Brain Asymmetry and Visual Working Memory: Investigating the Impact of Emotional Distractors

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Abstract

Visual working memory plays a crucial role in the learning process . Research has demonstrated a positive correlation between better visual working memory and higher positive affect, which is associated with increased activation of the left hemisphere. However, the precise relationship between brain asymmetry and visual working memory remains unclear. Alpha oscillations are important for inhibitory functions related to task-irrelevant information. This study aims to explore the relationship between visual working memory, positive affect, and brain alpha asymmetry. Our results indicate a link between better visual working memory, higher positive affect, and increased right alpha activity (indicating higher left hemisphere activation). This finding may have implications for training methods aimed at enhancing visual working memory by adjusting brain asymmetry and affecting emotional states. Further studies are necessary to gain a comprehensive understanding of this relationship.

Keywords: visual working memory, brain asymmetry, affects, alpha oscillations

Introduction

Working Memory

Learning involves acquiring new information, and memory is the result of learning . As per the memory model, for information to be stored in long-term memory for later recall, it must first be processed in working memory effectively (Cowan, 1999). Visual working memory is notably linked to academic success, showing a particularly robust connection with mathematical proficiency in young learners (Bull et al., 2008).

Affect and Visual Working Memory

The cognitive-affective theory of learning underscores the interplay between cognitive and emotional processes during learning, aligning with cognitive load theory's focus on managing cognitive load during learning tasks (Ip & Li, 2015; Panasiti et al., 2019). Positive affect has been shown to enhance controlled processing rather than simple storage processing, resulting in improved performance on tasks requiring cognitive control and information manipulation (Ashby & Isen, 1999). Conversely, negative affect has been linked to increased risk of poorer cognitive function, adverse health outcomes, and reduced quality of life among older adults (Memmott et al., 2018).

Emotional distractions have a notable impact on cognitive load and performance across different types of distractors, including negative, neutral, and positive stimuli. Negative visual content tends to strongly capture attention, influencing task performance. Moreover, healthy individuals, particularly younger ones, exhibit an attentional bias towards negative stimuli, a phenomenon associated with trait anxiety (Ladouceur et al., 2009).

Affect and Brain Asymmetry

Brain asymmetry, particularly in alpha oscillations measured by electroencephalogram (EEG), has garnered significant attention in individuals with affective disorders (de Aguiar Neto & Rosa, 2019). These oscillations largely mirror regulatory processes, particularly in inhibiting task-irrelevant cortical areas (Jensen & Mazaheri, 2010). Alpha asymmetry specifically denotes the disparity in alpha power (8-12Hz) between the brain's right and left regions, assessed through EEG during resting states (Park et al., 2019). A negative alpha asymmetry score indicates a higher alpha power on the right side, signaling relative left-sided cortical activity attributed to the inhibitory function of frontal alpha waves (Blackhart et al., 2006). Research has consistently demonstrated that more pronounced symptoms of depression and anxiety correlate with a relatively heightened activation in the right frontal cortex (Adolph & Margraf, 2017). Similarly, in healthy females, those exhibiting greater left-sided frontal activation during rest tend to experience amplified positive affect in response to positive stimuli (Wheeler et al., 1993). Conversely, individuals with more right-sided frontal activation at rest often report more intense negative affect when exposed to negative stimuli, in contrast to those displaying greater left-frontal activation.

Visual Working Memory and Brain Asymmetry

Visual working memory tasks often show right-lateralized alpha power dominance due to the inhibitory role of frontal alpha waves, implying a more engaged left hemisphere (Pavlov & Kotchoubey, 2022). Conversely, research indicates that individuals with higher beta/alpha frequency ratios in the left prefrontal cortex exhibit better abilities to filter out irrelevant information (Ambrosini & Vallesi, 2017). Yet, the precise connection between visual working memory and brain asymmetry in alpha frequency remains unclear, given limited research. Notably, disrupted upper alpha synchronization during working memory retention is observed in depression and after traumatic events, underscoring the need for further exploration of its correlation with visual working memory (Segrave et al., 2010). Investigating the relationship between brain asymmetry and visual working memory could yield valuable insights.

Research Questions

Based on the research gap identified in the literature review, this pilot study aims to address the relationship between visual working memory, affect and brian alpha asymmetry. We hypothesize that 1) individuals with higher positive affect show better visual working memory; 2) higher positive affect correlates with higher left brain activation; 3) individuals with higher left brain activation show better visual working memory.

