

Investigating the Selection of Internal Representations Based on Visual Search

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McGill University, Montreal

August 2024

A thesis submitted to McGill University in partial fulfillment of the
requirements of the degree of Master of Science



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ABSTRACT

The human brain has limited capacity, and attention serves to prioritize relevant information amidst a vast array of stimuli. Some information has an intrinsic potential of capturing attention, such as physically salient ones. While externally salient stimuli can influence attention through bottom-up, stimulus-driven mechanisms, they can also be modulated by top-down, goal-directed processes. However, it remains unclear whether such mechanisms similarly govern the selection of internal representations in working memory.

To address this, we designed a dual-task experiment where a visual search task was embedded within the working memory retention period. Participants were required to remember the orientations of two colored bars presented in the left and right visual hemifields. During the search task, one target and one distractor appeared in opposite hemifields, with a salient stimulus in the search display serving as a retro-cue to guide memory selection. The salient stimulus could either match the color of the memory target (pro-condition), match the color of the non-memory target (anti-condition), or be absent (neutral condition). Additionally, the spatial relationship between the salient stimulus and memory target (ipsilateral vs. contralateral) was examined to assess its influence on the selection of internal representations.

Behavioral results showed higher memory precision in the pro-condition compared to the other conditions, suggesting that salient stimuli acting as forward cues facilitate the selection of internal representations. In the anti-condition, memory precision was higher when the salient distractor appeared in the same hemifield as the memory target compared to the contralateral hemifield, indicating suppression of the internal representation in the same hemifield as the

salient distractor. Event-related potential (ERP) results revealed that during memory encoding, the pro-condition elicited stronger P1 and N3 components in frontal and parietal electrodes compared to the anti-condition. Furthermore, in the anti-condition, early frontal ERP components (N1, P2, N3) differed between ipsilateral and contralateral trials, while during memory retrieval, occipital P2 components showed differences in both pro- and anti-conditions based on spatial alignment. These findings highlight the role of salient stimuli in memory selection, which depends on their relevance in the search task.

Resting-state fMRI analysis revealed that the functional characteristics of the superior occipital gyrus were associated with memory precision differences between the anti- and neutral conditions. The superior occipital gyrus showed functional connectivity with both the superior parietal lobule and the superior frontal gyrus, emphasizing the integrated role of frontal, parietal, and occipital regions in visual processing and spatial localization.

In conclusion, this study demonstrates that internal representation selection is significantly enhanced when stimulus-driven and goal-directed processes are aligned, while goal-directed control dominates under conflicting conditions. These findings provide neural evidence for the integration of attentional and memory systems across the frontal, parietal, and occipital regions, offering critical insights into the mechanisms of selective attention and memory in dynamic environments. The global significance of this research lies in its potential applications to fields such as cognitive training, neurorehabilitation, and artificial intelligence, where optimizing attentional and memory processes can improve human performance in complex, real-world scenarios.

RÉSUMÉ

Le cerveau humain a une capacité limitée, et l'attention sert à prioriser les informations pertinentes parmi une multitude de stimuli. Certaines informations ont un potentiel intrinsèque pour capter l'attention, comme celles qui sont physiquement saillantes. Bien que les stimuli saillants externes puissent influencer l'attention par des mécanismes ascendants (guidés par les stimuli), ils peuvent également être modulés par des processus descendants (guidés par les objectifs). Cependant, il reste incertain si ces mécanismes gouvernent de manière similaire la sélection des représentations internes dans la mémoire de travail.

Pour explorer cette question, nous avons conçu une expérience à double tâche dans laquelle une tâche de recherche visuelle a été intégrée à la période de rétention de la mémoire de travail. Les participants devaient mémoriser les orientations de deux barres colorées présentées dans les champs visuels gauche et droit. Pendant la tâche de recherche, une cible et un distracteur apparaissaient dans des champs opposés, avec un stimulus saillant dans l'affichage de recherche servant de rétro-indice pour guider la sélection mnésique. Le stimulus saillant pouvait soit correspondre à la couleur de la cible mémorielle (condition pro), soit correspondre à la couleur de la non-cible mémorielle (condition anti), soit être absent (condition neutre). De plus, la relation spatiale entre le stimulus saillant et la cible mémorielle (ipsilatérale vs. contralatérale) a été examinée pour évaluer son influence sur la sélection des représentations internes.

Les résultats comportementaux ont montré une précision mnésique plus élevée dans la condition pro par rapport aux autres conditions, suggérant que les stimuli saillants agissant comme indices prospectifs facilitent la sélection des représentations internes. Dans la condition anti, la précision mnésique était plus élevée lorsque le distracteur saillant apparaissait dans le même hémichamp que la cible mémorielle comparé à l'hémichamp controlatéral, indiquant une suppression de la représentation interne associée à l'hémichamp du distracteur saillant. Les résultats des potentiels évoqués (ERP) ont révélé que, lors de l'encodage mnésique, la condition pro induisait des composantes P1 et N3 plus fortes dans les électrodes frontales et pariétales par rapport à la condition anti. En outre, dans la condition anti, les composantes précoces des ERP frontaux (N1, P2, N3) différaient entre les essais ipsilatéraux et controlatéraux, tandis que lors de la récupération mnésique, les composantes P2 occipitales montraient des différences dans les conditions pro et anti selon l'alignement spatial. Ces résultats mettent en évidence le rôle des stimuli saillants dans la sélection mnésique, dépendant de leur pertinence dans la tâche de recherche.

L'analyse IRMf en état de repos a révélé que les caractéristiques fonctionnelles du gyrus occipital supérieur étaient associées aux différences de précision mnésique entre les conditions anti et neutre. Ce gyrus, fonctionnellement connecté au lobule pariétal supérieur et au gyrus frontal supérieur, souligne le rôle intégré des régions frontales, pariétales et occipitales dans le traitement visuel et la localisation spatiale.

En conclusion, cette étude démontre que la sélection des représentations internes est significativement améliorée lorsque les processus ascendants et descendants sont alignés, tandis que le contrôle descendant domine en cas de conflit. Ces résultats fournissent des preuves neuronales de l'intégration des systèmes attentionnels et mnésiques au sein des régions frontales, pariétales et occipitales, offrant des éclairages cruciaux sur les mécanismes de l'attention sélective et de la mémoire dans des environnements dynamiques. La signification globale de cette recherche réside dans ses applications potentielles à des domaines tels que l'entraînement cognitif, la neuro-réhabilitation et l'intelligence artificielle, où l'optimisation des processus attentionnels et mnésiques peut améliorer les performances humaines dans des scénarios complexes et réels.

Acknowledgements

First and foremost, I would like to express my heartfelt gratitude to my supervisors, Professor Chai and Professor Jin. Thank you for allowing me to be your student and for your patient, meticulous, and sincere guidance. With your help, I have become someone I never imagined I could be. I also want to thank you for your assistance in choosing research directions, designing experiments, collecting data, and writing my thesis.

Next, I would like to thank my committee members, Dr. Maiya Geddes, Dr. Suresh Krishna, and Dr. Mayada Elsabbagh. Thank you for repeatedly offering valuable suggestions during our committee meetings, helping to improve my research.

I also want to express my gratitude to everyone in the Chai Lab, including Jonah Kember, Hilary Sweatman, Hongxiu Jiang, Paula Andrea Toro Vargas, Delaram Shirzad, etc. Thank you for your help with statistical analysis during our group meetings.

Finally, I would like to thank my friend Guanchen Li for the support in my life, which has made my research progress smoother and my life more enjoyable.

Contribution of authors

The body of work presented in this thesis would not have been made possible without a close collaboration between myself and my M.Sc. supervisors, Prof. Xiaoqian Chai and Prof. Zhenlan Jin. Listed below are the specific contributions:

Xiaoqian Chai: Provided critical insights that significantly shaped the experimental design, supported the analysis of resting-state functional connectivity (rsFC) data, offered expert advice on statistical analysis, and played a key role in the interpretation of the results.

Zhenlan Jin: Played a central role in designing the experiments, offered essential guidance on participant recruitment, and was instrumental in interpreting the results. Additionally, Dr. Jin supervised the collection and comprehensive analysis of behavioral and imaging data from the study participants.

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Chapter 1: Introduction

1.1 Research Background and Significance

1.1.1 Attention and Working Memory Representation

Attention is generally defined as the limited allocation of cognitive processing resources, determining an individual's ability to perceive, process, and respond to environmental stimuli or information. It is the process (or mechanism)^[1] of selecting information for prioritized processing. This cognitive mechanism is similar to a spotlight, illuminating designated parts of the cognitive scene, allowing us to focus attention on specific information while ignoring irrelevant information.

The two basic dimensions of attention are divided into external attention and internal attention, as shown in Figure 1-1. External attention involves the selection and processing of external sensory inputs, which can be based on sensory modalities (such as visual, auditory, etc.), spatial location, or time points. Internal attention, on the other hand, involves the regulation of internal psychological states, affecting the selection and processing of internal information, such as the manipulation of representations in working memory, long-term memory, task rules, decision-making, and responses. This internal information might be related to future planning or memory retrieval. The process of attention involves regions in the prefrontal cortex and posterior parietal cortex, which are responsible for generating top-down signals that bias target information selection and resource competition^[2, 3]. However, these regions not only

influence the selection of external perception but also guide the processing of internal information. Therefore, whether there exists a unified mechanism to perform all these functions or whether multiple distinct mechanisms related to internal attention exist is an important direction of current research.

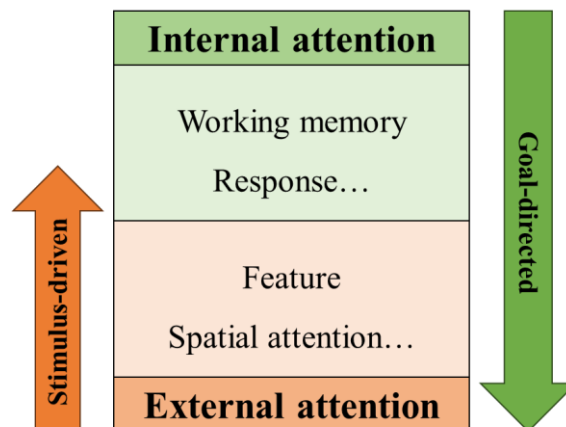


Figure 1-1 Distinction between internal and external attention

In the cognitive processing related to internal attention, working memory is a key component. It serves as a temporary platform for the temporary storage, manipulation, and use of goal-related information^[4]. Because working memory can maintain and manipulate information without sensory support^[5, 6], this characteristic enables it to process and modify internal representations. Thus, internal representations in working memory are defined as the internal depiction of information in working memory.

Multiple studies have found that the presence of significant stimuli during the memory delay period can impair working memory representations^[7, 8]. However, this impairment is more severe when the salient stimuli differ from the memorized items in task-relevant feature dimensions^[7, 9]. Conversely, when the information of salient stimuli matches the color^[10], orientation^[11, 12], and spatial location^[13, 14] of the working

memory representations, it attracts attention. The occipital cortex plays an important role in maintaining working memory representations^[15-18], but internal attention can affect working memory tasks. For instance, encoding and manipulating information in working memory can trigger cognitive interference^[19], which can disrupt simple spatial localization abilities^[20] and reduce search efficiency^[21]. This effect is mutual: the content of working memory can influence our attention allocation to internal information, while changes in perceptual attention can adjust the information maintained in working memory^[22]. Currently, the neural mechanisms by which attention affects working memory representations remain unclear.

