$ vs. $50\%_{Happy}$ + $50\%_{Angry}$ vs. $100\%_{Angry}$) design, with social anxiety severity entered as a covariate.

Primary Task Outcomes

At the behavioral level, we used a mixed-design RM-ANOVA to examine whether SAAC-related behavior differed between frequent and infrequent cannabis users. We examined between-group differences in both proportions of approach-avoidance choice selections as well as the duration required to make approach-avoidance selections (RT). Specifically, we tested if frequent and infrequent cannabis users differed in the extent of SAAC-related behavioral effects, which is characterized by more intermediate approach-avoidance choice selections and longer RTs in response to $50\%_{Happy}$ + $50\%_{Angry}$ faces compared to $100\%_{Happy}$ and $100\%_{Angry}$ faces. At the neural level, we used the identical analytic strategy to examine between-group differences in SAAC effects in FMθ activity. Specifically, we assessed if frequent and infrequent cannabis users differed in SAAC-related FMθ activity, which is putatively characterized by greater FMθ activity in response to $50\%_{Happy}$ + $50\%_{Angry}$ faces compared to $100\%_{Happy}$ and $100\%_{Angry}$ faces.

Procedure

All study procedures were approved by the local institutional review board before the beginning of data collection. At the beginning of the single experimental session, participants provided written informed consent. Participants then completed the remainder of the study in the experimentation room, which contained a chair, a computer, and EEG material.

Once participants arrived at the lab, they were asked to provide a urine sample to verify their cannabis group assignment. For the infrequent cannabis user group, the urine sample was required to be negative for cannabis, whereas the urine sample was required to be positive for cannabis in the frequent cannabis user group. Individuals who tested positive for drugs other than cannabis or stimulants (used for Attention-Deficit/Hyperactivity Disorder) were excluded from the study. We then completed a breathalyzer exam to confirm current blood alcohol level and a NarcoCheck saliva test to assess acute intoxication. After the breathalyzer and NarcoCheck exam confirmed the participant was not acutely intoxicated, the participant continued with the remaining study procedures.

Following this process, research staff measured the participants' heads and prepared the necessary EEG material. While research staff prepared the EEG cap, a trained graduate student or research assistant administered both the Cahalan interview to confirm drinking patterns as well as the EC-TLFB to confirm cannabis use patterns. Afterwards, the participant filled out self-report measures using the lab computer (e.g., DFAQ-CU, MPS, DSM Severity Measure for Social Anxiety-Adult). Once self-report questionnaires were completed, the participant completed the 47-minute SAAC task. Finally, participants were debriefed and compensated with either course credit or monetary compensation.

Data analysis plan

All analyses were conducted in SPSS Statistics. Each of the variables were screened for normality by examining skewness and kurtosis, as well as inspections of histograms and Q-Q plots when necessary. To test our hypotheses, we conducted a 2 (Group: Infrequent Users vs. Frequent Cannabis Users) × 3 (Face Morph: $100\%_{Happy}$, $100\%_{Angry}$, $50\%_{Happy}/50\%_{Angry}$) mixed-design repeated measures ANOVA for each dependent variable. As a sensitivity analysis, repeated measures ANCOVAs were conducted with social anxiety severity entered as a covariate to evaluate whether group differences were accounted for by social anxiety symptoms.

Hypothesis 1a. As tested by a significant 2 (Group: Infrequent Users vs. Frequent Cannabis Use) × 3 (Face Morph: $50\%_{Happy}$ + $50\%_{Angry}$ vs. $100\%_{Happy}$ vs. $100\%_{Angry}$) interaction, we hypothesized that frequent cannabis users would exhibit more avoidance selections and fewer approach selections during SAAC ($50\%_{Happy}$ + $50\%_{Angry}$ faces), compared to infrequent cannabis users. No group differences were expected in response to $100\%_{Happy}$ or $100\%_{Angry}$ faces that do not induce SAAC.

Hypothesis 1b. As evidenced by a significant 2 (Group: Infrequent Users vs. Frequent Cannabis Use) × 3 (Face Morph: $50\%_{Happy}$ + $50\%_{Angry}$ vs. $100\%_{Happy}$ vs. $100\%_{Angry}$) interaction, we hypothesized that frequent cannabis users would exhibit greater SAAC-related increases in RT in response to conflict faces ($50\%_{Happy}$ + $50\%_{Angry}$) compared to infrequent cannabis users, suggesting impaired conflict resolution. No group differences were expected in response to $100\%_{Happy}$ or $100\%_{Angry}$ faces that do not induce SAAC.

Hypothesis 2. As evidenced by a significant 2 (Group: Infrequent Users vs. Frequent Cannabis Use) x 3 (Face Morph: 50%$_{Happy}$ + 50%$_{Angry}$ vs. 100%$_{Happy}$ vs. 100%$_{Angry}$) interaction, we hypothesized that frequent cannabis users would exhibit blunted increases in SAAC-related FMθ activity in response to conflict faces (50%$_{Happy}$ + 50%$_{Angry}$) compared to infrequent cannabis users. No group differences were expected in response to 100%$_{Happy}$ or 100%$_{Angry}$ faces that do not induce SAAC.

Sample size. The final sample consisted of 31 participants (n = 16 frequent cannabis users and n = 15 infrequent cannabis users). This sample size reflected the number of eligible participants who could be feasibly recruited to successfully complete the EEG protocol within the constraints of the project's timeline and available resources.

Results

Visual inspection of boxplots and Q-Q plots indicated minimal deviations of distribution for behavioral rating variables, particularly 100%$_{Happy}$ and 100%$_{Angry}$ morph conditions, whereas reaction time demonstrated acceptable distribution characteristics. To further evaluate robustness, a nonparametric Friedman test was conducted for behavioral ratings and produced convergent findings with the repeated-measures ANOVAs ($p < 0.001$), indicating that morph effects remained significant independent of normality assumptions and supporting the confidence of behavioral findings. Additionally, Mauchly's test of sphericity indicated that the assumption of sphericity was met for behavioral ratings and reaction times (all $ps > 0.05$).