Materials and Methods

Participants

5 female students from UM were recruited, 4 subjects were aged at 22~24 years old, 1 was aged at 50~60 years old. All participants were right-handed, no color blindness and informed the consent form of ethics approval obtained from the Human Research Ethics Committee, University of Macau.

Study design

A cross-sectional design was employed in this study. Participants were asked to complete two behavioral tasks aimed at assessing visual working memory ability in a predetermined sequence. Additionally, two five-minute resting-state EEG data were recorded, and participants also completed the PANAS scale to assess their affective states.

Positive Affectivity Negative Affectivity Schedule (PANAS)

The PANAS is a self-rating measure consisting of 10 items for positive affect (PA) and 10 items for negative affect (NA), which captures temporary mood states (Watson et al., 1988). This scale demonstrates good internal consistency reliabilities, with a Cronbach's alpha of 0.88 for PA and 0.87 for NA. Previous studies have indicated the potential impact of affective states on visual working memory and brain asymmetry (Adolph & Margraf, 2017; Wheeler et al., 1993). We employed the PANAS to evaluate the participants' current levels of positive affect.

Emotional Memory Task and Memory Recognition Task

Experimental stimuli

For the Emotional Memory task, we utilized affective visual stimuli sourced from the International Affective Picture System (Lang et al., 2005). Specifically, 225 images were selected for experimental stimuli which were standardized according to their ratings for valence and arousal. For these 225 images, 75 were positive, 75 were negative, and 75 were neutral. The selection of stimuli was based on the norms provided in the IAPS technical report, ensuring that (i) positive, neutral, and negative stimuli significantly differed from each other in terms of valence ratings (positive > neutral > negative), and (ii) positive and negative stimuli were equally arousing, whereas neutral stimuli were significantly less arousing. In the Emotional Memory Task, participants were instructed to remember symbols. These symbols sourced from Microsoft Database to form 20 unique pairs of stimuli, adapted from Panasiti et al. (2019) were used as both target and non-target stimuli during the task.

Emotional Memory Task

To examine the impact of emotional distractors on participants' working memory performance, the Emotional Memory Task is employed. This task is a modified version of the classic memory N-Back task, where participants are shown with a sequence of stimuli (typically letters) and are required to indicate when the current stimulus matches the one presented n steps earlier in the sequence. In our version, we used symbols instead of letters to prevent the utilization of rehearsal strategies that could make the task easier (Figure 1). The 20 pairs of symbols were shown in Figure 2.