Research has shown that attention and working memory are closely connected^[1, 23-25]. Some studies suggest that "working memory" can be understood as the sustained attention to specific attributes, objects, or events over time^[1], sharing a single, limited resource with attention^[26]. Others advocate for viewing working memory as a unique active storage mechanism^[27], interacting with long-term memory through attentional filters that select and restrict information flow based on relevance^[28]. Contemporary research on internal attention is limited, but increasing evidence indicates that working memory largely relies on internal attention to process incoming perceptual data and retrieve long-term memory representations to enhance behavioral performance. Internal attention not only facilitates the storage of information in working memory and long-term memory but also dynamically re-prioritizes information in working memory to align with current and future tasks. For example, if behavioral goals change after

encoding, internal attention can shift to information relevant to these updated goals, thereby enhancing their impact^[29-31]. Additionally, it can quickly transition to alternative internal representations when necessary^[28].

Tasks involving attention and working memory typically include three stages: working memory encoding, visual search, and working memory retrieval. The working memory encoding stage is responsible for maintaining visual information relevant to the current task^[32], focusing on selectively encoding task-relevant information and retaining related information. In visual search tasks, cueing operations guide attention to specific locations, determining which objects are encoded into working memory^[33] and retained after encoding. Notably, the binding of memory item features in working memory does not require continuous attention to these items^[34]. Moreover, the selective maintenance of visual object representations in working memory can occur independently of the direction of attention^[35, 36]. However, few studies focus on the retrieval stage during the working memory delay process, which involves recovering the required memory items from maintained information for further processing or response. This stage requires individuals to selectively retrieve information related to current task goals from working memory while inhibiting irrelevant or interfering information. The efficiency of retrieval depends not only on the effectiveness of the encoding and maintenance stages but also on the clarity of retrieval cues and the specificity of memory traces.

Therefore, this study aims to explore the brain mechanisms behind the process of

internally guided attention directing targets stored in working memory representations.

1.1.2 Top-Down and Bottom-Up Attention Selection Mechanisms

A visual scene contains a vast amount of information, and we mainly select information using two types of attention selection methods: top-down (goal-directed) and bottom-up (stimulus-driven). Top-down attention voluntarily shifts towards sensory stimuli that align with our goals, while bottom-up attention is involuntarily attracted by external stimuli. Existing literature suggests that this attention mechanism applies not only to external stimuli but also to the selection of internal representations from working memory^[30, 31, 37].

However, in the visual field, when multiple stimuli are present simultaneously, top-down (goal-directed) and bottom-up (stimulus-driven) mechanisms compete for neural representation by mutually inhibiting each other's activities^[38], as shown in Figure 1-2. This interaction makes it complex to study the effects of these two attention mechanisms separately. However, research has demonstrated that studying their interactions and the relative timing of their activities can effectively reveal the different neural mechanisms between goal-directed and stimulus-driven attention. When top-down attention is focused, prefrontal neurons respond first to the processing of target locations, whereas in bottom-up attention, parietal regions exhibit earlier activity^[39]. Additionally, when measuring brain oscillation frequencies, synchrony between frontal and parietal regions increases, particularly with higher oscillation frequencies in lower frequencies during top-down attention modulation^[2]. The enhancement of spatial

attention is associated with increased synchrony between the posterior parietal cortex and medial temporal areas^[40], while the enhancement of the extrastriate cortex is related to the processing of sensory inputs^[41]. These findings reveal the different neural bases of top-down and bottom-up attention mechanisms in the brain and highlight their complementary roles in attention regulation.

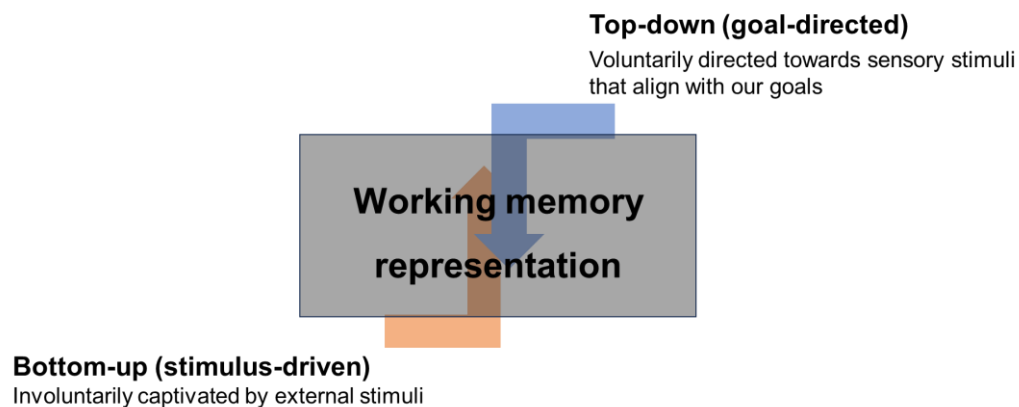


Figure 1-2 The role of top-down and bottom-up mechanisms on working memory representations

To investigate the effects of top-down and bottom-up attention on visual working memory representations, this study utilized retro-cues indicating information related to the upcoming task^[31, 37]. Retro-cues can actively allocate attention to memory content related to the target. However, the correlation between the features of the retro-cues and the features in the working memory representations can also involuntarily allocate attention to the matching memory content. This study employed two different cues, which have been proven effective in exploring the influences of top-down and bottom-up mechanisms^[42]. In the dual-task of working memory and visual search, one cue was consistent with the target item of the memory (pro), involving a synergistic mechanism

of both bottom-up and top-down processes. The other cue corresponded to the information of the competing item in memory (anti), involving conflicting mechanisms of top-down and bottom-up processes. Additionally, to isolate the pure effect of involuntary capture, the study established a task setting without any cues as a baseline, which included only the top-down mechanism. These three conditions effectively study the attention selection processes of top-down and bottom-up mechanisms in working memory representations.

Furthermore, Slotnick et al. ^[43] demonstrated that spatial location information is encoded at an early stage in the striate cortex. When information related to the memory item reappears on the same side in the working memory representation, it facilitates the selection of the target spatial side^[44]. The presence of related distractors as targets on the same side aids the selection process, producing more pronounced attention effects. The intraparietal sulcus, superior frontal gyrus, and superior temporal cortex work together to autonomously shift spatial attention to task-relevant locations^[45]. Additionally, the parietal cortex contains topographical maps based on attention focus that can be used for such spatial orientation^[46, 47]. When attention needs to be reoriented to a target appearing in a previously unattended location, another circuit primarily located at the right temporoparietal junction is activated^[39, 48]. These studies reveal the different regions and mechanisms in the brain involved in attention shifting, emphasizing their significant roles in processing spatial attention. Therefore, spatial location information can influence the encoding and maintenance of working memory

representations.

Hence, the primary objective of this study is to examine whether goal-directed and stimulus-driven attention equally affect and compete for the selection of these internal representations.

1.2 Application of EEG Technology in Working Memory

Electroencephalography (EEG) has played an important role in exploring brain mechanisms. EEG signals, with millisecond-level temporal resolution, can capture the rapid changes in brain activity, providing direct evidence of electrophysiological activity, especially when exploring the brain's immediate response to specific stimuli or tasks. In studies of EEG signals, scientists have discovered a specific brain signal related to tasks by averaging the EEG recorded in the same time window of the same event. This signal is called an event-related potential (ERP)^[49]. ERPs have high temporal resolution and reflect the changes in brain wave amplitude over time. Therefore, analyzing ERPs can effectively capture the rapid dynamic changes in neural activity related to attentional processes. Another widely used analysis method in EEG research is the time-frequency analysis, which involves analyzing the signal in both the time domain and the frequency domain. This analysis uses Fourier transform or wavelet transform on raw EEG data to obtain information on how EEG frequencies change over time. Time-frequency signals are divided based on different frequencies of EEG signals and reflect the rate of change of brain signals over time.

In working memory tasks involving goal-relevant and goal-irrelevant information, ERP studies have shown that the P1 component may reflect sensory selection through top-down inhibition^[50, 51], while the N1 component is attributed to the indicators of attention orientation. Relevant stimuli elicit more pronounced P2 components in the anterior brain distribution, indicating the detection of attention stimuli and the selection of task-related stimuli^[52, 53]. The P2 component also represents the indexing function of working memory^[54-56], especially during the encoding phase^[57, 58]. Furthermore, the N2 component reflects the active inhibition of irrelevant stimuli entering working memory^[59]. The N3 component reflects the encoding of attention and working memory, and it is associated with successfully performing tasks and correctly identifying information^[60-62]. Additionally, in visual search tasks, two well-known components, Pd and N2pc, are identified. The presence of the Pd component indicates active inhibition^[43], while the N2pc component, triggered by search targets and other objects with target-defining features, is generally considered a marker for the deployment of attention to these objects^[63-65].

Time-frequency analysis results show that the alpha and theta bands play significant roles in guiding attention in working memory representations. A decrease in alpha power during the encoding process of working memory indicates active visual processing^[66], while an increase in alpha power plays a positive functional role in preventing distracting information from flowing into the region retaining memory items^[67]. Alpha oscillations protect new memories by inhibiting further sensory

processing that could interfere with stored information^[68]. The theta band power is crucial during the encoding and delay periods. Raghavachari et al^[69] found a significant increase in theta band amplitude during encoding in a working memory task. The theta band reflects a gating mechanism that enhances the processing of working memory task-related information and inhibits task-irrelevant information. Additionally, the amplitude of the theta band is related to working memory load; as the amount of encoded information increases, theta activity becomes stronger^[70].

Spatial location also plays a critical role in working memory representations, as demonstrated by alpha lateralization during item probing^[71, 72], even if the location is not important for task completion^[73, 74]. Additionally, in EEG studies, locating memory items on the same side or opposite side of visual search targets may lead to different brain activity patterns. Notably, when memory items and targets are on the same side, the N2pc component associated with spatial attention may be more pronounced, indicating more focused attention. Memory load and spatial congruence effects may also differ, possibly reflected in specific EEG bands (e.g., theta or alpha waves). When memory items are on the opposite side, the brain may exhibit different activity patterns due to the need to distribute attention between spatial locations. Moreover, when memory items and targets are on the same side, the spatial overlap may increase memory load, which may be reflected in theta and alpha waves.

1.3 Application of Resting-State fMRI in Working Memory

Resting-state functional magnetic resonance imaging (rs-fMRI) captures fMRI images when the brain is not performing specific cognitive tasks but remains quiet, relaxed, and awake. This imaging method is based on Blood Oxygen Level Dependent (BOLD) signals to reflect brain activity^[75]. rs-fMRI images have millimeter-level high spatial resolution, providing precise localization of brain structure and functional activity. By measuring blood flow changes associated with neural activity, rs-fMRI reveals the activity of different brain regions during rest. It can also study brain activity differences in cognitive behavior among different individuals based on individual variations.

There is one common quantitative indicator used in rs-fMRI data analysis to evaluate brain functional activity and network connectivity characteristics: Regional Homogeneity (ReHo). This indicator reflects spontaneous neural activity characteristics of the brain at rest and are commonly referred to as local feature indicators of brain functional connectivity. ReHo (Regional Homogeneity) assesses the functional homogeneity within a brain region by calculating the similarity of BOLD signal time series among adjacent voxels. High ReHo values indicate strong synchrony of functional activities within a region, reflecting the coordination of local neuronal activity.