For midfrontal theta (FMθ) activity, visual inspections of boxplots and Q-Q plots demonstrated acceptable distribution characteristics. Mauchly's test of sphericity indicated that the assumption of sphericity was met for the Early Window analyses ($p = 0.88$) but was violated for the Late Window analyses ($p < 0.004$). To ensure a consistent test of within-subject effects, Greenhouse-Geisser corrections were applied to all repeated-measures analyses (Greenhouse & Geisser, 1959).

For the RM-ANCOVA sensitivity analyses, homogeneity of variance was satisfied for all behavioral and neural sensitivity analyses (all *ps* > 0.05). The assumption of homogeneity of regression slopes was satisfied for both reaction time and all FMθ sensitivity analyses (all *ps* > 0.05) but was violated for the behavioral rating sensitivity analysis ($p = 0.002$). However, given that cannabis-related differences were not significant in either the primary behavioral rating analysis or when controlling for social anxiety in the sensitivity analysis, this assumption violation did not alter the overall pattern of findings.

Validation of Sampling Approach

As expected, frequent cannabis users reported significantly greater scores on the Marijuana Problem Scale compared to infrequent cannabis users ($t(14.82) = -4.08$, $p < 0.001$, $d = 1.51$, 95% CI [-6.92, -2.17]). Additionally, frequent cannabis users also reported significantly greater engagement in social avoidance behavior compared to infrequent cannabis users ($t(29) = -2.53$, $p = 0.02$, $d = 0.98$, 95% CI [-10.44, -1.10]). Collectively, these results validate our sampling approach by demonstrating that frequent cannabis users exhibited both cannabis-related impairment and impaired social functioning compared to infrequent users.

Validation of SAAC Task Effects

As expected, we observed robust conflict-related behavioral effects on the SAAC task. For approach-avoidance decisions to social reward-threat conflict, we observed a significant main effect of face morph on both approach-avoidance decisions ($F_{(1.75,\ 50.86)} = 91.61$, $p < 0.001$) as well as RT ($F_{(1.84,\ 53.52)} = 23.91$, $p < 0.001$). Demonstrating that when the SAAC reliably elicited approach-avoidance conflict, participants exhibited more equivalent approach-avoidance choices as well as longer RTs to $50\%_{\text{Happy}}$ + $50\%_{\text{Angry}}$ faces compared to both $100\%_{\text{Happy}}$ and $100\%_{\text{Angry}}$ faces (all *p*s < 0.001; see Figure 2 and Figure 3). These results demonstrate that the SAAC robustly elicited the expected approach-avoidance conflict effects. However, contrary to expectations, there was no significant main effect of Face Morph in either FMθ time window (Early Window: $F_{(1.98,\ 57.45)} = 0.43$, $p = 0.65$; Late Window: $F_{(1.51,\ 43.71)} = 0.23$, $p = 0.74$), suggesting no overall differences in FMθ activity across morph conditions as a function of social reward-threat conflict.

Behavioral Analyses

Hypothesis 1a

For the social reward-threat conflict model, we unexpectedly did not observe a significant Morph × Cannabis Group interaction ($F_{(1.75,\ 50.86)} = 1.33$, $p = 0.27$). Contrary to our hypothesis, this non-significant interaction indicates that frequent and infrequent cannabis users did not significantly differ in modulation of approach-avoidance decisions as a function of social reward-threat conflict. Additionally, there was not a significant main effect of Cannabis Group ($F_{(1,\ 29)} = 0.74$, $p = 0.40$) indicating that frequent and infrequent cannabis users did not differ overall in approach-avoidance decisions across morph conditions. Moreover, confirmatory post-hoc analyses demonstrated that frequent cannabis users also did not exhibit differences in approach-avoidance decisions compared to infrequent cannabis users for any social reward-threat conflict morph ($100\%_{Happy}$, $50\%_{Happy} + 50\%_{Angry}$, $100\%_{Angry}$; all *p*s > 0.15; see Figure 2). For the social reward and social threat models, exploratory analyses also demonstrated non-significant Morph × Cannabis Group interactions (both *p*s > 0.20).

Hypothesis 1b

For the social reward-threat conflict model, we unexpectedly did not observe a significant Morph × Cannabis Group interaction ($F_{(1.84, 53.39)} = 0.43$, $p = 0.64$). Contrary to our hypothesis, this non-significant interaction indicates that frequent and infrequent cannabis users did not differ in modulation of RT as a function of social reward-threat conflict. Additionally, there was no significant main effect of Cannabis Group ($F_{(1, 29)} = 0.00$, $p = 0.99$), indicating that frequent and infrequent cannabis users did not differ overall in reaction time across morph conditions. Moreover, confirmatory post-hoc analyses demonstrated that frequent cannabis users also did not exhibit differences in reaction time compared to infrequent cannabis users for any social reward-threat conflict morph ($100\%_{Happy}$, $50\%_{Happy} + 50\%_{Angry}$, $100\%_{Angry}$; all *p*s > 0.70; see Figure 3). For the social reward and social threat models, exploratory analyses also demonstrated non-significant Morph × Cannabis Group interactions (both *p*s > 0.24).

Neural Analyses

Hypothesis 2

Early Window. For the social reward-threat conflict model, we unexpectedly did not observe a significant Morph × Cannabis Group interaction ($F_{(2, 57.45)} = 1.56$, $p =$

0.22). Contrary to our hypothesis, this non-significant interaction indicates that frequent and infrequent cannabis users did not differ in modulation of FMθ activity as a function of social reward-threat conflict. Additionally, there was no significant main effect of Cannabis Group ($F_{(1, 29)} = 0.59$, $p = 0.45$), indicating that frequent and infrequent cannabis users did not differ overall in FMθ activity across morph conditions. Moreover, confirmatory post-hoc analyses demonstrated that frequent cannabis users also did not exhibit differences in FMθ activity compared to infrequent cannabis users for any social reward-threat conflict morphs ($100\%_{Happy}$, $50\%_{Happy}$ + $50\%_{Angry}$, $100\%_{Angry}$; all ps > 0.20; see Figure 4). For the social reward and social threat models, exploratory analyses also demonstrated non-significant Morph × Cannabis Group interactions in the early window (both *ps* > 0.29).