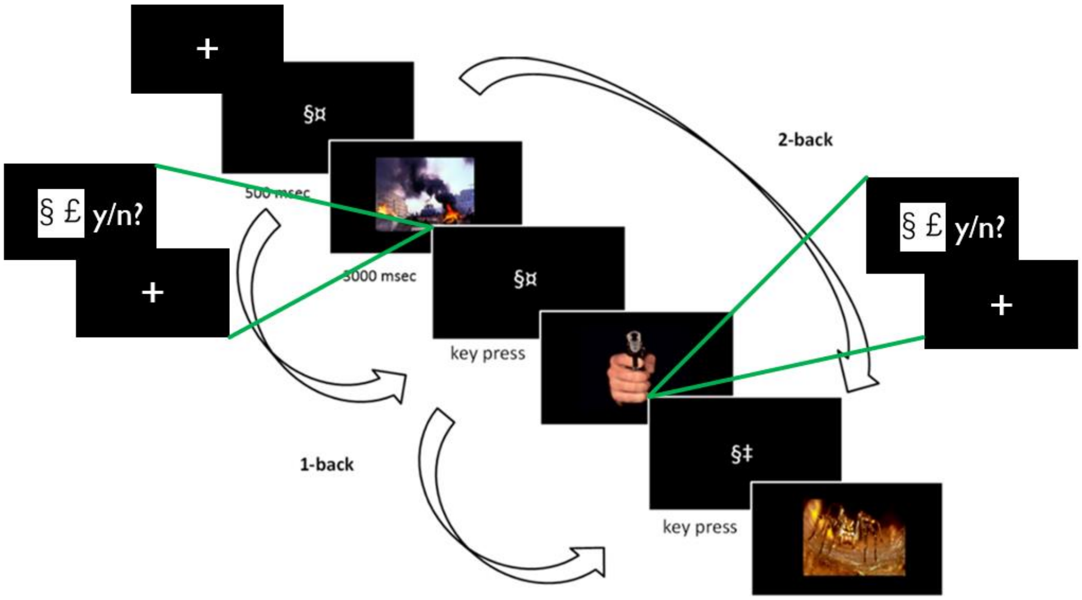

Figure 1 Timeline of the Emotional Memory task

Symbol pairs
§ £
§ ‡
¤ #
¤ ¥
‡ #
‡ ¥
£ ‡
£ §
~ ¤
~ ‹

¥ §
¥ £
º ~
º ^
^ ¤
^ º
‹
^
‹ ~
‹ º

Figure 2. Pairs of symbols used as target/non target stimuli

Within our study, we integrated two levels of difficulty: 1-back (n=1) and 2-back (n=2). The Emotional Memory task was a part of a larger experimental session. To mitigate potential carryover effects, the task order was counterbalanced among participants, and 10-minute breaks were allocated between tasks. The sequence of 1-back and 2-back Emotional Memory task blocks was also counterbalanced across participants. Stimuli were presented using Opensesame Software on a computer. Each experimental block included 20 stimuli paired with 20 emotional distractors. Initially, participants viewed a pair of symbols in black on a white background for 500 ms, followed by a 3000 ms emotional distractor. This pattern repeated 20 times per block.

Participants were instructed to press the key ‘y’ for yes or ‘n’ for no, indicating whether the pair of symbols shown on the screen matched the one presented either once or twice before. They had 3500 ms to make their response. To maintain focus, participants were reminded to avoid distraction from the emotional images displayed between symbol pairs. Each participant completed two blocks: one for the 1-back task and one for the 2-back task, across three emotional stimuli categories: negative, positive, and neutral. This resulted in a total of 12 blocks for each participant in the Emotional Memory task. The order of the emotional stimuli was counterbalanced among participants. Subsequently, participants proceeded to the Memory Recognition task.

Memory Recognition Task

After the Emotional Memory Task, prticipants were unexpectedly presented with a Memory Recognition Task comprising 135 emotion images sourced from the IAPS (Lang et al., 2008). Among these, 90 emotion image stimuli (30 per valence) were considered familiar as they had been used previously in the Emotional Memory Tasks. The remaining 45 emotion images (15 per valence) were unfamiliar, having not been presented in the prior task. Responses were categorized as correct when participants correctly identified the familiar stimuli as seen and the unfamiliar stimuli as unseen. Conversely, responses were deemed incorrect when participants incorrectly categorized familiar stimuli as unseen and unfamiliar stimuli as seen.

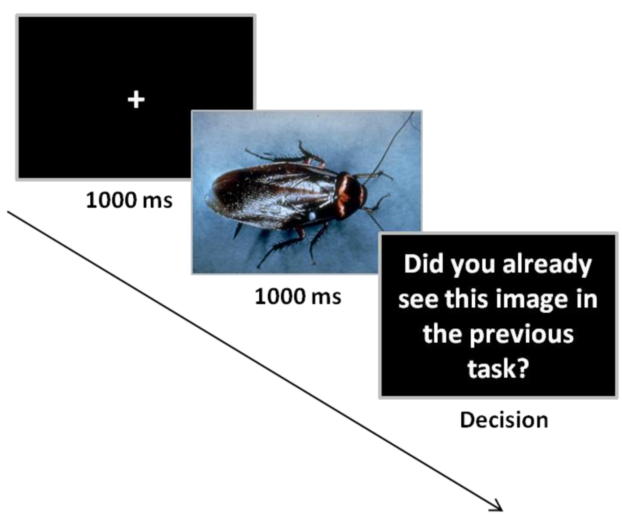

Figure 3. Timeline of the memory recognition task

Each trial in the Memory Recognition Task adhered to a defined sequence (refer to Figure 3 for the task design): 1) A 1000 ms fixation cross was shown. 2) An emotion image stimulus appeared for 1000 ms. 3) Participants responded to the question "Did you already see this image in the previous task?" by pressing a key. The emotional images were randomized in their presentation order to mitigate potential order effects or biases.