Resting-state functional MRI imaging, with its high spatial resolution, can accurately localize brain regions involved in these processes. Working memory tasks

are mediated by a broad network of frontal, parietal, and sensory cortex regions, containing simple visual features and spatial location information^[76-80]. Therefore, the sustained activity changes usually observed in the frontoparietal cortex during working memory may reflect the representation of task-related and feature-specific information. Specifically, in working memory representation tasks, the precentral gyrus and postcentral gyrus, located in the frontal and parietal lobes respectively, are two important brain regions related to spatial memory load^[81]. Enhanced activity in the precentral gyrus is typically associated with the maintenance phase of working memory and may reflect an "internal motion" mode of the brain when maintaining working memory involving spatial and motion component information^[82]. For instance, in tasks requiring the retention of spatial location information or complex hand movement sequence memory, the precentral gyrus may be involved in simulating or maintaining these movement-related memory representations. The postcentral gyrus may participate in the preliminary processing and encoding of spatial information. Activity during the encoding phase suggests that the postcentral gyrus plays a role in converting sensory input into information that can be further processed and maintained by the working memory system. However, reduced activity in the postcentral gyrus during the retrieval phase may reflect a decreased reliance on preliminary sensory encoding regions during working memory retrieval or reconstruction^[83].

Panichello et al.^[84] found that attentional selection enhances working memory representations in the prefrontal and parietal cortices. This enhancement is more

pronounced in the lateral prefrontal cortex (LPFC), frontal eye fields (FEF), and parietal cortex after cue presentation. Excessive difference values during working memory retrieval are associated with a lack of enhancement in these brain regions. It is noteworthy that retrieving relevant working memory items does not weaken the memory representations of non-retrieved items, suggesting a mechanism different from competitive attention processes. The angular gyrus (AG) plays a role in visual search by forming visual-motor response associations between the target and the hand or fingers making judgments. The angular gyrus processes symbols and characters in visual information, helping to identify important elements in visual scenes^[85]. In visual search tasks, people need to identify specific targets (e.g., specific letters or shapes) from a complex background, requiring advanced processing and interpretation of visual information. Activity in the angular gyrus can facilitate the recognition of target features and speed up the search process. The angular gyrus is also associated with the regulation of spatial attention^[86], closely connected with the parietal and frontal regions. In visual search tasks, the angular gyrus may interact with these regions to regulate attention to specific spatial locations, thereby influencing search efficiency.

Based on sections 1.2 and 1.3, we understand that combining EEG and resting-state functional MRI (rs-fMRI) technologies can provide high temporal and spatial resolution brain activity information. This integrated analysis method can depict the temporal dynamics and spatial distribution of brain activity, offering a more comprehensive study of cognitive mechanisms in the brain^[87].

1.4 Research Significance

Everyday behavior largely relies on the continuous selection of relevant information, which includes responding to external environmental cues and manipulating internal representations in memory. In the field of attention allocation research, the literature often emphasizes the distinction between top-down (goal-directed) and bottom-up (stimulus-driven) attention selection mechanisms. We may consciously focus attention on sensory stimuli consistent with our goals, or our attention may be involuntarily drawn by external stimuli. Notably, this concept also applies to the internal domain, where the allocation of attention guides the selection of working memory representations. As Cowan^[88] noted, attention plays a crucial role in the activation, maintenance, and manipulation of representations in working memory. Recent studies highlight the bidirectional interaction between attention and working memory, indicating that working memory information is influenced by attention selection, particularly when salient stimuli match representations in working memory. Therefore, this study hypothesizes that the selection mechanism of salient stimuli in internal representations is similar to that of external stimuli.

The goal of this study is to explore whether goal-directed and stimulus-driven attention selection mechanisms also apply to the selection and competition of internal representations in working memory. To achieve this goal, this study employs a dual-task experimental paradigm combining working memory and visual search tasks, using electroencephalography (EEG) and resting-state functional magnetic resonance

imaging (rs-fMRI) as primary research tools. By using retro-cues to match relevant information of memory items, the study investigates how attention affects working memory representations. Specifically, this study aims to investigate three primary questions: (1) How do top-down and bottom-up attention control mechanisms affect working memory representation through the selection of salient stimuli in internal representations, as observed in behavioral data? (2) How do target memory enhancement and interference suppression alter EEG activity? (3) Which brain regions are associated with behavioral performance in enhancing and suppressing working memory representation, as revealed by resting-state fMRI data? Through this research, we aim to elucidate the brain activity mechanisms by which attention influences internal representations in working memory, providing new evidence for understanding their interactions.

Chapter 2: Experimental Design and Behavioral Data Analysis

2.1 Experimental Design and Data Collection

2.1.1 Dual-Task Experiment of Working Memory and Visual Search

This study employs a dual-task experiment combining working memory and visual search tasks to investigate the brain mechanisms underlying attention-guided processes in working memory representations. The experimental design is shown in Figure 2-1:

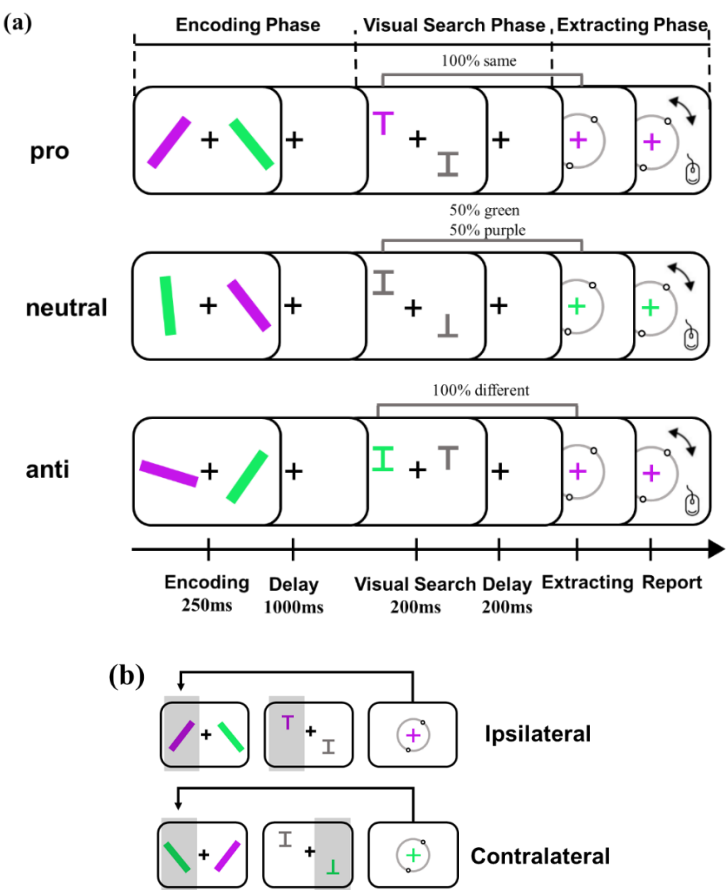


Figure 2-1 Schematic Diagram of the Dual-Task Experiment of Working Memory and Visual Search. (a) Flowchart of the experimental procedure under the pro, neutral, and anti conditions. (b) Illustration of ipsilateral and contralateral spatial positions relative to the target item.

The experiment was conducted using the Psychtoolbox toolkit in MATLAB^[89, 90].

Participants sat approximately 50 cm away from a display monitor (resolution: 1920 × 1080 pixels; refresh rate: 60 Hz). The memory task involved a green (RGB: 21, 235, 99) and a purple (RGB: 197, 21, 234) rectangular bar, each assigned a randomly allocated orientation from 180 possible directions. Each bar had a visual angle width of 5.7° and a height of 0.8°, located 5.7° to the left and right of the central fixation point.

The experiment began with the working memory encoding phase, starting with a 250 ms encoding screen displaying the memory items (purple and green bars) at random angles and a central black fixation cross. Participants needed to remember the angles of the memory items of different colors. This was followed by a 1000 ms delay screen with a fixed central cross. Next was the visual search phase, where participants saw a 200 ms visual search screen containing the letters "T" and "I." These letters randomly appeared in two of the four positions (upper left, lower left, upper right, and lower right) on the screen, always on opposite sides. The letter "T" was the target, appearing in either its upright or inverted orientation with a 50% probability in each trial. Participants had to determine the orientation of the letter "T": pressing the left mouse button for upright "T" and the right mouse button for inverted "T." The letter "I" served as a distractor. After the visual search screen, a central black fixation cross appeared for 1800 ms, during which participants had to respond to the target as quickly as possible.

Following this, the working memory retrieval phase began, where a memory probe appeared on the screen, consisting of a circle with a colored central cross and two

circular buttons. The colored cross indicated which memory item to report, with the cross color remaining until the report was completed. Participants had unlimited time to start reporting but needed to complete the report within 5000 ms after starting the response. The response dial appeared at a random angle, centered around the fixation cross, and had the same diameter as the rectangular memory items. A strip between the two circular buttons on the dial indicated the current reported angle. Participants used the computer mouse with their dominant hand (right hand) to report. They initiated the report by pressing the left mouse button and terminated the report by releasing the mouse button. After the response, the correct angle of the memory item was displayed as feedback, indicating the quality of the report (Figure 2-1(a)).

The experiment included three different blocks: "pro," "neutral," and "anti," distinguished by cues on the visual search screen. In the "pro" block, the target on the visual search screen served as the cue, with its color 100% matching the color of the memory item to be retrieved (e.g., a green cue indicating the green item). Conversely, in the "anti" block, the distractor color served as the cue, with its color 100% opposite to the color of the memory item to be retrieved (e.g., a green cue indicating the purple item). The "neutral" block contained no cues about the color of the memory item to be retrieved.

In the experiment, participants first had to remember the angles of the purple and green memory items, then perform the visual search task to determine the orientation of the letter "T" (left mouse button for upright, right mouse button for inverted), while

ignoring the distractor letter "I." Participants had to respond as quickly as possible within 1800 ms after the visual search screen appeared. After the visual search task, participants used the cue to report the angle of the memory item indicated by the color of the cross in the circle's center. The probabilities of the purple and green memory items appearing on the left or right side of the encoding screen were each 50%, as were the target and distractor items' positions and orientations on the visual search screen, and the reporting probabilities in the retrieval phase.

Before the formal experiment, participants practiced each condition ("pro," "neutral," "anti") to ensure an accuracy rate of over 80%. After practice, the formal experiment consisted of three conditions, each lasting about 9 minutes and containing 64 trials, for a total of 192 trials per participant. Participants were informed about the condition they would perform before each experimental block, and the three conditions were counterbalanced across participants. Regarding spatial positions, the relative position of the target item in the visual search task and the memory item to be reported was categorized as "ipsilateral" or "contralateral," as illustrated in Figure 2-1(b). Therefore, the experimental factors in this study were: 3 experimental conditions ("pro," "neutral," "anti") * spatial relative position ("ipsilateral," "contralateral").

2.1.2 EEG Data Collection

Thirty healthy right-handed participants (13 females) from the University of Electronic Science and Technology of China, aged 18-26 years (mean age 22.47 years, age range 20.57-24.3 years), participated in this experiment. All participants had no

history of neurological issues and had normal color vision. Each participant signed an informed consent form before the experiment. The study was approved by the Ethics Committee of the University of Electronic Science and Technology of China. The methods were conducted according to approved guidelines, and all experiments complied with the Declaration of Helsinki.

