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Exploring the Neurophysiological Impact of Calligraphy Practice on Anxiety Reduction: An EEG-Based Analysis

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Abstract. This study delved into the mitigating effects of calligraphy practice on anxiety and its underlying neural mechanisms. Participants were subjected to Velten self-representation induction to evoke negative emotions, during which their calligraphy practice was combined with EEG data collection and spectral analysis to assess their pre- and post-anxiety states. The findings revealed a notable surge in beta-band (13-30 Hz) power following anxiety induction, with an average increase of 65.74%. Conversely, a marked reduction in beta-band power, averaging a 38.18% decrease, was observed after participants engaged in calligraphy practice.Subjective evaluations using the State Anxiety Inventory (SAI) scale corroborated these results, showing a significant escalation in scores post-anxiety induction (from 42.5 to 60.4), and a substantial decline after calligraphy practice (to 32.1), further underscoring the efficacy of calligraphy in anxiety reduction. Notably, higher affective potency scores were associated with regular and clerical scripts, indicating that these calligraphic styles may exert a more pronounced positive impact on emotional regulation.The study's findings suggest that calligraphy practice can effectively alleviate anxiety by significantly diminishing beta-band power, a mechanism that parallels the focused attention and reduced external distraction observed in meditation. By doing so, calligraphy may harness a similar psychological mechanism to meditation. This research offers a neuroscientific foundation for the therapeutic use of calligraphy in emotional regulation, potentially paving the way for novel emotion-healing strategies in the realm of mental health.

Keywords. Calligraphy practice, EEG analysis, anxiety detection, art healing

1. Introduction

In our contemporary society, where anxiety and stress have become pervasive challenges to mental health, the therapeutic role of art in emotional healing is gaining significant attention. Calligraphy, a revered aspect of traditional Chinese culture, is not only valued for its artistic merit but also for its potential to regulate psychological states. Despite its recognized benefits, the neuroscientific basis of calligraphy's impact on well-being remains largely uncharted. Studies have shown that writing activities can significantly lower anxiety and physiological stress responses in individuals[1]. Furthermore, clinical studies on calligraphic handwriting have also uncovered therapeutic benefits for a variety of behavioral and psychosomatic conditions, including attention deficit hyperactivity disorder (ADHD) in children (Kao et al., 1997),

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Alzheimer's disease (Kao, 2003; Kao et al., 2000a,b), hypertension (Guo et al., 2001; Kao et al., 2001), and Diabetes II (Kao et al., 2000a)[2]. Unlike other art therapies, calligraphy's focus on repetition and regularity not only aids in achieving a state of flow but also uniquely enhances mental resilience and promotes inner peace. While these findings provide a solid foundation for exploring calligraphy's healing potential, a systematic investigation into the efficacy of different calligraphic styles and the neural mechanisms involved is yet to be conducted, highlighting a significant opportunity for future research to delve into the intricacies of how calligraphy can serve as a powerful tool for emotional and mental health recovery.

Brainwave classifications, based on their frequency ranges, offer a window into an individual's physiological and psychological states. The δ-band, with frequencies between 0.5 to 3.5 Hz, is rarely observed in adult EEGs and is typically associated with deep brain states such as deep anesthesia or deep sleep. The θ-band, ranging from 3.5 to 7.5 Hz, is indicative of a state of heightened relaxation and mild drowsiness. The α-band, with frequencies from 7.5 to 13.5 Hz, is most prominent in EEG signal acquisition, especially when an adult is in a quiet, eyes-closed state, signifying a relaxed yet alert mind. Lastly, the β-band, with frequencies between 13.5 to 35 Hz, becomes more active during periods of tension, high concentration, or intense mental activity, marking a transition from the more relaxed α-band to a state of active cognition. These classifications are pivotal for interpreting neurological data, providing insights into cognitive and emotional states that are invaluable across neuroscience, psychology, and medical fields[3].