Electrophysiology (EEG) Procedures

During the EEG recording, a 32-electrode BioSemi cap and amplifier were utilized, with the Cz electrode serving as the reference. The BioSemi application software was employed for data acquisition. To maintain impedance below 5 kOhm, the POz electrode was designated as the ground electrode. Data were sampled at a frequency of 2048 Hz and digitized using a 24-bit AD converter. For offline data processing, EEGLAB 2024.0 within Matlab (version R2023a; MathWorks Inc., Natick, MA, USA) was utilized (Delorme & Makeig, 2004).

During a 5-minute resting period with dimmed lights, EEG data was recorded. Participants were instructed to keep their eyes closed while remaining alert (Alyagon et al., 2020; Zibman et al., 2019). To eliminate transitional influences, the first 30 seconds and the last 10 seconds of the resting state EEG data were removed. The data were then filtered using a high-pass filter at 1 Hz and notch FIR filters at 45-55 Hz to remove unwanted frequencies. Noisy channels were automatically detected and further reviewed manually for rejection. Rejection criteria included an absolute amplitude threshold of ±150 µV. Interpolation using spline interpolation was performed to replace the rejected channels. The data were then re-referenced to the average reference. Next, the data were transformed to the frequency domain through a fast Fourier transform (1-100 Hz) with a frequency resolution of 0.125 Hz, and with a 1.5 s Hanning Window. Alpha power (8-12 Hz) was extracted for each electrode, and brain asymmetry scores were calculated as the decibel-transformed ratio in alpha power between the left electrodes and the right electrodes using the provided formula: Left alpha brain asymmetry = log10 (left electrode's alpha power) − log10 (contralateral homologous electrode's alpha power). Ultimately, the alpha brain asymmetry scores obtained from 16 pairs of electrodes were averaged to derive a total brain asymmetry score.

Results

Demographic, psychometric, and psycho-behavioral results

Five female students from the University of Macau participated in the study, with ages ranging from 22 to 60 and a mean age of 29.2 (SD = 12.42). Notably, four participants fell within the age range of 22 to 24. Based on a median split of standardized positive affect (PA) scores following the methodology of Ladouceur et al. (2009), participants were categorized into two groups: a High Positive Affect group (N=3) and a Low Positive Affect group (N=2). Statistical analysis revealed no significant differences between the two groups (all $p > 0.05$) in PANAS-PA scores.

Table 1. Demographic Data of the Participants in the Study

Variable	Range	M	SD	t Value	p Value
Age	22-60	29.2	12.42	-0.13	0.90 (> 0.05)
Gender	Females	/	/	/	/
PANAS-PA Score	19-45	30.0	9.23	0.0	1.0

Emotional Memory Task

In the Emotional Memory Task, accuracy was measured to assess valence. Average accuracy scores were calculated for negative (neg), neutral (neu), and positive (pos) stimuli across five subjects. Surprisingly, our findings contradicted previous literature that showed lower accuracy for negative stimuli compared to positive and neutral stimuli. Instead, we observed a different pattern: negative stimuli had lower accuracy than neutral, and neutral stimuli had lower accuracy than positive. These results suggest that negative affect may hinder working memory accuracy, while positive affect may enhance it in comparison to neutral affect.

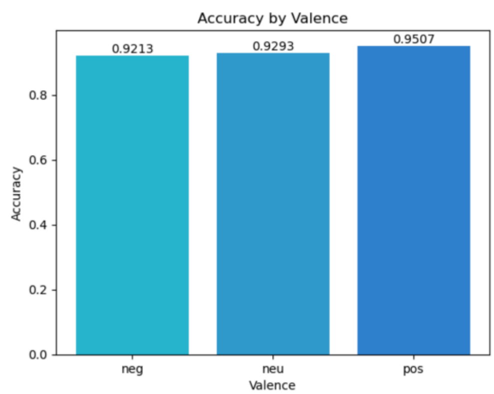

Figure 4. Main Effect of Valence in Emotional Memory Task

In the Emotional Memory Task, tasks were categorized as load 1 (1-back) or load 2 (2-back) based on difficulty levels. The average accuracy per participant was calculated, and Pearson correlation tests explored the relationship between PANAS scores and accuracy within the group. T-tests compared accuracy between load 1 and load 2. A significant difference was found between 1-back and 2-back tasks, indicating varying difficulty levels. While a weak correlation between PANAS scores and accuracy was initially observed (Load 1: $p=0.16 > 0.05$, Load 2: $p=0.14 > 0.05$), the significant difference between 1-back and 2-back tasks remained after excluding age-incompatible data (both $p = 0.04 < 0.05$). Additionally, a significant correlation ($p = 0.04 < 0.05$)

between PANAS scores and accuracy was observed, suggesting that emotional state influences task performance when age-incompatible data are excluded.