EEG signals were recorded using the eego™ mylab portable EEG recording system (ANT Neuro, Enschede, the Netherlands), which includes the eego™ EEG amplifier, a 64-channel waveguard™ EEG cap, and eego™ mylab acquisition and analysis software, as shown in Figure 2-2. The sampling rate was 1000 Hz, and impedance was kept below 10 k Ω ^[91]. The ground electrode was GND, and the reference electrode was the average of all channels.



Figure 2-2 The eego™ mylab Portable EEG Recording System

2.1.3 Resting-State fMRI Data Collection

Resting-state fMRI data were additionally collected from the same participants as the EEG experiment, excluding five participants who had metal implants. Ultimately, 25 healthy participants (10 females) fully participated in this experiment. They were all

students from the University of Electronic Science and Technology of China (mean age 22.2 years, age range 20.2-24.2 years). All participants were right-handed, had normal or corrected-to-normal vision, no metal implants in or on their bodies, no history of psychiatric disorders or family history of such, and no claustrophobia. Before the experiment, participants read and signed a written informed consent form, changed into experimental clothing, and both the experimenter and participants underwent metal detection to ensure no metal objects were brought into the MRI scanning room. The study was approved by the Ethics and Human Protection Committee of the Magnetic Resonance Imaging Research Center at the University of Electronic Science and Technology of China.

The 3.0 Tesla MRI scanner (GE, Discovery MR750) at the University of Electronic Science and Technology of China's Magnetic Resonance Center provided the equipment support for MRI data collection. Specific scanning parameters were as follows: Functional MRI (fMRI) scanning parameters: T2-weighted imaging sequence, repetition time (TR) of 2000 ms, echo time of 30 ms, flip angle of 90°, field of view (FOV) 240×240 mm², slice thickness of 3.75 mm, interslice gap of 0.6 mm, matrix size of 64×64, resolution of 3.75×3.75×3 mm³, interleaved scanning method, with a total of 43 slices. The scanning duration for the resting state fMRI data was 6'50". Structural MRI scanning parameters: T1-weighted imaging sequence, repetition time of 5.96 ms, echo time of 1.96 ms, flip angle of 90°, field of view (FOV) 256×256 mm², matrix size of 256×256, single voxel size of 1×1×1 mm³, with a total of 156 slices. The scanning

duration for the structural MRI data was 3'50''.

2.2 Behavioral Data Analysis

After excluding behavioral data outliers exceeding three standard deviations, the study analyzed data from the 30 participants in the behavioral (EEG) experiment across three behavioral tasks: (1) The mean angular deviation between the reported memory item and the target memory item during the working memory retrieval phase. To maintain the maximum angular deviation within a 90° range, the following formula was used:

$$\text{Angular Deviation} = |180 \times (90 - |\text{Target Angle} - \text{Reported Angle}|) - |\text{Target Angle} - \text{Reported Angle}|$$

(2) The mean reaction time (RT) for judging the target item in the visual search task. (3) The mean accuracy (ACC) for judging the target item in the visual search task. Behavioral performance differences were calculated using repeated measures analysis of variance (ANOVA) in SPSS software. The main factors were: (1) Condition: pro, neutral, and anti. (2) Position: ipsilateral and contralateral

The results of the behavioral data analysis are shown in Figure 2-3. Repeated measures ANOVA revealed a significant main effect of condition on angular deviation ($F(1, 29) = 13.690, p < 0.001, \eta^2_p = 0.321$). The mean angular deviation in the pro condition was significantly lower than in the neutral condition ($t(29) = -3.609, p = 0.001$) and the anti condition ($t(29) = -5.665, p < 0.001$), as shown in Figure 2-3(a). Next, the study explored the impact of ipsilateral and contralateral positions on angular deviation.

Repeated measures ANOVA revealed an interaction between condition ("pro," "neutral," "anti") and position ("ipsilateral," "contralateral") ($F(2, 58) = 3.590, p = 0.034, \eta^2p = 0.110$), as shown in Figure 2-3(b). Notably, this interaction was driven by the difference in mean angular deviation between ipsilateral and contralateral positions in the anti condition ($t(29) = -2.190, p = 0.037$).

Additionally, the study calculated the mean reaction time for the visual search task, revealing a significant main effect of condition ($F(2, 58) = 5.885, p = 0.005, \eta^2p = 0.303$), as shown in Figure 2-3(c). Specifically, both the pro ($t(29) = 2.411, p = 0.022$) and anti conditions ($t(29) = 3.470, p = 0.002$) had slower reaction times compared to the neutral condition. Significant differences were found between the ipsilateral positions in the anti and neutral conditions ($t(29) = 3.279, p = 0.018$) and between the contralateral positions in the anti and neutral conditions ($t(29) = 3.442, p = 0.012$).

The study also calculated the mean accuracy for the visual search task. The results showed a significant difference between the pro and neutral conditions ($t(29) = -2.799, p = 0.027$), as shown in Figure 2-3(d).

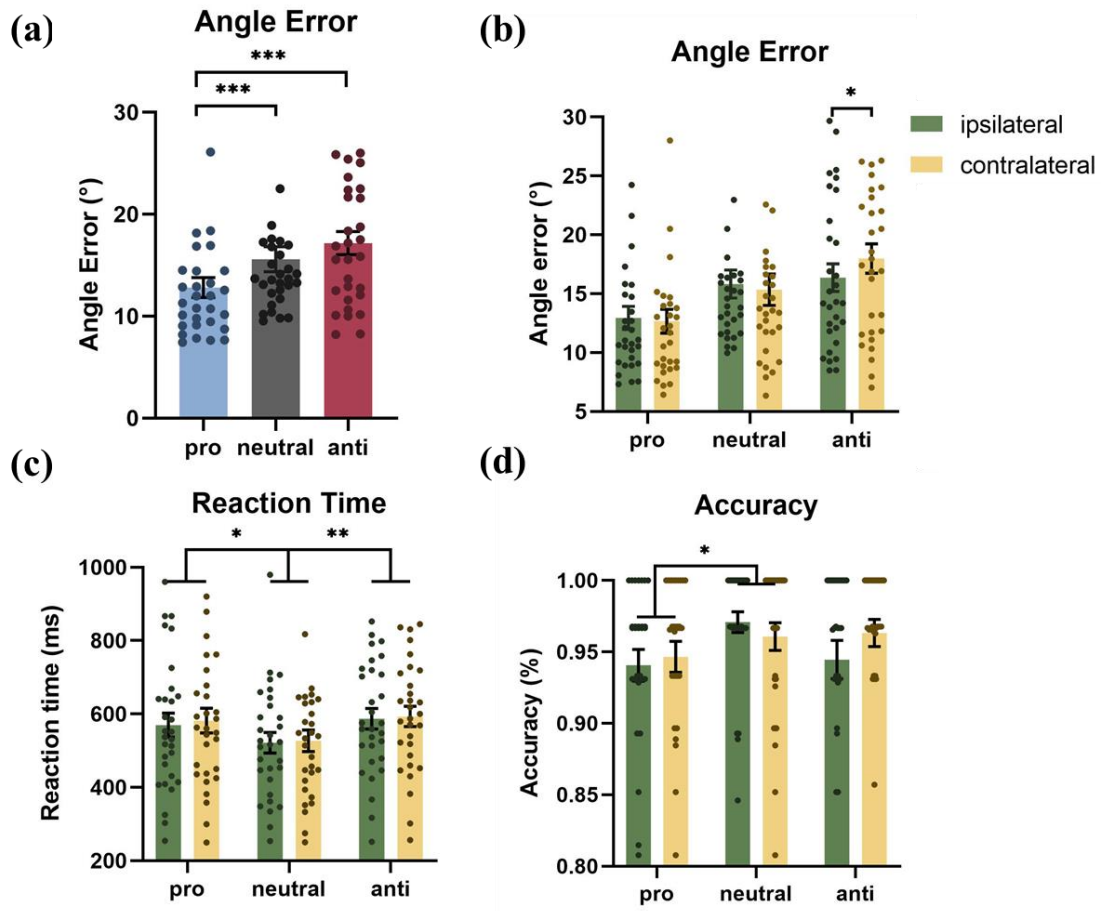


Figure 2-3 Behavioral Results of Angular Deviation, Reaction Time, and Accuracy. (a) Mean angular deviation in the working memory task under the condition factors ("pro," "neutral," "anti"). (b) Mean angular deviation in the working memory task under the condition factors ("pro," "neutral," "anti") and position factors ("ipsilateral," "contralateral"). (c) Mean reaction time in the visual search task under the condition and position factors. (d) Mean accuracy in the visual search task under the condition and position factors. Note: Error bars represent the standard deviation of the mean. * indicates $p < 0.05$ after Bonferroni correction^[92], ** indicates $p < 0.01$ after Bonferroni correction, *** indicates $p < 0.001$ after Bonferroni correction.

2.3 Discussion of Behavioral Results

In summary, the behavioral data results from this study indicate that in the working memory task, cues in the pro condition enhance working memory representations,

while cues in the anti condition disrupt them. Specifically, the mean angular deviation was 12.80 degrees in the pro condition and 17.17 degrees in the anti condition. When considering the positional factor, significant differences were observed between ipsilateral and contralateral positions in the anti condition, suggesting that spatial information affects working memory representations, revealing a complex interaction between condition and position. Specifically, the mean angular deviation was 16.36 degrees for ipsilateral and 17.98 degrees for contralateral positions in the anti condition.

In the visual search task, cues had a disruptive rather than inhibitory effect, with the fastest reaction times and highest accuracy observed in the neutral condition without cues. Specifically, the mean reaction time was 524.23 ms in the neutral condition, 51.54 ms faster than the pro condition, and 65.70 ms faster than the anti condition. The mean accuracy was 96.58% in the neutral condition, 2.22% higher than the pro condition, and 1.18% higher than the anti condition.

The behavioral data results from both the working memory task and the visual search task indicate that the experiment successfully simulated the different effects of top-down and bottom-up attention mechanisms on working memory representations.

2.4 Chapter Summary

This chapter detailed the behavioral results regarding the impact of attention on working memory representations. The results indicate that in the working memory task, cues in the pro condition significantly enhanced working memory representations,

while cues in the anti condition caused a disruptive effect, as evidenced by the comparison of mean angular deviations. Additionally, analysis considering the positional factor revealed that spatial information had a significant impact on working memory representations in the anti condition, further indicating a complex interaction between condition and position.

In the visual search task, the presence of cues interfered with task performance, with the fastest reaction times and highest accuracy observed in the neutral condition. This result highlights more efficient information processing in the absence of cues. In summary, different attention mechanisms (top-down vs. bottom-up) have significantly different effects on working memory representations and visual search task performance.

In the next chapter, the study will build on the current research to further explore ERP results. By analyzing ERP signals, the study aims to reveal how top-down and bottom-up attention mechanisms affect information processing at the neurophysiological level.

Chapter 3: Investigating the Influence of Attention on Working Memory Representations through Event-Related Potential Analysis

The behavioral results in Chapter 2 indicate that salient stimuli as positive cues facilitate the selection of internal representations in working memory. Additionally, spatial information impacts working memory representations, with internal representations at salient distractor locations being suppressed. The experimental design successfully simulated top-down and bottom-up attention selection processes. Therefore, this chapter will utilize event-related potential (ERP) data from EEG to capture the precise instantaneous changes in the brain during the temporally dynamic experimental process. It aims to study the neural signal variations and cognitive processes involved in the selection of working memory representations via top-down and bottom-up attention mechanisms.