In our study, we evaluated the anxiety-alleviating effects of various calligraphy styles by examining electroencephalogram (EEG) signals both prior to and following the induction of an anxious mood. The therapeutic impact of calligraphy on anxiety was determined through an analysis of EEG signal characteristics in the frequency domain, specifically by assessing the Power Spectral Density (PSD) [4]. Additionally, we quantified and contrasted the shifts in beta-band power to discern the extent to which calligraphy might mitigate anxiety, providing a neuroscientific perspective on the calming effects of this traditional art form.

2. Methodology

2.1. Purpose of the experiment

The therapeutic efficacy and significance of calligraphy practice in alleviating anxiety were investigated through the meticulous recording and subsequent analysis of participants' electroencephalogram (EEG) data, capturing changes in brainwave patterns both before and after engaging in the calligraphic exercise.

2.2. Experimental design

For the induction of negative mood, we employed a selection of 40 self-statements derived from the Velten mood induction experiment, which articulate the psychological and physiological aspects of anxiety. Examples include statements like "I am insecure inside and full of fear for the future." Extensive research, including studies referenced [5][6], has demonstrated the high arousal potential of these statements in eliciting anxiety through self-reflective introspection. The methodology was further validated by

Orton et al. [7], who successfully utilized Velten's statements to induce anxiety in their study.

In addition to the verbal stimuli, music was selected based on a preliminary study that confirmed its effectiveness in provoking anxiety[8]. During the experiment, participants were instructed to softly read the 40 Velten self-statements at a pace of approximately 12 seconds per statement. Concurrently, the principal investigator played music designed to induce anxiety and guided participants to visualize as many relevant anxiety-provoking scenarios as possible while reading the statements, thereby intensifying the experience of anxiety. This multi-modal approach was aimed at creating a comprehensive anxiety-inducing environment to facilitate a deeper exploration of the anxiety-relief effects of calligraphy practice.

In the calligraphy practice segment of the study, participants engaged in the act of copying various styles of calligraphy for a duration of three minutes per type. This exercise allowed for a focused and mindful replication of the calligraphic art, enabling participants to immerse themselves in the therapeutic process of writing.

For the assessment of anxiety levels, participants were administered the State Anxiety Inventory (SAI) scale. The SAI is a comprehensive 20-item questionnaire, comprising 10 items that pertain to positive emotions and 10 items that relate to negative emotions. This scale is designed to evaluate the current or recent past experience and sensation of fear, nervousness, apprehension, and neuroticism. Widely utilized in numerous studies, the SAI serves as a reliable instrument for gauging the intensity of anxiety provoked by diverse stimuli. Scores on the SAI range from 20 to 80, with higher scores indicating a greater degree of anxiety, thus providing a quantifiable measure of the anxiety experienced by individuals in response to specific conditions or events.

2.3. Experimental procedures

The experimental procedure was meticulously structured and executed in the following sequence, as depicted in Figure 1:

- Preparation Step: Participants were ushered into the laboratory to acclimate for a 10-minute resting period, during which they completed the initial State Anxiety Inventory (SAI) scale. Concurrently, baseline EEG readings were obtained to establish a neurological reference point.
- Anxiety Induction Step: Against the backdrop of music designed to evoke anxiety, participants were tasked with reading a series of 40 Velten sentences. Following this anxiety-inducing exercise, EEG signals were recorded to capture the neurological responses post-anxiety induction.
- Calligraphy experiment Step（Figure 2）: Participants then engaged in the act of calligraphy copying, with EEG signals being continuously monitored to track any changes in brain activity associated with the calligraphic practice.
- Assessment Step: Upon conclusion of the calligraphy session, participants were asked to complete the SAI scale once more to assess any shifts in anxiety levels. Additionally, they were prompted to rate their subjective emotional experiences throughout the process, including their arousal level and affective valence, providing a comprehensive evaluation of the intervention's impact on both psychological and physiological states.