Group results also indicated a notable interaction between group and cognitive load, with the High Positive Affect (HPA) group consistently outperforming the Low Positive Affect (LPA) group under both cognitive load conditions.

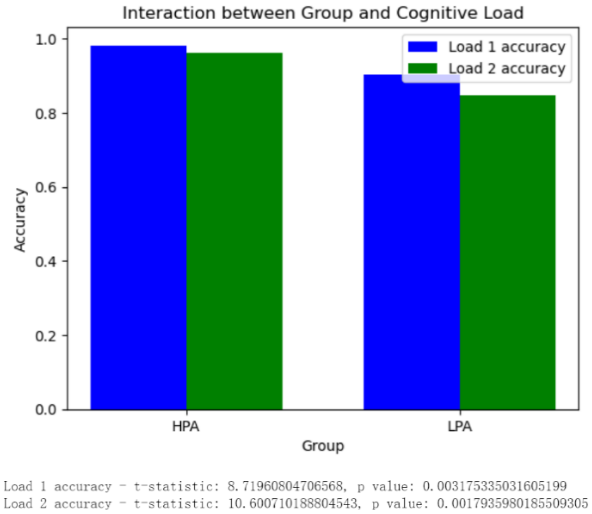

Figure 5. Interaction between PANAS-PA Scores and Cognitive Load

Emotion Recognition Task

In the Emotion Recognition Task, the analysis centered on accuracy, looking at average scores across five subjects for negative (neg), neutral (neu), and positive (pos) stimuli. Based on previous literature, it was expected that neutral stimuli would show lower accuracy compared to positive and negative stimuli. However, the actual results displayed a distinct pattern, with neutral stimuli exhibiting the lowest accuracy, followed by negative stimuli, and then positive stimuli. These outcomes suggest that positive emotion images are more memorable than negative and neutral ones, while negative emotion images are easier to recall than neutral ones.

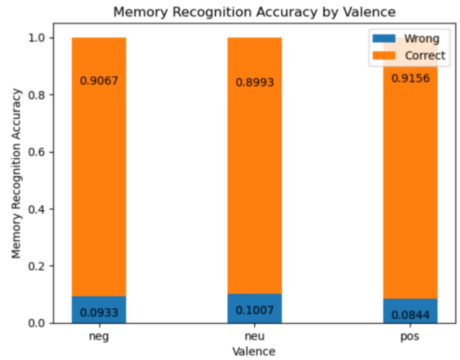

Figure 6. Accuracy in the Emotion Recognition Task

Correlation analyses

Correlation between PANAS-PA Scores and Brain Asymmetry

Brain asymmetry data was collected using two resting-state EEG measurements per participant. Due to data quality issues, most subjects had only one usable dataset, preventing result averaging. Pearson correlation tests were conducted to examine the relationship between PANAS-PA (Positive Affect) scores and brain asymmetry. Overall, a weak correlation between PANAS-PA scores and brain asymmetry was observed ($p > 0.05$). However, after excluding age-incompatible data, a significant correlation was found, indicating that higher positive affect was associated with lower brain asymmetry, suggesting higher right alpha power and more activity in the left brain ($p < 0.05$).

As shown in the figure, groups with high positive affect (High PA) exhibited significantly lower brain asymmetry compared to those with low positive affect (Low PA), with statistical significance at $p = 0.0043$.