3.1 Data Preprocessing

EEG data were preprocessed with functions from the EEGLAB^[93] toolbox in MATLAB. The preprocessing steps included re-referencing to the average of all electrodes, applying a band-pass filter between 0.1 Hz and 30 Hz, performing Independent Component Analysis (ICA) to remove artifacts, detrending to eliminate linear trends, identifying and replacing bad electrode channels, and removing bad trials. The data were then segmented according to different experimental stages (setting the

start time of each task phase as 0ms): the working memory encoding phase (0ms to 1250ms), the visual search phase (0ms to 2000ms), and the working memory retrieval phase (0ms to 1000ms). A 200ms pre-stimulus baseline correction was applied to each task phase.

Furthermore, the experiment was divided into six conditions based on the experimental factors: pro_ips (ipsilateral in the pro condition), pro_contr (contralateral in the pro condition), neutral_ips (ipsilateral in the neutral condition), neutral_contr (contralateral in the neutral condition), anti_ips (ipsilateral in the anti-condition), and anti_contr (contralateral in the anti-condition). Waveform plots were then generated for these six conditions, with time (ms) on the x-axis and amplitude (μ V) on the y-axis. The plots were color-coded as follows: solid blue line for pro_ips, dashed blue line for pro_contr, solid gray line for neutral_ips, dashed gray line for neutral_contr, solid red line for anti_ips, and dashed red line for anti_contr.

Based on the distribution of electrodes on the scalp, this study selected several individual electrodes for ERP analysis. For the anterior region of the brain: AF3, AF4, F3, F4, FC3, FC4, C3, and C4; for the posterior region: CP3, CP4, P3, P4, PO5, PO6, O1, and O2; and for the midline: Fz, FCz, Cz, Pz, and Poz to calculate the amplitudes at different stages, as shown in Figure 3-1.

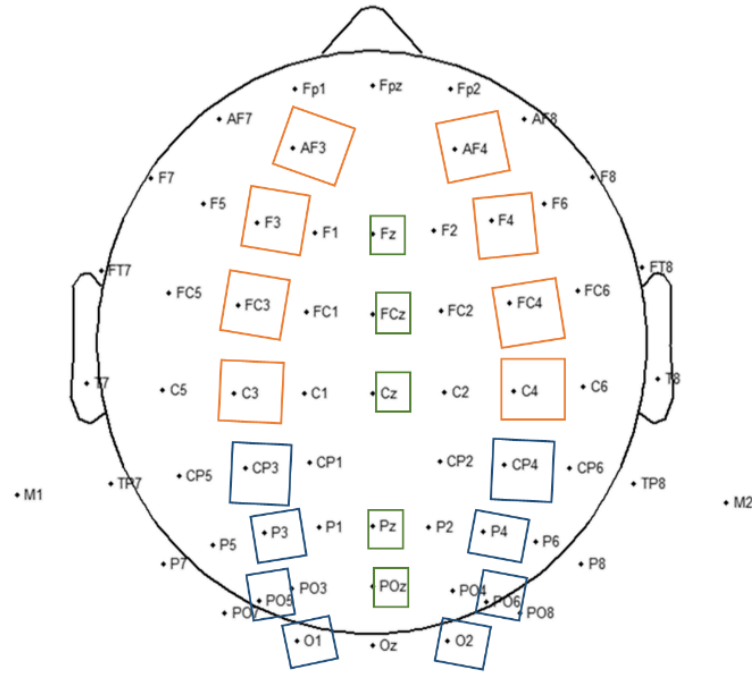


Figure 3-1 Distribution location of selected electrodes in the brain

3.2 Statistical analysis of data

3.2.1 Analysis of event-related potentials in the encoding phase of working memory

During the working memory encoding phase (0ms-1250ms), the P1 component was observed at the posterior electrode CP4 (Figure 3-2 (a)) within the time window of 100ms-150ms. Repeated measures ANOVA results indicated a significant main effect among the three conditions at the CP4 electrode ($F_{(2, 58)} = 3.403, p = 0.040, \eta^2p = 0.105$). Specifically, there was a significant difference between the pro condition and the neutral condition ($t_{(29)} = 2.912, p = 0.021$) (Figure 3-2 (c)). Figure 3-2 (b) shows the average topographical map of the P1 component within the 100ms-150ms time window during the working memory encoding phase.

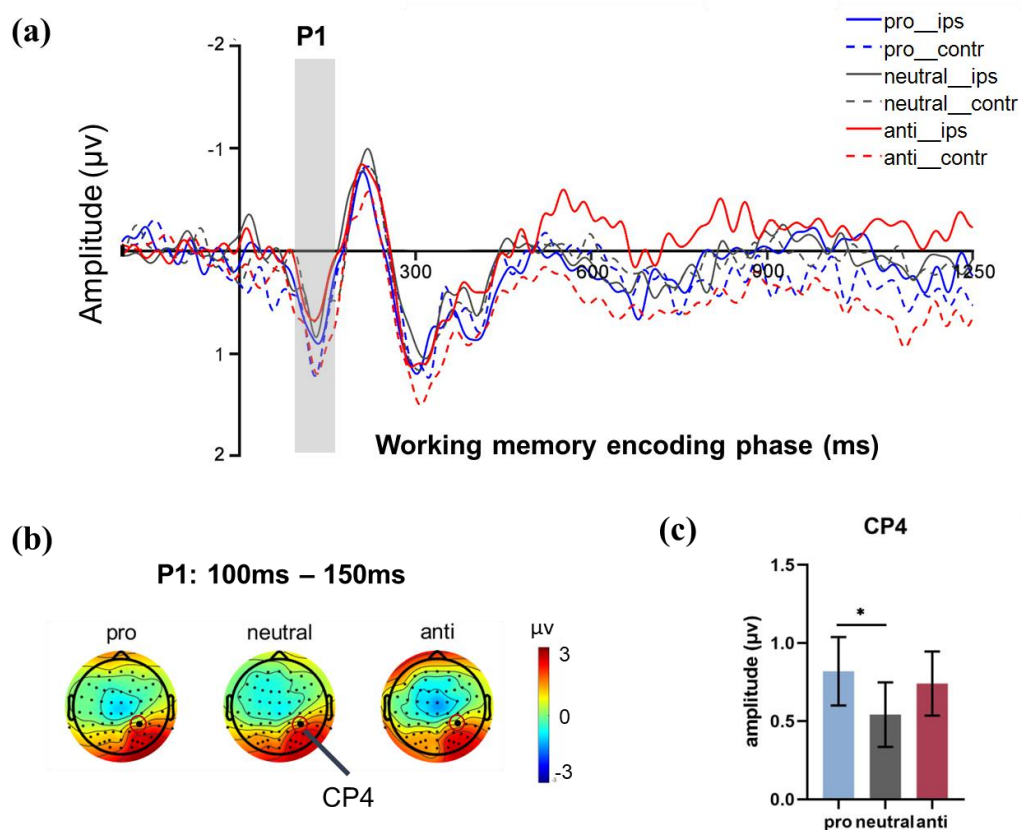


Figure 3-2 P1 component in the encoding phase of working memory. (a) Waveform plots of P1 component electrodes in pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) Average topography of P1 component from 100ms to 150ms, and (c) Wave amplitude histograms of CP4 electrodes for three conditions. Note: Error lines indicate the standard deviation of the mean values. * Represents $p < 0.05$ after Bonferroni correction.

During the working memory encoding phase, the N3 component was observed at the anterior electrodes (left side: F3, Fp1, AF3; right side: AF4, F4, FC4, C4; midline: Fpz, Fz, FCz) within the time window of 300ms-400ms (Figure 3-3 (a)). Repeated measures ANOVA results indicated significant main effects among the three conditions at the F3 electrode ($F_{(1, 29)} = 3.370, p = 0.041, \eta^2 p = 0.104$) (Figure 3-3 (c)) and the F4

electrode ($F_{(1, 29)} = 4.073, p = 0.022, \eta^2p = 0.123$) (Figure 3-3 (d)). Specifically, at the F3 electrode, there was a significant difference between the pro and neutral conditions ($t_{(29)} = -3.227, p = 0.003$), and at the F4 electrode, there was a significant difference between the pro and anti-conditions ($t_{(29)} = -2.397, p = 0.023$). Figure 3-3 (b) shows the average topographical map of the N3 component within the 300ms-400ms time window during the working memory encoding phase.

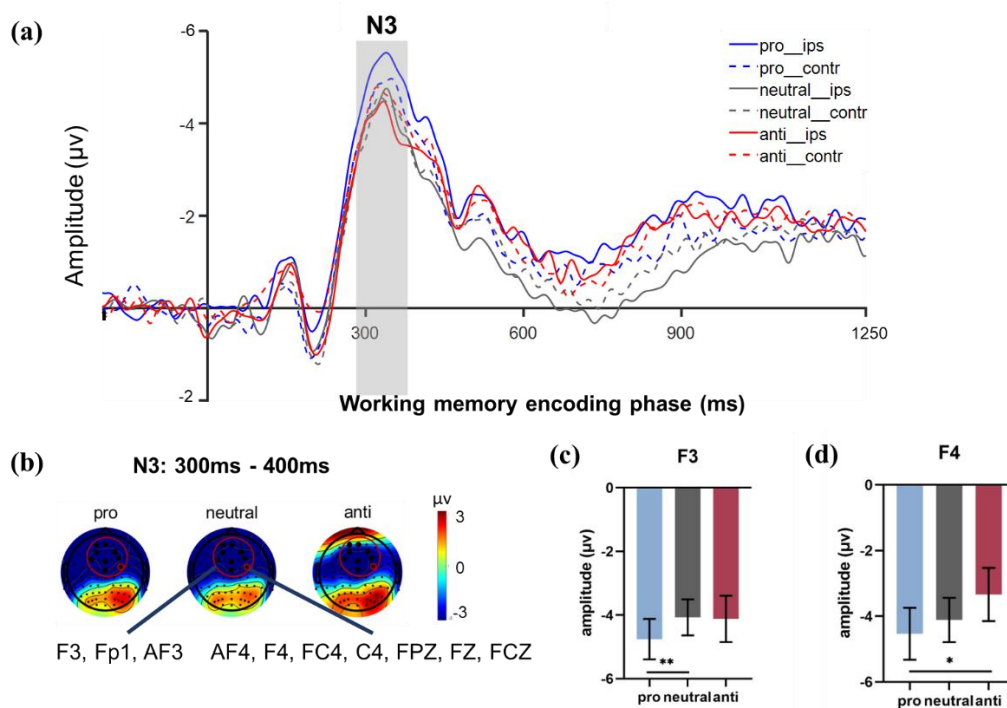


Figure 3-3 N3 components in the encoding phase of working memory. (a) Waveform plots of the N3 component under pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) Average topographic plots of the N3 component from 300ms to 400ms, (c) Wave amplitudes of the F3 electrode for three conditions, (d) Wave amplitudes of the F4 electrode for three conditions at the F4 electrode. Note: Error lines indicate the standard deviation of the mean values. * Represents $p < 0.05$, ** represents $p < 0.01$ after Bonferroni correction.