Late Window. For the social reward-threat conflict model, we also unexpectedly did not observe a significant Morph × Cannabis Group interaction ($F_{(1.51, 43.71)} = 1.47$, $p = 0.24$). Contrary to our hypothesis, this non-significant interaction indicates that frequent and infrequent cannabis users did not differ in modulation of FMθ activity as a function of social reward-threat conflict. Additionally, there was no significant main effect of Cannabis Group ($F_{(1, 29)} = 1.94$, $p = 0.17$), indicating that frequent and infrequent cannabis users did not differ overall in FMθ activity across morph conditions. Moreover, confirmatory post-hoc analyses demonstrated that frequent cannabis users also did not exhibit differences in FMθ activity compared to infrequent cannabis users for any social reward-threat conflict morphs ($100\%_{Happy}$, $50\%_{Happy}$ + $50\%_{Angry}$, $100\%_{Angry}$; all *ps* > 0.07; see Figure 5). For the social reward model, exploratory analyses demonstrated a non-significant Morph × Cannabis Group interaction ($p = 0.85$). Although the ambiguous social threat model yielded a significant interaction (p = 0.04), post-hoc analyses indicated no significant group differences at any morph level (all *ps* > 0.13).

Sensitivity Analyses: Social Anxiety Severity

To examine whether social anxiety severity influenced behavioral and neural cannabis-related differences, separate ANCOVAs were conducted with social anxiety severity entered as a continuous covariate. For social reward-threat conflict ratings and reaction time, the Morph × Participant Group interaction remained non-significant after controlling for social anxiety severity (Rating: $F_{(1.71, 47.86)} = 0.17$, $p = 0.81$; RT: $F_{(1.75, 49.06)} = 0.65$, $p = 0.51$), indicating that frequent and infrequent cannabis users did not differ in behavioral responses across morph conditions after accounting for social anxiety severity. Similarly, for FMθ activity, the Morph × Participant Group interaction remained non-significant in both early and late windows after controlling for social anxiety severity (Early: $F_{(1.99, 55.72)} = 1.17$, $p = 0.32$; Late: $F_{(1.51, 42.21)} = 1.30$, $p = 0.28$), indicating that frequent and infrequent cannabis users did not differ in neural responses across morph conditions after accounting for social anxiety severity.

Discussion

The current study sought to characterize how frequent cannabis use may disrupt behavioral and neural responses to social approach-avoidance conflict. Using the SAAC paradigm, we compared social conflict-related approach-avoidance responses, reaction time, and midfrontal theta (FMθ) activity between frequent and infrequent cannabis users. Contrary to our hypotheses, however, frequent and infrequent cannabis users did not differ in conflict-related effects across any behavioral or neural measures. Similarly, across the larger sample, we unexpectedly did not observe conflict-related modulation of early or late FMθ signals. While these findings do not support our original hypotheses, these results may ultimately provide some degree of insight into the specific conditions in which frequent cannabis use may disrupt processes related to social approach-avoidance conflict. Prior to discussing these implications, it is important to first highlight factors that seem unlikely to have contributed to the lack of cannabis-related differences in this study.

First, frequent cannabis users in the current study exhibited significant degrees of impairment, which suggests that our sampling approach was successful in recruiting groups that reliably differed in relevant clinical constructs. First, frequent cannabis users exhibited significantly greater cannabis-specific impairment on the Marijuana Problem Scale compared to infrequent cannabis users. This finding demonstrates that frequent cannabis users were not simply using cannabis recreationally but were instead using cannabis to a degree that produced impairments in daily life. Second, and consistent with prior literature linking cannabis use to social avoidance (Buckner et al., 2007; Buckner & Schmidt, 2008), frequent cannabis users also reported engaging in significantly greater degrees of social avoidance behavior. Given that social avoidance behavior is a construct associated with impaired social motivation to social reward-threat conflict (Evans et al., 2023), frequent cannabis users would be expected to similarly exhibit dysregulated social approach-avoidance conflict processing in the current study. Together, these two findings demonstrate that frequent cannabis users in the current study exhibited the expected pattern of cannabis-related impairment as well as social dysfunction. Given this impairment demonstrated by the frequent cannabis user group, it seems unlikely that the lack of group differences in the current study can be attributed to using an ineffective sampling approach or sub-optimal recruitment criteria.

Second, the SAAC paradigm robustly elicited social approach-avoidance conflict effects on behavioral measures in the current study, which rules out the possibility that the lack of cannabis-related differences can be attributed to the paradigm failing to elicit social approach-avoidance conflict. Replicating previous findings in unselected samples, $50\%_{\text{Happy}}$ + $50\%_{\text{Angry}}$ facial expressions were characterized by equivalent approach-avoidance responses and longer RTs during decision-making compared to unambiguous social reward ($100\%_{\text{Happy}}$) and unambiguous social threat ($100\%_{\text{Angry}}$). These patterns are hallmark features of approach-avoidance conflict and demonstrate that the SAAC paradigm robustly elicited social approach-avoidance conflict in the current study. As a result, the lack of differences in SAAC measures between frequent and infrequent cannabis users cannot be attributed to a failure to reliably elicit social approach-avoidance conflict more generally in the current study.

Instead, it is possible that the lack of cannabis use-related differences in social approach-avoidance conflict processing may be attributable to the type of conflict elicited by the SAAC paradigm, which is consistent with the unexpected lack of FMθ activity in the current study. Previous studies examining FMθ have largely used paradigms such as the Stroop, Flanker, or Simon tasks that evoke stimulus-response conflict using explicit response contingencies that define behavioral responses as correct or incorrect (Cavanagh & Shackman, 2015; Nigbur et al., 2011). In these paradigms, participants must arbitrate between competing response tendencies in order to produce an accurate behavioral response with FMθ putatively serving to recruit cognitive control mechanisms that are necessary to resolve any stimulus-response conflict. In contrast, the SAAC paradigm used in the current study elicits social approach-avoidance conflict by using ambiguous social stimuli that do not specify objectively correct or incorrect behavioral responses. Therefore, rather than eliciting stimulus-response conflict, the SAAC paradigm elicits motivational conflict due to competing approach and avoidance tendencies. Consistent with this interpretation, neither early nor later windows of FMθ activity exhibited significant conflict-related differences across the larger sample in the current study. Similarly, Lange et al. (2022) demonstrated that FMθ responses during different types of conflict appeared task-specific and did not strongly correlate between different types of conflict paradigms. Thus, one possibility for the lack of cannabis-related differences in social approach-avoidance conflict may be that frequent cannabis use primarily impairs other types of conflict processing such as stimulus-response conflict.