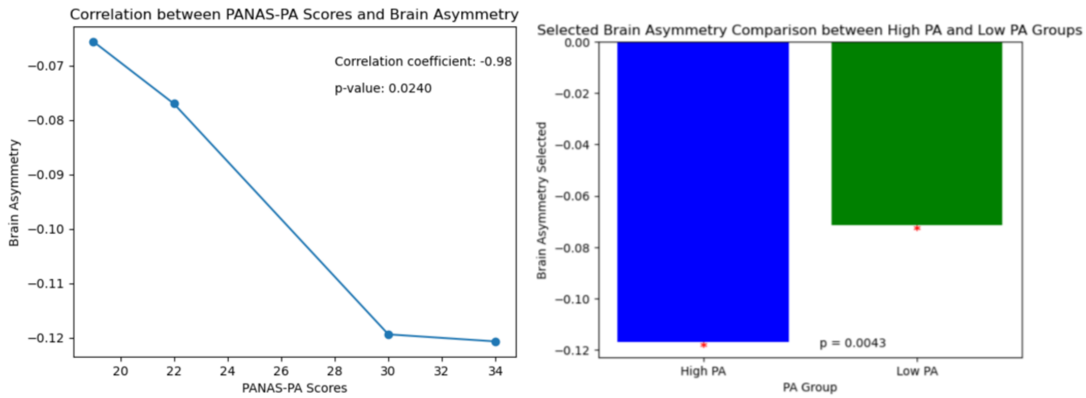

Figure 7. Correlation between PANAS Scores and Brain Asymmetry

Correlation between Affect and Working Memory (Emotional Memory Task)

Data analysis was conducted by measuring the average accuracy of two tasks per subject. Pearson correlation tests explored the relationship between PANAS-PA (Positive Affect) scores and accuracy. Across all data, a weak correlation was found between PANAS-PA scores and accuracy. However, when age-incompatible data was excluded, a significant correlation emerged, indicating that participants with higher PANAS-PA scores exhibited improved working memory performance. As depicted in the figure, individuals in the high positive affect (High PA) group displayed significantly better average accuracy compared to those in the low positive affect (Low PA) group, with statistical significance shown at p = 0.0023.

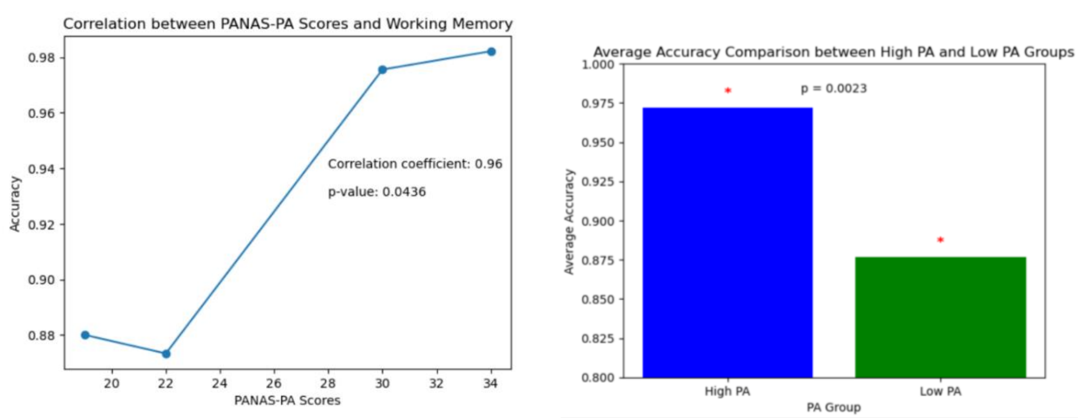

Figure 5. Correlation between PANAS-PA Scores and Working Memory

in Emotional Memory Task

Correlation between Brain Asymmetry and Working Memory (Emotional Memory Task)

Pearson correlation tests were used to investigate the relationship between accuracy and brain asymmetry. Across all data, a significant correlation was identified between accuracy and brain asymmetry ($p < 0.05$). Higher working memory ability was linked to lower brain asymmetry, which indicated increased right alpha power (more activity in the left brain). Additionally, when excluding age-incompatible data, a significant correlation between PANAS-PA scores and brain asymmetry was also found ($p < 0.05$).