3.2.2 Analysis of event-related potentials in the visual search stage

The visual search phase spanned from 1250ms to 3250ms, with 1250ms set as the zero point for plotting purposes. The N1 component was observed at anterior electrodes (left side: F3, Fp1, AF3; right side: Fp2, AF4, C4; midline: Fpz) (Figure 3-4 (a)) within the time window of 110ms-190ms. Repeated measures ANOVA results indicated interaction effects between condition and position at the F3 electrode ($F_{(2, 58)} = 4.289$, $p = 0.018$, $\eta^2p = 0.129$) (Figure 3-4 (c)) and AF4 electrode ($F_{(2, 58)} = 3.834$, $p = 0.027$, $\eta^2p = 0.117$) (Figure 3-4 (d)). Specifically, at the F3 electrode, significant differences were found between ipsilateral and contralateral positions in the neutral condition ($t_{(29)} = -2.287$, $p = 0.030$) and anti condition ($t_{(29)} = 2.345$, $p = 0.026$), driving the interaction. At the AF4 electrode, a significant difference between ipsilateral and contralateral positions in the pro condition also led to the interaction effect between condition and position ($t_{(29)} = -2.196$, $p = 0.036$). Additionally, a significant main effect of condition was observed at the Fpz electrode ($F_{(1, 29)} = 3.480$, $p = 0.037$, $\eta^2p = 0.107$), primarily due to the significant difference between the pro and anti conditions ($t_{(29)} = -2.609$, $p = 0.014$) (Figure 3-4 (e)). Figure 3-4 (b) shows the average topographical map of the N1 component within the 110ms-190ms time window during the visual search phase.

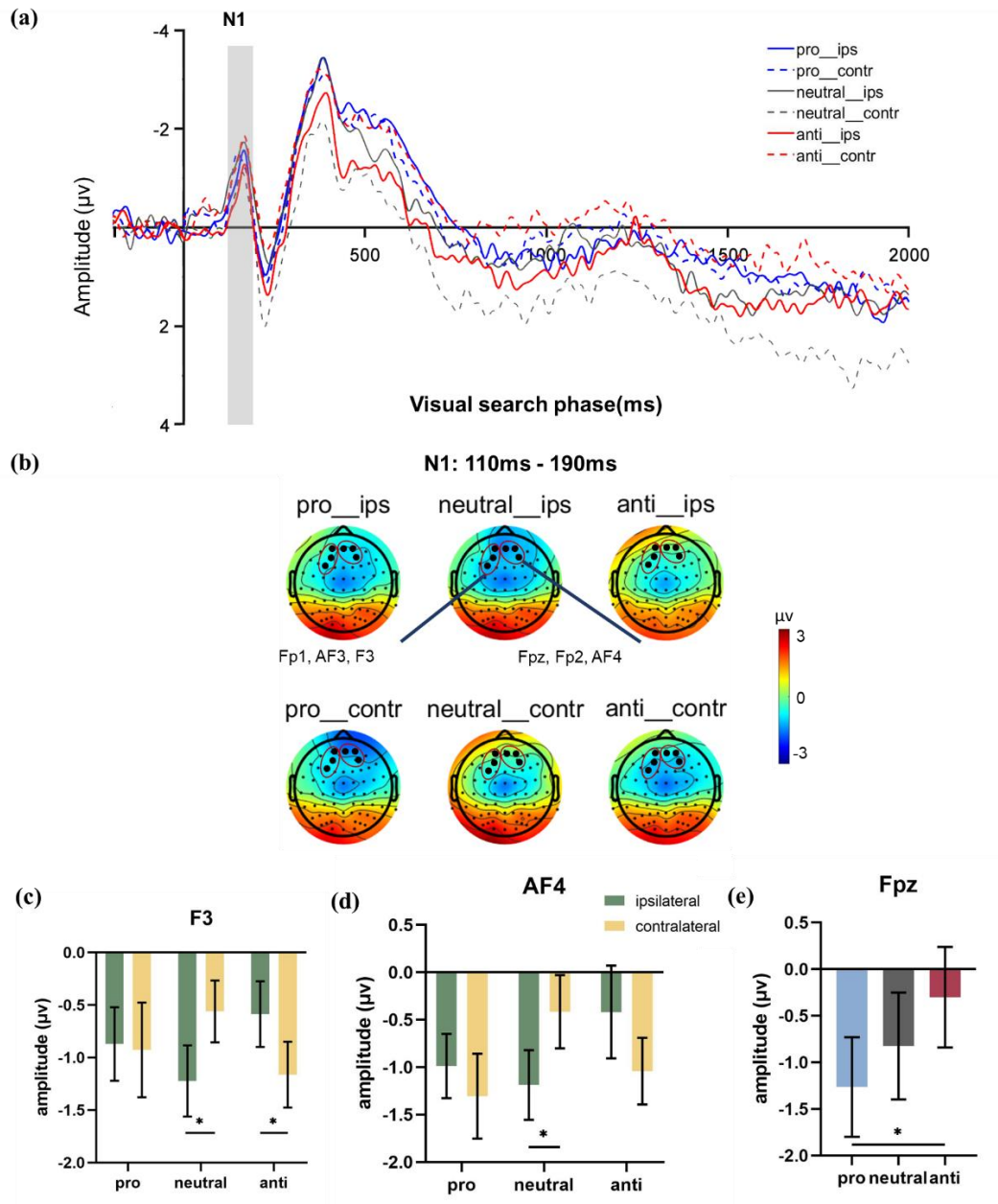


Figure 3-4 N1 components in the visual search phase. (a) Waveform maps of the N1 component in the pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) Average topography of the N1 component from 110ms to 190ms, (c) Wave amplitude of the F3 electrode in six conditions, (d) AF4 electrode wave amplitude in six conditions, (e) Fpz electrode wave amplitude in three conditions. Note: Error lines indicate the standard deviation of the mean. * Represents $p < 0.05$ after Bonferroni correction.

Similarly, the P2 component was observed at anterior electrodes (left side: Fp1, AF3, F3, FC3, C3; right side: Fpz, Fp2, AF4, F4, FC4, C4) (Figure 3-5 (a)) within the time window of 190ms-280ms. Repeated measures ANOVA results indicated interaction effects between condition and position at the F3 ($F_{(2, 58)} = 10.051, p < 0.001, \eta^2p = 0.419$) (Figure 3-5 (c)) and F4 ($F_{(2, 58)} = 5.812, p = 0.005, \eta^2p = 0.167$) electrodes (Figure 3-5 (d)). Specifically, significant differences were found between ipsilateral and contralateral positions in the neutral condition ($t_{(29)} = -3.819, p < 0.001$) and the anti condition ($t_{(29)} = -3.232, p = 0.003$) at the F3 electrode. Additionally, there were significant differences between the contralateral positions of the neutral and anti conditions ($t_{(29)} = 3.894, p = 0.003$). At the F4 electrode, significant differences were found between ipsilateral and contralateral positions in the neutral condition ($t_{(29)} = -3.315, p = 0.003$) and the anti condition ($t_{(29)} = 2.064, p = 0.048$). There were also significant differences between the contralateral positions of the neutral and anti conditions ($t_{(29)} = 2.811, p = 0.027$). Figure 3-5 (b) shows the average topographical map of the P2 component within the 190ms-280ms time window during the visual search phase.

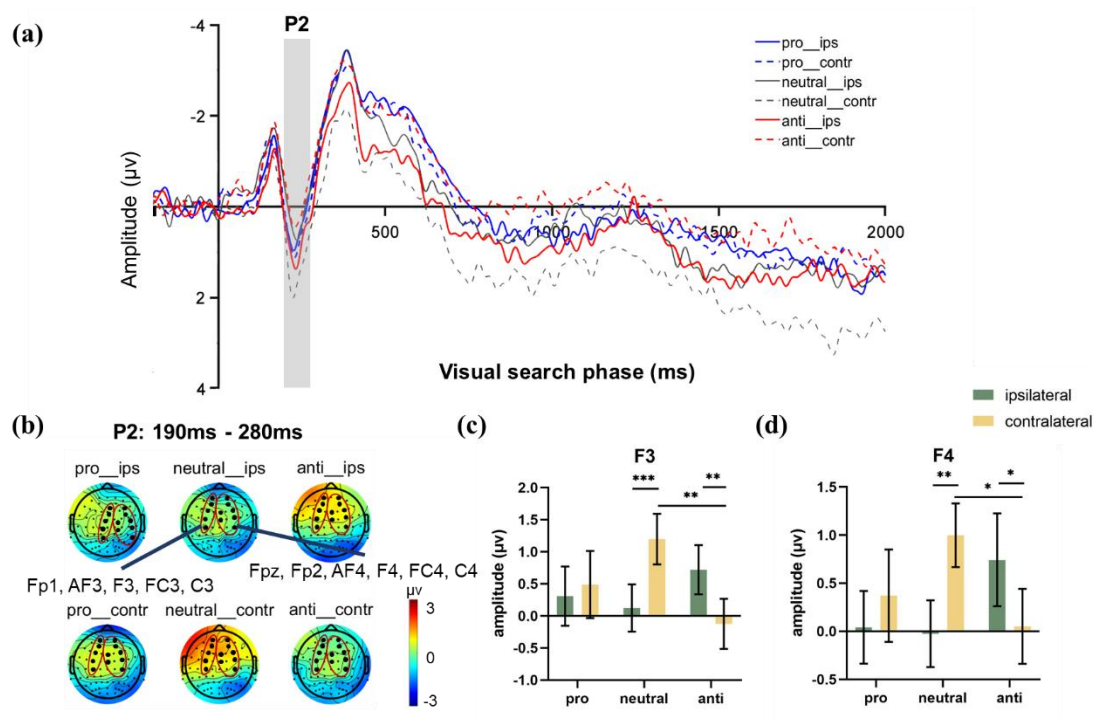


Figure 3-5 P2 components in the visual search phase. (a) Waveform maps of the P2 component in the pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti-contr conditions, (b) Average topography of the P2 component from 190ms to 280ms, (c) Wave amplitude of the F3 electrode in the six conditions, (d) F4 electrode wave amplitude under six conditions. Note: Error lines represent the standard deviation of the mean. * Represents $p < 0.05$ after Bonferroni correction, ** represents $p < 0.01$ after Bonferroni correction, and *** represents $p < 0.001$ after Bonferroni correction.

Likely, the N3 component was observed at anterior electrodes (left side: Fp1, AF3, F3, FC3, C3; right side: Fp2, AF4, F4, FC4, C4; midline: Fpz) (Figure 3-6 (a)) within the time window of 310ms-410ms. Repeated measures ANOVA results indicated significant interaction effects between condition and position at the F3 ($F_{(2, 58)} = 6.970$, $p = 0.002$, $\eta^2_p = 0.194$) (Figure 3-6 (c)) and AF4 ($F_{(2, 58)} = 6.877$, $p = 0.002$, $\eta^2_p = 0.192$) electrodes. Specifically, at the F3 electrode, significant differences were found between

ipsilateral and contralateral positions in the neutral condition ($t_{(29)} = -3.306, p = 0.003$) and the anti condition ($t_{(29)} = 2.127, p = 0.042$). There were also significant differences between the contralateral positions of the neutral and anti conditions at the F3 electrode ($t_{(29)} = 3.106, p = 0.012$). At the AF4 electrode, significant differences were found between ipsilateral and contralateral positions in the neutral condition ($t_{(29)} = -3.266, p = 0.003$) and the anti condition ($t_{(29)} = 2.110, p = 0.044$), as well as between the ipsilateral positions of the neutral and anti conditions ($t_{(29)} = 3.252, p = 0.012$). Figure 3-6 (b) shows the average topographical map of the N3 component within the 310ms-410ms time window during the visual search phase.