Relatedly, the lack of behavioral and neural group differences may reflect the absence of socially evaluative or consequential aspects of social conflict within the SAAC paradigm. Although the SAAC paradigm was designed to elicit social approach-avoidance conflict through emotionally ambiguous face morphs, participants' behavioral responses were not paired with any type of tangible outcome. In contrast, paradigms such as the approach-avoidance conflict task used by Lange et al., (2022) required participants to accept or reject stimuli associated with monetary reward or aversive punishment, with incorrect or disadvantageous decisions producing immediate, tangible consequences. Specifically, participants received highly salient positive reinforcement (e.g., monetary gain with rewarding auditory feedback) or aversive outcomes (e.g., monetary loss paired with white noise sound, 90 dB). Although these decisions also involved subjective evaluations of risk and reward, participants immediately received response-contingent positive and aversive consequences, which likely increased the salience of motivational conflict. In contrast, responses in the SAAC task occurred in the absence of any immediate interpersonal consequences, such as rejection, criticism, or exclusion. Instead, during the SAAC paradigm, participants simply choose whether they would anticipate approaching or avoiding other individuals with ambiguous faces in a social situation, but these choices do not produce any type of immediate, tangible outcomes. This distinction may be particularly important when examining social avoidance in frequent cannabis users, which has been linked to concerns regarding negative evaluation, rejection, and interpersonal discomfort (Buckner et al., 2011; Buckner & Zvolensky, 2014). If avoidance tendencies among frequent cannabis users emerge more strongly in contexts involving anticipated social evaluation or interpersonal threat, then paradigms lacking meaningful interpersonal outcomes such as the SAAC task may insufficiently engage the neural systems underlying such tendencies. Future studies may benefit from incorporating paradigms involving socially meaningful consequences, such as direct interpersonal feedback or experimentally induced exclusion paradigms such as Cyberball (Williams and Jarvis, 2006), which may evoke stronger affective and conflict-related neural responses.

Beyond the potential role of socially consequential outcomes, it may also be important to consider whether different forms of motivational conflict recruit FMθ similarly. Although FMθ has been observed during motivational decision-making, growing evidence suggests that its expression may nevertheless vary across conflict and motivational domains (Senftleben & Scherbaum, 2021). For example, Levy et al. (2023) demonstrated that FMθ differentiates among distinct forms of motivational conflict and proposed that FMθ may vary depending on the specific type of motivational conflict that is experienced by an individual. Specifically, FMθ was greater during avoidance-avoidance decision conflicts compared to approach-approach conflicts, suggesting that motivational conflict does not engage FMθ uniformly across conflict decisions. Similarly, Senftleben & Scherbaum (2021) reported that FMθ was sensitive to some, but not all, forms of subjective value-based conflict involving subjective decisions without objectively correct responses. In this study, value-based conflict involved subjective choices between smaller, more immediate rewards and larger, more delayed reward including conflict arising from choice ambiguity, choice repetition, and temporal delay. Specifically, ambiguous forms of subjective conflict, in which competing options had similar subjective value, failed to elicit reliable modulation of FMθ despite clear behavioral effects. Senftleben & Scherbaum (2021) proposed that this null effect may reflect a distinction between conflict involving competing activations and inhibitory processes in comparison to conflict reflecting ongoing deliberation between similarly valued options. Therefore, although participants behaviorally exhibited motivational conflict during these ambiguous decisions, FMθ did not reliably track all forms of subjective or value-based conflict. This distinction may be particularly relevant to the present findings, as the SAAC task elicited robust behavioral conflict effects despite the absence of conflict-related FMθ modulation. Taken together, it is plausible that the SAAC task elicited a form of motivational conflict that was qualitatively different from the conflict processes typically associated with both frequent cannabis usage more specifically as well as the recruitment of FMθ more generally.

In addition to these possibilities, the lack of cannabis-related differences in the current study could be attributable to heterogeneity of symptomology and/or impairment associated with frequent cannabis use. Although frequent cannabis users demonstrated greater behavioral social avoidance and cannabis-related impairments in the current study, cannabis-related neurocognitive dysfunction is known to be heterogenous across individuals. Consequently, both the degree and expression of cannabis-related neurocognitive dysfunction may have varied across individuals within the frequent cannabis use group. Prior research suggests that cannabis-related cognitive changes and neuroanatomical alterations are heterogenous and may vary according to differences in cannabis usage patterns such as earlier age of onset, quantity of use, and duration of use (Crean et al., 2011; Lorenzetti et al., 2016). Thus, cannabis use frequency alone may not fully capture clinically meaningful differences in cannabis experiences, as even across frequent users may vary considerably in age of onset, potency, chronicity, and severity of cannabis-related impairments (Volkow et al., 2014). Thus, although participants were grouped based on homogenous frequency of cannabis usage, these similar levels of cannabis use frequency may nevertheless substantively differ in the degree and manifestation of cannabis-related neurocognitive dysfunction. As such, although the frequent and infrequent cannabis user groups significantly differ on theoretically relevant behavioral and clinical characteristics in the current study, this type of cannabis-related heterogeneity in conjunction with a relatively small sample size may have precluded the detection of cannabis-related differences in social conflict processing.

Although the results of the current study did not support our hypotheses, these null findings nevertheless highlight several important directions for future research. First, it is possible that cannabis use-related differences only emerge in the context of immediate, rather than anticipated, social consequences. Thus, it may be necessary to incorporate tangible social consequences into social conflict paradigms to both enhance ecological validity and increase sensitivity to detecting cannabis-related differences. For example, future research may modify the SAAC paradigm to also present socially meaningful consequences such as social feedback, explicit acceptance or rejection outcomes, or experimentally manipulated interpersonal evaluation following participant choices. Alternatively, social exclusion paradigms such as Cyberball (Williams and Jarvis, 2006), may be used to experimentally induce perceptions of social exclusion that amplify cannabis use-related differences in social approach-avoidance conflict processing due to more robustly engaging affective and social-cognitive neural systems associated with rejection sensitivity. Second, future studies may also benefit from recruiting clinically informed comparison groups to better dissociate the impact of cannabis use and social anxiety on social conflict processing. For example, future research could directly compare frequent cannabis users with and without social anxiety as well as infrequent cannabis users with and without social anxiety. Using this type of factorial sampling design may help clarify whether altered social avoidance and conflict-related neural processing are more strongly linked to cannabis use, social anxiety, or the co-occurrence of these two factors.