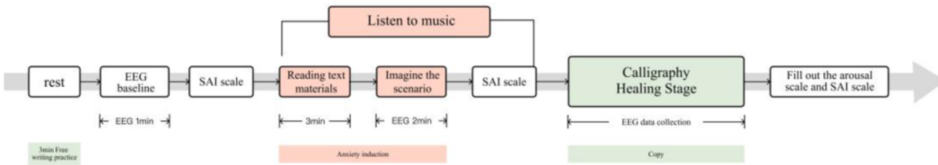

Figure 1. Experimental Procedure.

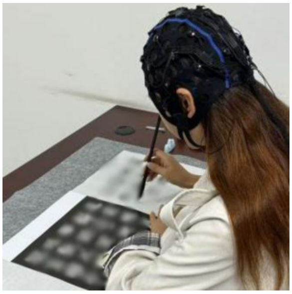

Figure 2. Calligraphy Experiment.

3. Methodology

3.1. Pre-processing of EEG data

The EEG data pre-processing procedure, executed within the EEGLAB environment, was a systematic series of steps designed to refine the raw EEG signals. Initially, data were imported and any unwanted noise levels were eliminated. This was followed by motor localization to pinpoint and address movement-related artifacts. The data were then filtered within a range of 0.1 Hz to 35 Hz to preserve the critical EEG information, with a sampling rate of 500 Hz. Independent Component Analysis (ICA) was employed to remove artifactual interferences, such as those caused by blinking and electromyographic (EMG) activity. Baseline correction was applied by extracting data segments from before anxiety induction, during the calligraphy exercise, and post-exercise, using the resting state as the reference baseline. The EEG data were then re-referenced using binaural referencing to avoid interference with the signals from the brain regions of interest, such as the central region for fine motor control and the prefrontal lobe for cognitive and emotional regulation. This method also minimized the impact of head movement and reduced the presence of artifacts, as ear signals typically exhibit fewer disturbances. Finally, the continuous EEG data were segmented into epochs of 2 seconds each, with a 0.5-second overlap between epochs, ensuring comprehensive data coverage and facilitating a thorough analysis of the EEG signals throughout the experiment.

This meticulous pre-processing ensures that the EEG data is of the highest quality, thereby preparing it for accurate subsequent analysis and processing.

3.2. Spectrum analysis

The meticulous pre-processing of EEG data ensures that each subject's epoch data is of superior quality, ready for further analysis. The preprocessed data from each epoch for each participant are superimposed and averaged, followed by a secondary superimposition across all subjects to aggregate the data. This aggregation allows us to transform the time-domain information of the discrete signals into frequency-domain information using the Fast Fourier Transform (FFT). The FFT is an efficient algorithm for computing the Discrete Fourier Transform (DFT), which significantly reduces computational complexity and is well-suited for handling the large-scale data processing demands of our experiment.

After applying the FFT, we proceed with a series of operations to extract the frequency domain characteristics of the EEG signals. Specifically, we focus on the power spectral density (PSD) of the β-band (13-30 Hz) during the calligraphy process and calculate the average power values. This analytical approach provides a robust framework for understanding the neural underpinnings of the calligraphy-induced anxiety alleviation effects.The mathematical and algorithmic expressions applied in this part:

- Discrete Fourier Transfer (DFT):

$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi}{N}kn}, k = 0,1,..., N-1 \tag{1}$$

- The Fast Fourier Transform (FFT) is an optimization of the Discrete Fourier Transform (DFT) that enables efficient computation through a partitioning strategy, often employing butterfly operations. This method allows for the decomposition and recursive calculation of the DFT, thereby streamlining the process. The essence of the FFT can be encapsulated in the following formulaic representation:
  FFT decomposition formula:

$$X[K] = X_{\mathrm{eve}n}[k] + e^{-j\frac{2\pi}{N}k} X_{odd}[k] \tag{2}$$

FFT butterfly arithmetic formula:
The essence of the Fast Fourier Transform (FFT) is encapsulated within its butterfly structure, a computational mechanism that efficiently pairs the elements X[k] and X[k+N/2] for processing. This pairing is a key operation in the FFT algorithm, facilitating the transformation of data with remarkable efficiency:

$$X[K] = X_{\mathrm{eve}n}[k] + W_N^k X_{odd}[k] \tag{3}$$

$$X[K + N/2] = X_{\mathrm{eve}n}[k] - W_N^k X_{odd}[k] \tag{4}$$

where this is the complex exponent known as the twiddle factor.