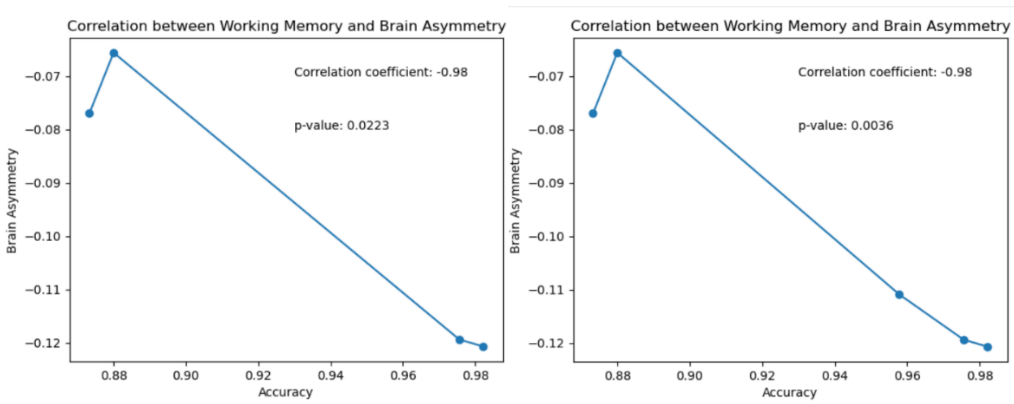

Figure 8. Correlation between Working Memory and Brain Asymmetry

in Emotional Memory Task

Correlation between Affect and Working Memory (Memory Recognition Task)

We examined the relationship between emotional affect, as measured by PANAS-PA scores, and memory task accuracy. Pearson Correlation Tests were conducted to analyze the average accuracy of the memory task per subject. The results indicated a weak correlation between PANAS-PA scores and accuracy ($P > 0.05$) across all data. Even when age incompatible data was excluded, the correlation remained weak ($P > 0.05$), suggesting that emotional affect, as quantified by PANAS-PA scores, does not strongly influence memory task accuracy.

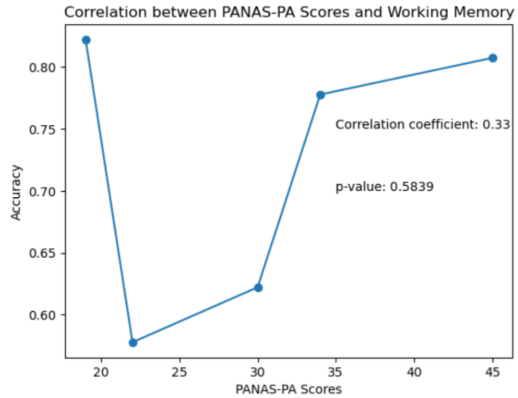

Figure 9. Correlation between PANAS-PA Scores and Working Memory in Emotion Recognition Task

Correlation between Brain Asymmetry and Working Memory (Memory Recognition Task)

Pearson Correlation Tests were utilized for data analysis. The results revealed a weak correlation between accuracy and brain asymmetry ($p < 0.05$) across all data. When data incompatible with age was excluded, there was also a weak correlation between PANAS-PA scores and brain asymmetry ($p < 0.05$), suggesting subtle but significant relationships in the variables studied.

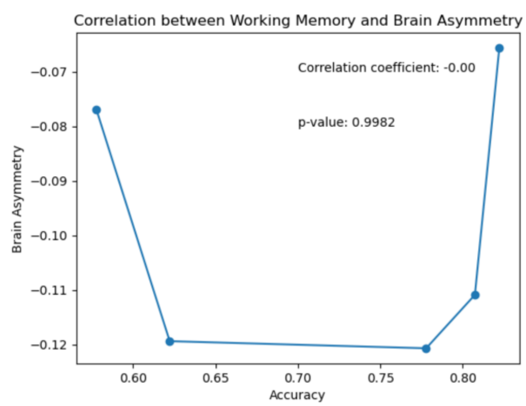

Figure 10. Correlation between Working Memory and Brain Asymmetry in Emotion Recognition Task

Discussion

The findings of this pilot study align with our three hypotheses, indicating a positive correlation between improved visual working memory, increased positive affect, and heightened left brian activation. This study has implicaiton in the learning process. To improve visual working memory, fostering positive affect and left brian activation could be beneficial. Engaging in certain training or exercises to modify brian alpha asymmetry before learning might enhance learning outcomes, for instance, through mindfulness practices (Szumska et al., 2021). Neuromodulation treatments like Transcranial Magnetic Stimulation (TMS) and neurofeedback hold promise as well (Szumska et al., 2021). These methods could involve activating the left hemisphere or boosting right alpha activity. However, it's essential to conduct further research before applying these techniques in real-world human applications.