Lastly, several limitations should be considered when interpreting the findings of the current study. First, the sample size was modest which may have limited statistical power to detect both group differences as well as conflict-related differences in FMθ. Although the SAAC paradigm performed as expected and group comparisons demonstrated clinical differences in social dysfunction and cannabis-related impairment, a larger sample may nevertheless be needed to detect reliable, but more subtle effects. Additionally, and as noted previously, cannabis users were recruited exclusively based on cannabis use frequency, rather than other cannabis usage factors. Because cannabis-related neurocognitive impairments are known to vary as a function of severity, age of onset, and impairment (Crean et al., 2011; Lorenzetti et al., 2016), grouping participants exclusively based on cannabis use frequency may have limited the sensitivity to detect cannabis-related differences. Finally, we only measured social approach-avoidance conflict in the current study, which does not measure other types of cognitive conflict such as stimulus-response conflicts. Therefore, it remains possible that using a stimulus-response conflict paradigm would produce a distinct pattern of cannabis-related differences.

In conclusion, the present findings did not support our hypotheses regarding cannabis use-related differences in behavioral or neural measures of social approach-avoidance conflict. Nevertheless, these findings contribute to a more nuanced clinical understanding of social dysfunction among frequent cannabis users by suggesting that cannabis-related social difficulties may not reflect generalized impairments in social conflict processing alone. In fact, social dysfunction associated with cannabis use may emerge through more complex interactions among cannabis use, motivational processes, functional consequences, and interpersonal context. These findings highlight the importance of considering social functioning as context-dependent, rather than a uniform deficit, associated with frequent cannabis use. Although contrary to our hypotheses, the present findings may help clarify models of cannabis-related social dysfunction and provide groundwork for examining neural mechanisms that contribute to social functioning among cannabis users.

Tables and Figures

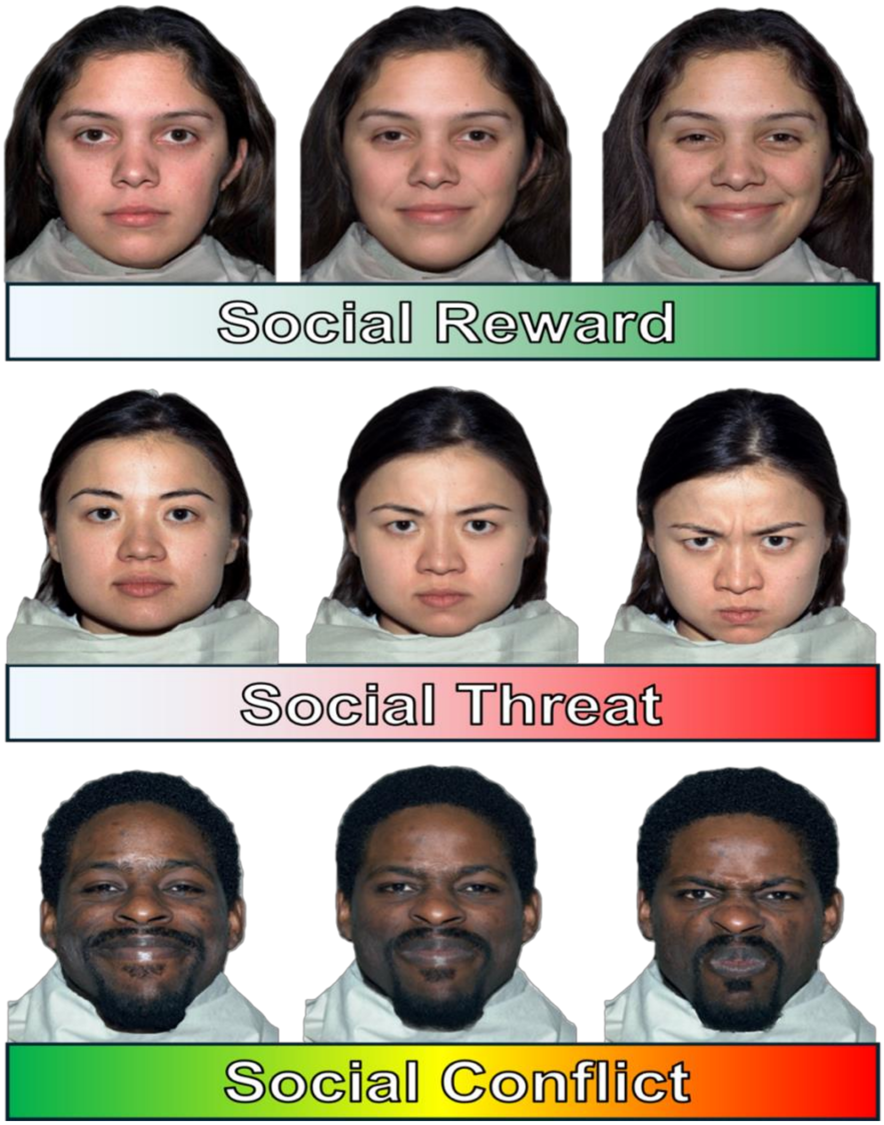
Table 1

Sample Characteristics and Demographics

Sample Characteristics	Infrequent Users (*n* = 16)	Frequent Users (*n* = 15)
	***M* (SD)**	***M* (SD)**
Age	*29.38* (11.00)	*31.00* (11.61)
Demographics	***n* (%)**	***n* (%)**
Sex		
Female	6 (37.50%)	6 (40.00%)
Male	10 (62.50%)	9 (60.00%)
Race/Ethnicity		
White	11 (73.30%)	13 (81.30%)
Black	2 (13.30%)	1 (6.30%)
Hispanic	2 (13.30%)	1 (6.30%)
Other/Multi-Racial	0 (0.00%)	1 (6.30%)
Education		
High School	4 (25.00%)	1 (6.70%)
Some College	1 (6.30%)	12 (80.00%)
Bachelor's Degree	2 (13.30%)	2 (13.30%)
Post-Graduate Degree	4 (25.00%)	0 (0.00%)
Marital status		
Married	5 (31.30%)	3 (20.00%)
Divorced	1 (6.30%)	4 (26.7%)
Separated	0 (0.00%)	1 (6.7%)
Single/Never Married	10 (62.5%)	7 (62.5%)
Household Income		
$0-19,999	0 (0.00%)	0 (0.00%)
$20,000-29,999	2 (12.50%)	2 (13.30%)
$30,000-39,999	1 (6.30%)	2 (13.30%)
$40,000-49,999	0 (0.00%)	1 (6.70%)
$50,000-59,999	0 (0.00%)	1 (6.70%)
$60,000-69,999	4 (25.00%)	0 (0.00%)
$70,000-79,999	0 (0.00%)	1 (6.70%)
$80,000-89,999	2 (12.50%)	1 (6.70%)
$90,000-99,999	1 (6.30%)	1 (6.70%)
$100,000+	6 (37.50%)	6 (40.00%)