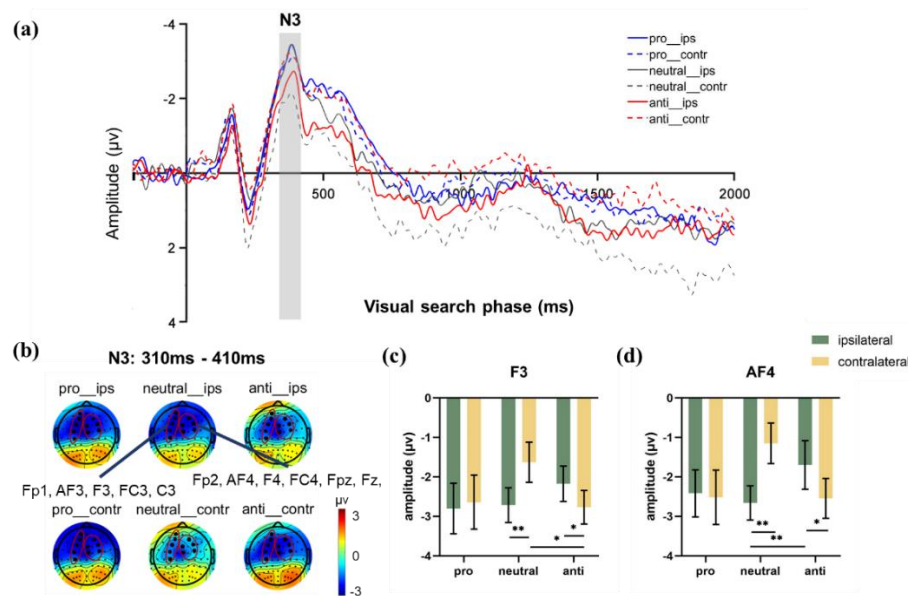


Figure 3-6 N3 components in the visual search phase. (a) Waveform maps of the N3 component in the pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) Average topography of the N3 component from 310 ms to 410 ms, (c) Wave amplitude of the F3 electrode in the six conditions, (d) AF4 electrode wave amplitude in six conditions. Note: Error lines represent the standard deviation of the mean. * Represents $p < 0.05$ after Bonferroni correction, ** represents $p < 0.01$ after Bonferroni correction, and *** represents $p < 0.001$ after Bonferroni correction.

This study also calculated two well-known components in the visual search task, N2pc (400ms-450ms) and Pd (450ms-470ms). The calculation was done by subtracting the ipsilateral condition from the contralateral condition for the three conditions (pro_contr - pro_ips, neutral_contr - neutral_ips, anti_contr - anti_ips) to obtain the difference values. Taking the posterior electrode PO8 as an example (Figure 3-7 (a)), repeated measures ANOVA results were not significant. However, Figure 3-7 (b) shows that the N2pc component had the largest contralateral-ipsilateral difference in the anti condition, followed by the pro condition, with the neutral condition having the smallest difference. Figure 3-7 (e) similarly indicates that the Pd component had the largest contralateral-ipsilateral difference in the anti condition, followed by the pro condition, with the neutral condition having the smallest difference. Figures 3-7 (b) and 3-7 (d) show the average topographical maps of the N2pc (400ms-450ms) and Pd (450ms-470ms) components within their respective time windows.

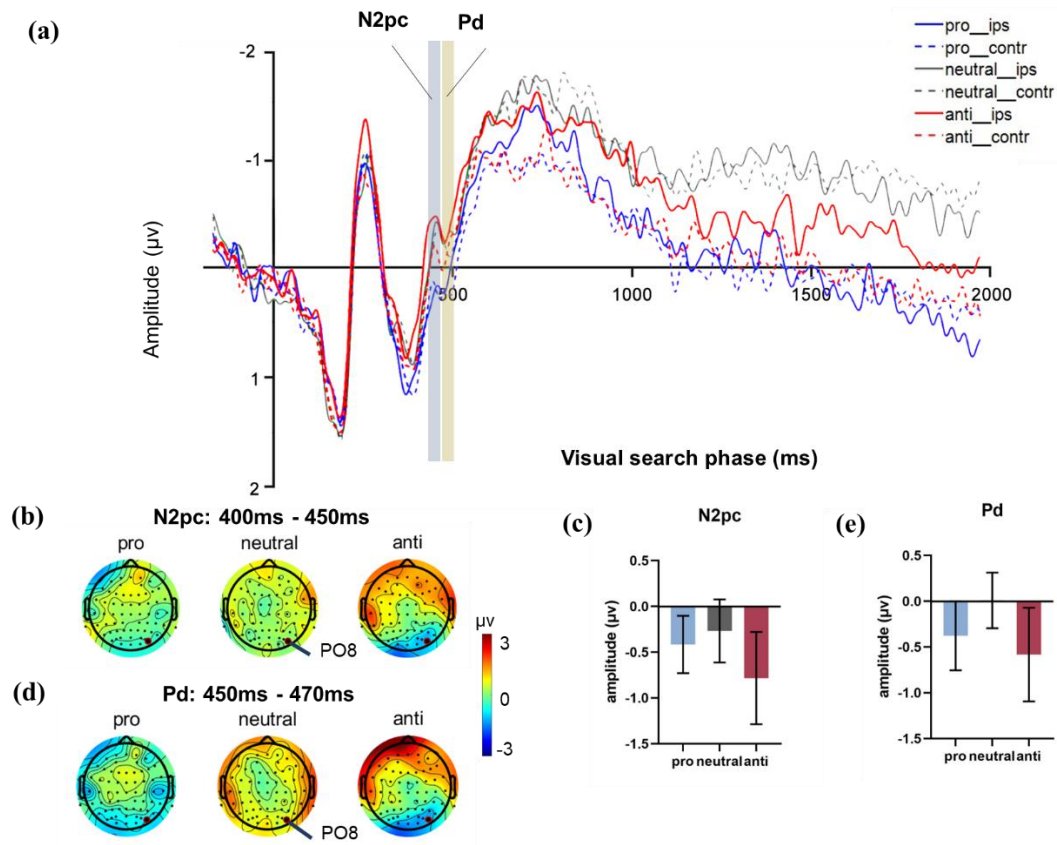


Figure 3-7 N2pc and Pd components in the visual search phase. (a) Waveforms of the N2pc and Pd components in the pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) average topographic maps of the N2pc component from 400ms to 450ms, (c) wave amplitudes of the PO8 electrode in the three conditions, (d) Average topography of the Pd component from 450ms to 470ms, (e) Wave amplitude of the PO8 electrode under three conditions. Note: Error lines indicate the standard deviation of the mean values.

3.2.3 Analysis of event-related potentials in the extraction phase of working memory

The working memory retrieval phase spanned from 3250ms to 4250ms, with 3250ms set as the zero point for plotting purposes. The P2 component was observed at

the posterior electrodes POz and O1 (Figure 3-7 (a)) within the time window of 130ms-200ms. Repeated measures ANOVA results indicated a significant interaction between condition and position at the POz electrode ($F_{(2, 58)} = 2.951, p = 0.004, \eta^2p = 0.170$) (Figure 3-7 (c)). This interaction was primarily driven by differences between ipsilateral and contralateral positions in the pro condition ($t_{(29)} = 2.424, p = 0.022$) and the anti condition ($t_{(29)} = -2.535, p = 0.017$). A similar interaction effect was observed at the O1 electrode ($F_{(2, 58)} = 4.353, p = 0.017, \eta^2p = 0.131$) (Figure 3-7 (d)), mainly due to differences between ipsilateral positions in the neutral and anti conditions ($t_{(29)} = -2.631, p = 0.013$). Figure 3-7 (b) shows the average topographical map of the P2 component within the 190ms-280ms time window during the visual search phase.

Within the same 130ms-200ms time window, the N2 component was observed at the anterior electrode FCz. Figure 3-8 (a) shows the waveform, and Figure 3-8 (b) shows the average topographical map within this time window. Repeated measures ANOVA revealed a significant main effect among the three conditions ($F_{(2, 58)} = 4.742, p = 0.012, \eta^2p = 0.141$) (Figure 3-8 (c)), with significant differences between the pro and neutral conditions ($t_{(29)} = 2.910, p = 0.007$) as well as between the pro and anti conditions ($t_{(29)} = 2.885, p = 0.007$).

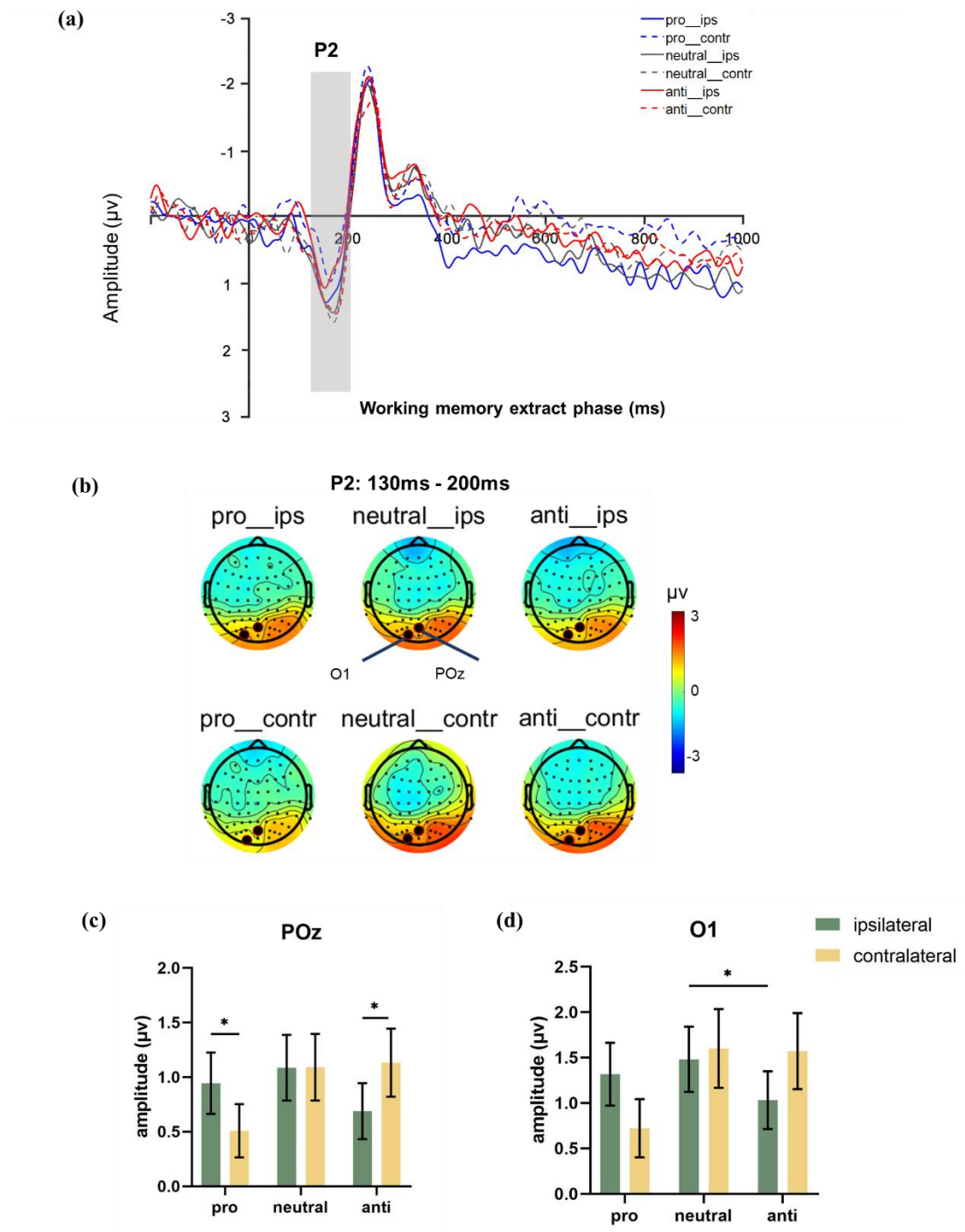


Figure 3-8 P2 components in the working memory extraction phase. (a) Waveform maps of the P2 component in the pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) Average topography of the P2 component from 130ms to 200ms, (c) Wave amplitude of the POz electrode in the six conditions, (d) O1 electrode wave amplitude in six conditions. Note: Error lines represent the standard deviation of the mean. *Represents $p < 0.05$ after Bonferroni correction.