$$W_N^k = e^{-j\frac{2\pi}{N}k} \tag{5}$$

Regarding computational efficiency, the Fast Fourier Transform (FFT) converts the Discrete Fourier Transform (DFT) of N data points into $\log_2 N$ stages, with each stage involving N/2 butterfly calculations. Consequently, the overall computational complexity is significantly reduced, as detailed below:
Computational efficiency:

$$O(N\log N) \tag{6}$$

- Power Spectral Density (PSD) is a pivotal concept in the frequency domain analysis of signals, extensively utilized in signal processing and statistical analysis. PSD delineates the distribution of power across different frequencies, indicating the power intensity per unit frequency. The common methodologies for calculating PSD encompass definitions rooted in the Fourier transform and approaches based on the autocorrelation function. In this study, our calculation of PSD is grounded in the definition derived from the Fourier transform:

$$S_x[K]_{dB} = 10 \cdot \log_{10}\left(\frac{1}{N}\left|X[k]\right|^2\right) \tag{7}$$

In this context, X[k] denotes the Discrete Fourier Transform (DFT) of the signal x[n]. The variable N represents the duration of the signal, specified by the total number of samples. $S_x[k]_{dB}$ in decibels (dB) signifies the power spectral density at the k-th frequency point, providing a measure of the signal's power distribution across the frequency spectrum.

4. Results

4.1. EEG spectrum analysis results

The frequency domain analysis presented in Table 1 revealed significant changes in β-band power following the induction of anxiety, with a substantial mean increase of 65.74%. Conversely, engaging in calligraphy practice led to a notable reduction in β-band power, with a mean decrease of 38.18%. We define ΔBP as the differential in β-band power between the task-state and the baseline, thereby quantifying the impact of the anxiety induction and calligraphy practice on β-band activity.

Table 1. Average Power of Beta Band During the Baseline Step, Anxiety Induction Step, and Calligraphy Writing Step

Condition	Beta Power	ΔBP
Base	98.9434	/
Anxiety	163.9285	-64.9851
Write	61.1668	37.7766

Concurrently, we conducted an analysis to discern the variance in the power spectral density (PSD) of the β -band (13-30 Hz) across distinct task states in comparison with the baseline state. As depicted in Figure 3, when comparing the calligraphy task segment with the baseline segment, there is a notable difference in the PSD of the β-band. The PSD of the β-band during the calligraphy task is generally lower than that observed during the baseline state. This observation suggests that the anxiety-induced post-calligraphy task may have mitigated the subjects' nervousness and anxiety to a significant degree.

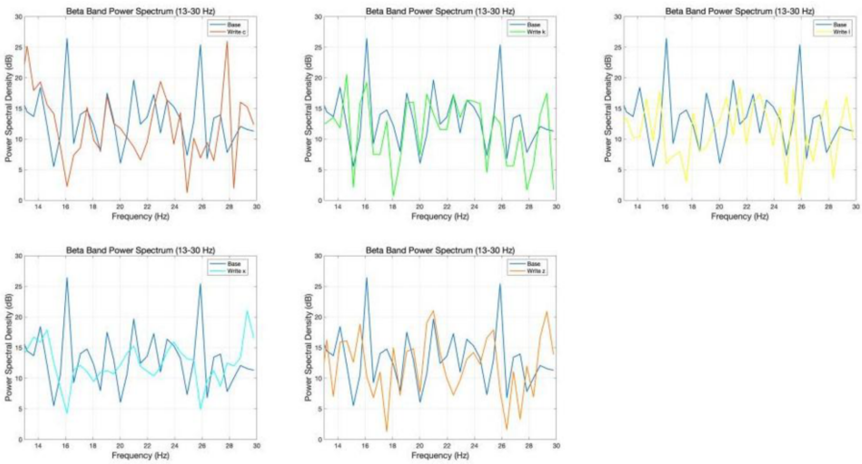

Figure 3. Beta Band Power Spectrum Of Writing Different Calligraphy Types.