Figure 1

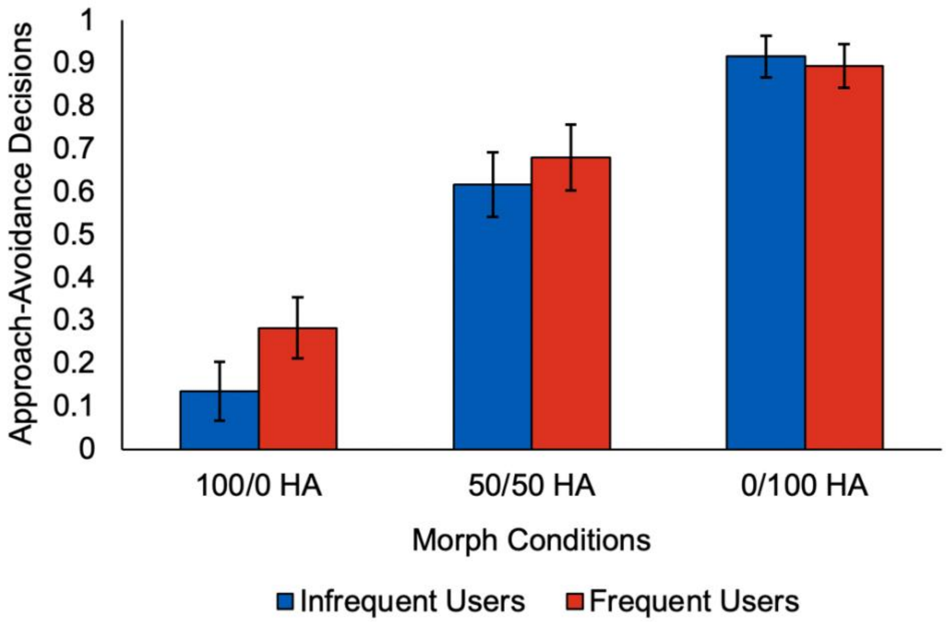
Social Approach-Avoidance Conflict task design.



Note. From left to right, facial expressions vary in:
Social Reward: ($0\%_{Happy}$, $50\%_{Happy}$, $100\%_{Happy}$).
Social Threat: ($0\%_{Angry}$, $50\%_{Angry}$, $100\%_{Angry}$).
Social Conflict: ($100\%_{Happy}$, $50\%_{Happy}$ + $50\%_{Angry}$, $100\%_{Angry}$).
Adapted from Evans et al. (2026).

Figure 2

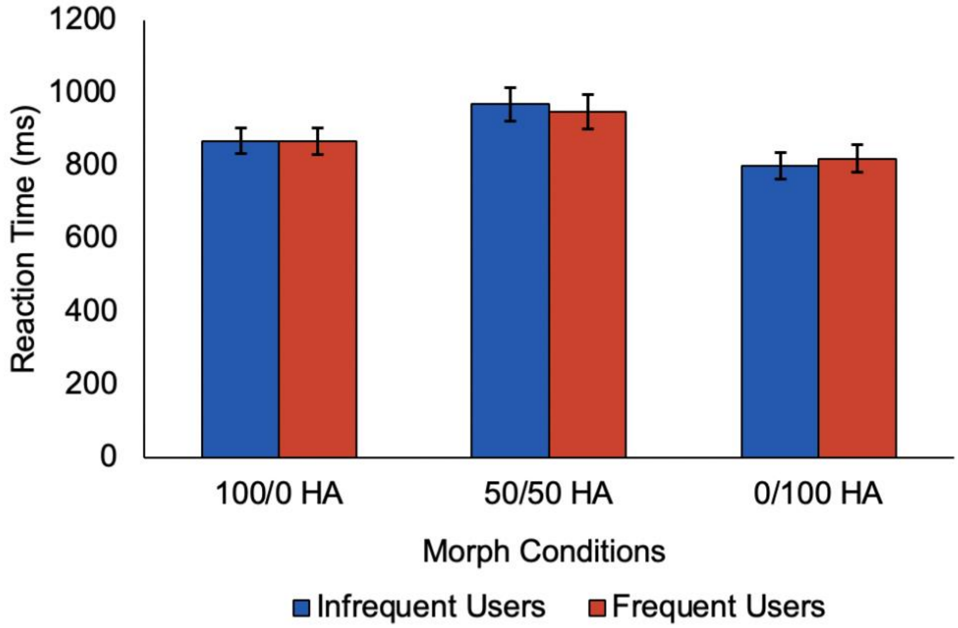
Morph Condition by Cannabis Group: Approach-Avoidance Decisions



Note. Participants exhibited greater avoidance decisions as social threat increased and social reward decreased. However, there was no significant Morph × Cannabis Group interaction effect, indicating that frequent cannabis users and infrequent cannabis users did not differ in approach-avoidance decisions across morph conditions.
From left to right, morph conditions vary in:
Social Conflict: ($100\%_{Happy}/0\%_{Angry}$, $50\%_{Happy} + 50\%_{Angry}$, $0\%_{Happy}/100\%_{Angry}$).