In this study's sample, one subject is notably older (aged 50-60 years) compared to the other subjects, who are between 22-24 years old. This age discrepancy may introduce bias into the results. McDowell et al. (1994) observed that older individuals had a reduced ability to perceive unpleasant emotions compared to younger counterparts. The right hemi-aging model suggests that the right hemisphere experiences more age-related decline than the left hemisphere, while the hemispheric asymmetry reduction in old adults (HAROLD) model proposes reduced lateralization of frontal activity during cognitive tasks in older adults (Cabeza, 2002; Dolcos et al., 2002). However, Cherry et al. (2005) found similar left-right asymmetry patterns in both younger and older participants. To address these considerations, the data from the older subject was removed, and statistical analysis was conducted again. The results remained statistically significant even after this adjustment. When carrying out an actural study, it is better to narrow the age range to reduce individual differences between samples.

The results of accuracy in Emotional Memory task and memory recognition task are partly inconsistent with our expectaions. In Emotional Memory task, our findings showed that negative stimuli were remembered less accurately than neutral stimuli, which in turn were remembered less accurately than positive stimuli. This contrasts with the typical order of negative < positive < neutral seen in previous studies. Our results are consistent with the idea that negative distractors may consume more attentional resources, as suggested by Panasiti et al. (2019). However, we also encountered inconsistencies with previous findings, which prompts us to consider possible reasons and outline future plans. One potential explanation for the discrepancy could be a ceiling effect in our task, which may have prevented the demonstration of different results between valence conditions. To address this, we plan to increase the task difficulty by implementing an emotional N-back task. Additionally, we noted inconsistencies in the subjects' judgments of valence compared to the International Affective Picture System (IAPS), especially in the case of neutral and positive photos. To mitigate this issue, we aim to increase the sample size and collect valence rating results directly from the subjects, ensuring more accurate and reliable data collection for future analyses.

In our study on memory recognition accuracy, we discovered a deviation from the typical order seen in previous research. Specifically, our findings showed that neutral stimuli were recognized with lower accuracy compared to negative stimuli, which were in turn recognized less accurately than positive stimuli. This contrasts with the established pattern of neutral < positive < negative observed in previous studies. Our results align with the notion that neutral distractors may require fewer attentional resources, as suggested by Panasiti et al.(2019) . One possible explanation for the inconsistency could be the inclusion of face photos specifically in the negative distractors, leading to heightened memory difficulties. In contrast, the positive and neutral distractors did not involve face photos. To address this issue, we plan to maintain consistency in the number and types of photos used for the three emotional distractors across conditions. Incorporating an equal and predetermined number of nature scenes, food items, utensils, animals, and humans consistently across all emotional distractor categories is crucial. This approach aims to ensure that any differences observed in memory recognition accuracy are not influenced by variations in the types of stimuli presented.

This study design of this pilot study has some other limitations and should be improve in the actual study. Firstly, it has a small sample size and includes only female subjects. Given that males and females may demonstrate distinct patterns of brain activation and connectivity during cognitive tasks and emotional processing, the findings may not be generalizable to the wider population (Knyazev, 2007). Future studies should aim for a larger sample size, with at least 31 subjects, using G*Power to achieve a power of 0.80 (α=0.05) to detect a small to moderate effect size (d=0.42) (Faul et al., 2007). Additionally, including a group of male subjects would provide a more comprehensive understanding of the phenomenon. Secondly, this study focuses solely on alpha oscillations, while other oscillations such as theta oscillations, associated with emotion regulation and memory encoding, and beta oscillations, involved in attentional activation, are also worth exploring (Herrmann et al., 2016; Knyazev, 2007). Thirdly, considering that positive and negative affect are independent in terms of individuals' long-term emotional experiences, studying negative affect would be valuable (Diener & Emmons, 1984).

In future studies, improvements can also be made in the EEG reocrding and affect measures. In the resting-state EEG data recording, the EEG paradigm can be repeated multiple times, for example, at least three times, to reduce noise by averaging the data. Secondly, using a 64- or 128-channel EEG cap for data recording can enhance the quality and specificity of the

EEG signals. It's important to conduct EEG recordings in an environment free from environmental artifacts, such as being away from fMRI equipment or other sources of electromagnetic interference. Regarding the assessment of affect, it's essential to consider the limitations of subjective measures like the PANAS scale. Individuals may interpret emotional words differently, leading to variations in their reported affective states. To complement subjective measures, incorporating objective measures such as physiological indicators (e.g., heart rate variability, skin conductance) and behavioral observations (e.g., frequency and intensity of smiles or frowns during social interactions) can provide a more comprehensive and reliable assessment of affective states (Diener & Emmons, 1984; Mather & Thayer, 2018).

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