4.2. Subjective rating results

Initially, the analysis of the State Anxiety Inventory (SAI) self-assessment scale, as detailed in Table 2, revealed a marked escalation in score values following the anxiety induction and a correspondingly significant reduction in scores after engaging in calligraphy. The mean and standard deviation of the SAI scale scores were 42.5 ± 8.21 prior to anxiety induction, 60.4 ± 9.61 post-induction, and 32.1 ± 4.41 following the calligraphy practice. These subjective assessment outcomes suggest that the anxiety induction was partially effective in eliciting anxiety in the subjects, while the subsequent calligraphy practice not only reduced their anxiety to a notable extent but also validated the efficacy of the experimental approach.

Table 2. SAI Anxiety Self-Assessment Scale Scores at Baseline, After Anxiety Induction, and Post-Calligraphy Writing

Anxiety Level	SAI Score
Base	42.5 ± 8.21
Anxiety	60.4 ± 9.61
Write	32.1 ± 4.41

Within the study, participants assigned higher emotional potency ratings to the regular and clerical script exercises, with mean potency ratings of 2.4 and 2.3, respectively. The cursive and seal script exercises received slightly lower affective valence ratings, at 0.8 and 1, respectively. Nonetheless, these forms of calligraphy still demonstrated a positive impact on emotion regulation, indicating that all types of script exercises contributed to a calming effect, albeit to varying degrees.

5. Discussion

5.1. Anxiety Relief Mechanisms

The findings of this study demonstrate that engaging in calligraphy practice significantly diminishes the power of the beta band, which is instrumental in reducing anxiety levels. This outcome aligns with prior research, indicating that calligraphy directs participants to concentrate their attention, thereby reducing external distractions. This effect is akin to the psychological mechanisms observed in meditation and other concentration-intensive activities. The beta band is linked to the brain's state of tension and heightened concentration; thus, a reduction in its power suggests a relaxation response and a mitigation of anxiety. As a structured and repetitive art form, calligraphy can harness the brain's focused attention through a rhythmic writing process and intricate movements, effectively easing the physiological arousal triggered by anxiety.

5.2. Limitations and future prospects

While this study yields promising results, it is not without its limitations. Firstly, the modest sample size of the experiment may limit the generalizability of our findings. To address this, future studies will expand both the sample size and the age range of participants to further substantiate the anxiety-alleviating effects of calligraphy practice.

Secondly, there is a possibility that different types of calligraphy may exert varying influences on emotional regulation. Consequently, upcoming research will delve deeper into these differences, examining the distinct emotional regulatory effects and the underlying mechanisms of various calligraphic styles in mitigating anxiety.

Lastly, the current study relied solely on EEG signal analysis to assess mood changes, without the integration of functional brain imaging techniques such as functional near-infrared spectroscopy (fNIRS) or functional magnetic resonance imaging (fMRI) to explore the activity patterns across different brain regions in greater depth. Future investigations can uncover the neural underpinnings of calligraphy in emotional regulation more comprehensively by employing multimodal brain imaging techniques in conjunction with the theoretical framework of neuroscience.

6. Conclusion

This study has successfully validated the therapeutic impact of calligraphy practice in mitigating anxiety. Through spectral analysis, we have demonstrated that engaging in calligraphy can significantly diminish the power of the beta band, thereby effectively easing anxiety symptoms. This discovery not only bolsters the scientific credibility of calligraphy as an instrument for emotional regulation but also paves the way for its integration into mental health practices. Although the study faced certain constraints, the findings offer compelling evidence that warrants further investigation into the role of calligraphy in the realm of emotional healing.

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