Figure 3

Morph Condition by Cannabis Group: Reaction Time

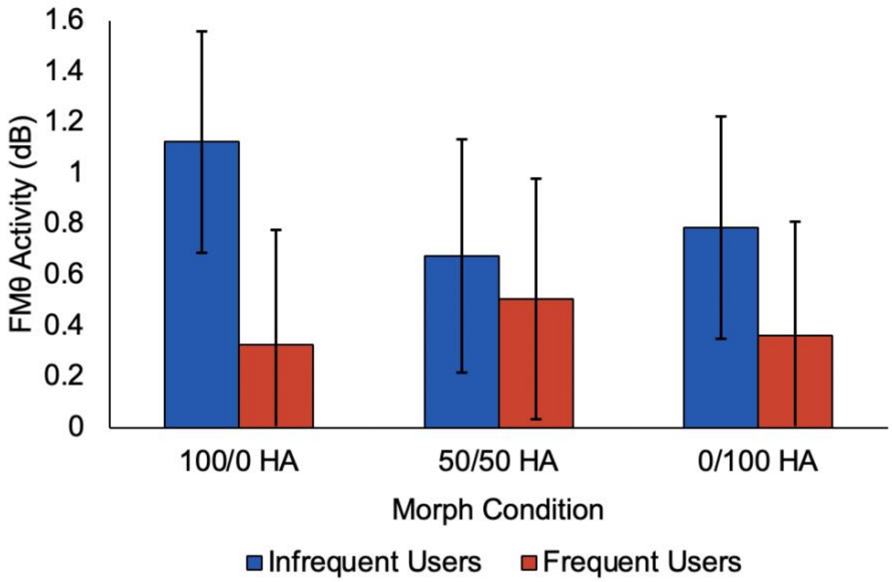


Note. Participants exhibited longer reaction times when responding social reward-threat conflict morphs (50%$_{Happy}$/50%$_{Angry}$). However, there was no significant Morph × Cannabis Group interaction effect, indicating that frequent cannabis users and infrequent cannabis users did not differ in reaction times across morph conditions. From left to right, morph conditions vary in:

Social Conflict: (100%$_{Happy}$/0%$_{Angry}$, 50%$_{Happy}$/50%$_{Angry}$, 0%$_{Happy}$/100%$_{Angry}$).

Figure 4

Morph Condition by Cannabis Group: Early Window



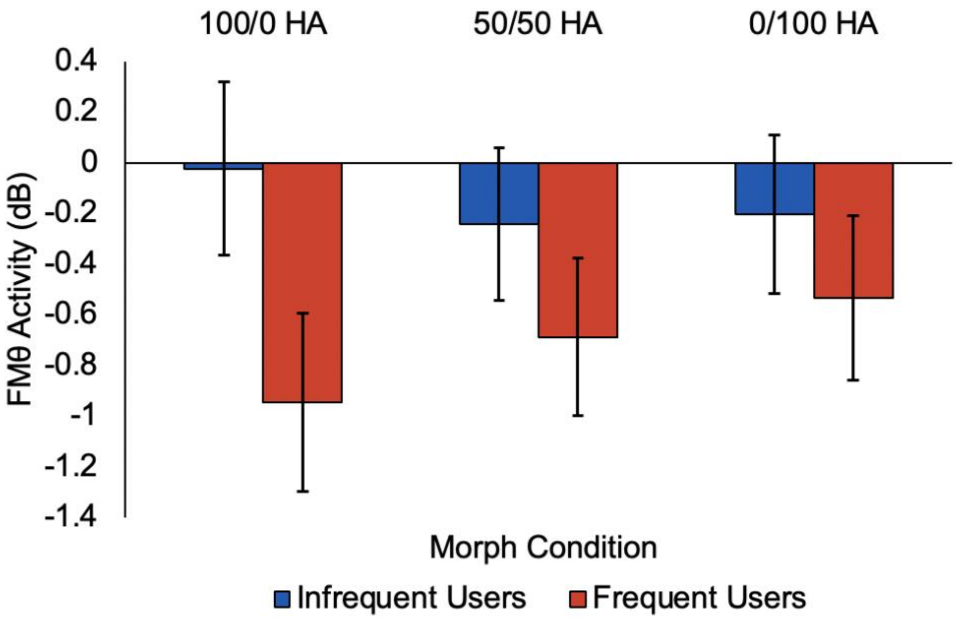
Note. Midfrontral theta (FMθ) activity during the early window (146 – 434 ms post-stimulus onset) is displayed for each morph condition and cannabis use group. There was no significant Morph × Cannabis Group interaction effect, indicating that frequent cannabis users and infrequent cannabis users did not differ in early-window FMθ activity across morph conditions.

From left to right, morph conditions vary in:

Social Conflict: (100%$_{Happy}$/0%$_{Angry}$, 50%$_{Happy}$/50%$_{Angry}$, 0%$_{Happy}$/100%$_{Angry}$).

Figure 5

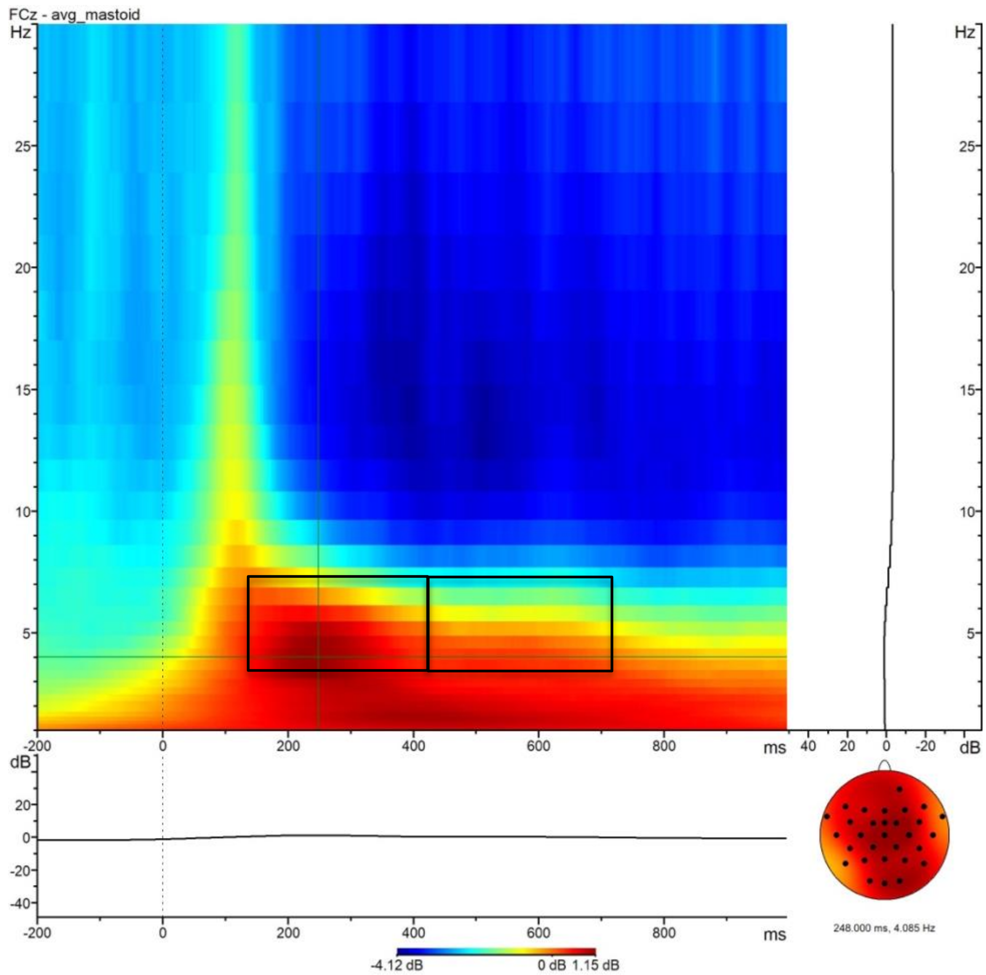
Morph Condition by Cannabis Group: Late Window



Note. Midfrontral theta (FMθ) activity during the late window (436 – 724 ms post-stimulus onset) is displayed for each morph condition and cannabis use group. There was no significant Morph × Cannabis Group interaction effect, indicating that frequent cannabis users and infrequent cannabis users did not differ in late-window FMθ activity across morph conditions.
From left to right, morph conditions vary in:
Social Conflict: (100%$_{\text{Happy}}$/0%$_{\text{Angry}}$, 50%$_{\text{Happy}}$/50%$_{\text{Angry}}$, 0%$_{\text{Happy}}$/100%$_{\text{Angry}}$).

Figure 6

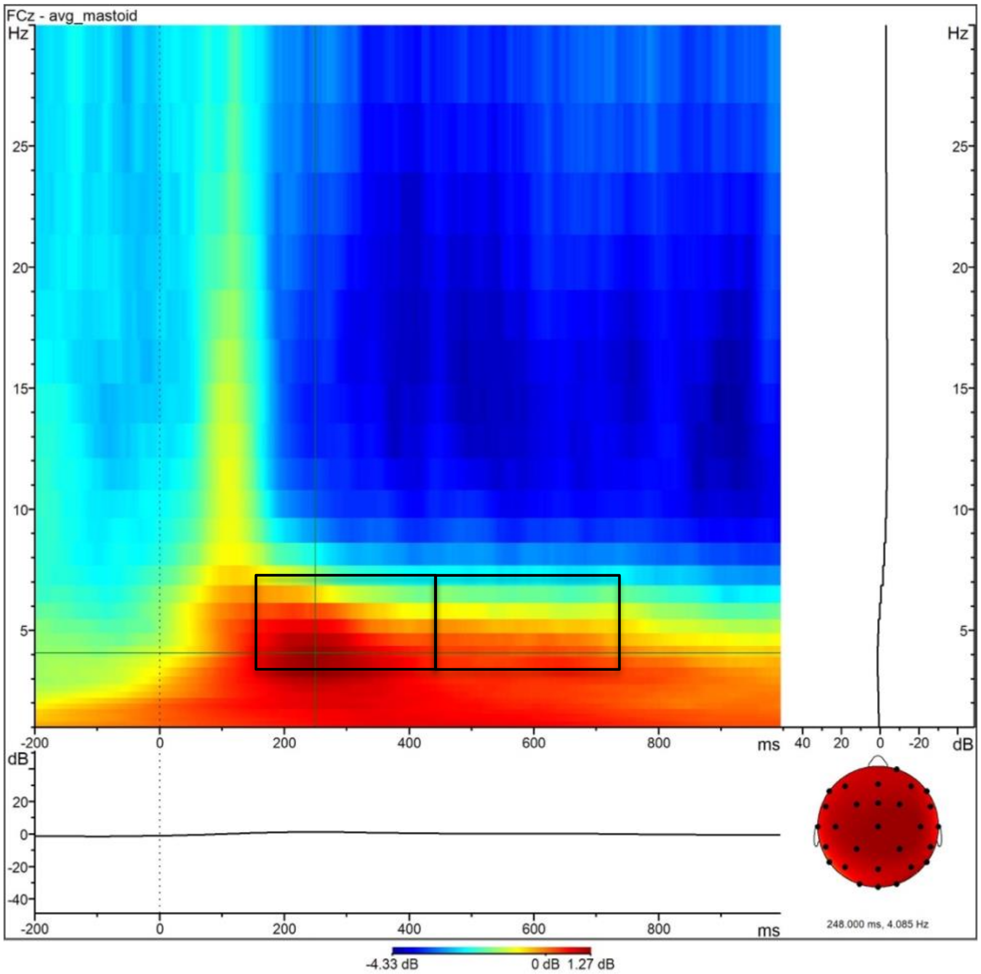
Time Frequency Plot of FCz Activity During Pure Reward and Threat



Note. Time-frequency representation of average FCz activity during responses to social reward (100%$_{\text{Happy}}$/0%$_{\text{Angry}}$) and social threat (0%$_{\text{Happy}}$/100%$_{\text{Angry}}$) conflict morphs. Black boxes indicate midfrontal theta (FMθ; 3.23 Hz – 7.34 Hz) regions of interest used to quantify neural activity during the early (146 – 434 ms) and late (436 – 724 ms) windows.

Figure 7

Time-frequency Plot of FCz Activity During Social Reward-Threat Conflict



Note. Time-frequency representation of average FCz activity during responses to social reward-threat conflict morphs ($50\%_{Happy}/50\%_{Angry}$). Black boxes indicate midfrontal theta (FMθ; 3.23 Hz – 7.34 Hz) regions of interest used to quantify neural activity during the early (146 – 434 ms) and late (436 – 724 ms) windows.

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