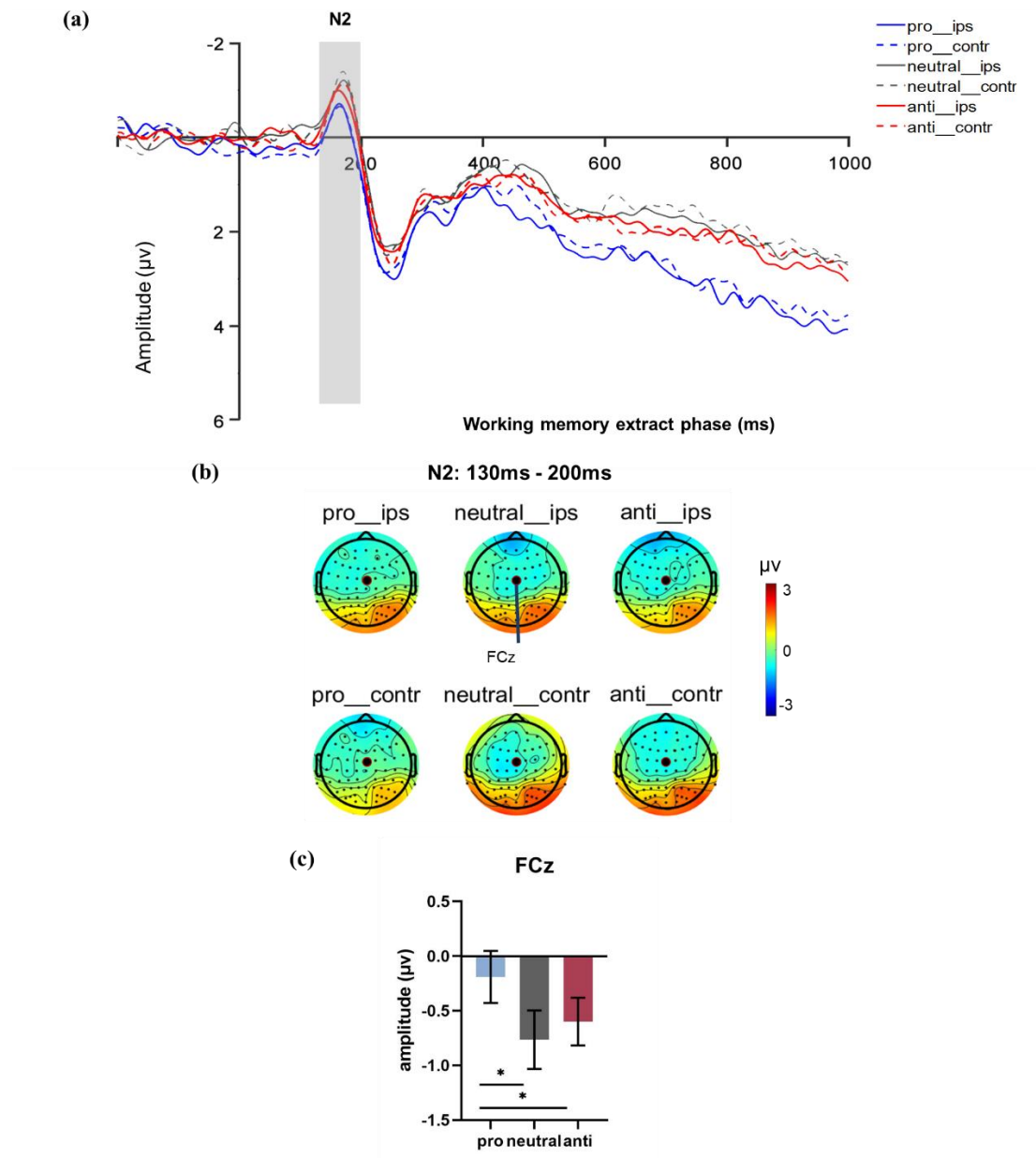


Figure 3-9 N2 components in the working memory extraction phase. (a) Waveform maps of the N2 component in the pro_ips, pro_contr, neutral_ips, neutral_contr, anti_ips, and anti_contr conditions, (b) Average topography of the N2 component from 130ms to 200ms, and (c) Wave amplitude of the FCz electrode in the three conditions. Note: Error lines indicate the standard deviation of the mean. *Represents Bonferroni-corrected $p < 0.05$

3.3 Discussion of event-related potential results

The event-related potential (ERP) data analysis in this study indicates that the brain regions involved in attention-guided working memory tasks are primarily distributed in the frontal and parietal areas, with some distribution also observed in the occipital region. This finding is consistent with previous research, which has shown that the frontoparietal network is related to the allocation of attentional resources for internal representations in working memory^[94].

During the working memory encoding phase, the P1 component was observed in the occipital region. It has been found that P1 can be influenced by top-down modulation of attention-driven visual processing^[95], and stimuli presented at relevant positions can elicit a larger P1 component^[51]. These amplitude modulations are known as the attentional effects on P1. Compared to the baseline neutral condition, the pro condition exhibited a larger P1 amplitude, suggesting that the salient stimulus in the pro condition attracted more attention as a form of sensory gain control. This gain modulation likely carries through to subsequent task stages. The N3 component observed in the frontal region during the working memory encoding phase suggests that the brain starts processing information from external stimuli and related task demands during this period^[60-62]. Trials with correct working memory retrieval typically elicit a larger N3 component^[96]. This pattern aligns with the trends in the behavioral data, where the pro condition showed the smallest angular deviation, followed by the neutral condition, and the anti condition showed the largest deviation. When participants

successfully perform the task and correctly identify information, the ERP response of the N3 component is more pronounced, and their behavioral performance is better. Thus, during the time window of the N3 component, the brain encodes information to facilitate more effective retrieval and identification in subsequent memory tasks.

In the visual search task, N1, P2, and N3 components were observed in the frontoparietal regions. The N1 component during the visual search stimulus presentation phase indicates the early stages of sensory stimulus processing and attention focus and orientation^[97, 98], and it is believed to reflect the involvement of feature-based attention processing^[99]. The results of this study show that compared to the baseline neutral condition, the ipsilateral position of the salient stimulus in the anti condition exhibited a larger N1 amplitude. This suggests that the brain allocated more processing resources to this position during the visual search task, leading to increased N1 activity. This indicates that the location of the salient stimulus in the anti condition induced greater bottom-up attention capture.

The P2 component during the visual search response phase serves to index working memory in the visual search task^[55, 56], matching incoming visual information with stored target information in working memory. Compared to the baseline neutral condition, the ipsilateral target in the anti condition elicited a larger P2 component, indicating a higher working memory load at this position. This reflects stronger early short-term memory storage^[100] and attention resource allocation, indicating a greater top-down effect.

The N3 component observed during the visual search response phase exhibited trends similar to the N1 component during the visual search stimulus presentation phase. The ipsilateral position of the salient stimulus in the anti condition had a larger N3 amplitude compared to the baseline neutral condition. However, as studied by Kotchoubey et al^[101], although N1 and N3 have similar distributions, their meanings differ. If an unrelated salient stimulus matches the current expectation, it ends with the P2 component after stimulus onset, but if it does not match the expectation, it leads to a larger negative deflection in the N3 component. The N3 component mainly appears when the interaction between the stimulus and spatial location is involved, rather than when the stimulus primarily guides the process.

Additionally, this study analyzed two well-known components in the visual search task, N2pc and Pd, in the parieto-occipital region. Both were calculated by subtracting the ipsilateral target from the contralateral target. N2pc indicates rapid reallocation of attention to task-relevant information during visual search, with larger amplitudes when the target attracts more attention^[65, 102]. The Pd component indexes activity related to inhibiting irrelevant or distracting information. When distractors are successfully inhibited, the Pd amplitude is larger^[102, 103]. However, no significant differences between conditions were observed in this study, only trends. Specifically, conditions with salient stimuli attracted more attention. The neutral condition without salient stimuli showed stronger distractor inhibition, and distractors in the anti condition were more challenging to inhibit. In a single visual search task, inhibiting distractors can

trigger top-down attention mechanisms, leading to shorter search reaction times^[104-106].

However, in this study, conditions with salient distractors resulted in slower reaction times, possibly related to the working memory task, further illustrating the interaction between attentional selection mechanisms and internal representations in working memory.

In the working memory retrieval phase, P2 and N2 components were observed in the parieto-occipital region, reflecting changes in visual attention related to task demands^[63, 107-109]. The P2 component in the occipital region is interpreted as a top-down process to match expected information, with non-matching items deviating from the matching rule, thereby triggering higher task demands^[107, 110]. This indicates that more attention resources were attracted to positions with salient stimuli when indexing memory information, reflecting bottom-up attention capture. The larger N2 amplitude in the frontocentral region reflects the need for more cognitive control and conflict monitoring when processing information that does not match memory. It is an ERP component of active interference resolution^[111, 112] and is considered related to the inhibition of irrelevant information^[112]. Therefore, compared to the pro condition, the neutral and anti conditions elicited a stronger top-down mechanism during working memory retrieval to inhibit irrelevant distractor information.

3.4 Chapter Summary

This chapter describes the results of the event-related potential (ERP) data analysis,

revealing that the role of salient stimuli in the selection of internal representations varies according to their role in the search task. Even though the brain is initially drawn to salient stimuli, resulting in bottom-up attention capture, fulfilling task-related demands induces a stronger top-down effect. Bottom-up effects are primarily observed in the frontoparietal regions, while top-down effects are more prominent in the parieto-occipital regions.

During the working memory encoding phase, the P1 component in the occipital region reflects sensitivity to attention. Notably, in the pro condition, a significant increase in P1 amplitude was observed, indicating bottom-up attention capture, which facilitates effective information encoding. The N3 component in the frontal region shows amplitude changes closely related to individual behavioral performance. This finding underscores the frontal lobe's crucial role in processing salient stimuli information and task demands, highlighting that increased N3 amplitude during successful information retrieval reflects cognitive load differences under different conditions: cognitive efficiency is highest in the pro condition and lowest in the anti condition compared to the baseline neutral condition.

In the visual search task, the N1, P2, and N3 components in the frontoparietal region reflect the early stages of salient stimulus processing, the indexing function of working memory, and the processing of information that does not match expectations, respectively. An increase in the N1 component indicates that more processing resources are allocated to a specific location, reflecting bottom-up attention capture. The P2

component signifies top-down indexing of working memory during the visual search task, while the increased N3 component indicates the processing of information that does not match expectations. This illustrates the complex modulation of internal working memory representations by top-down and bottom-up attention mechanisms during the visual search task.

During the working memory extract phase, the P2 and N2 components in the parieto-occipital region correspond to visual attention changes related to task demands. The P2 component reflects the matching of expected information and the allocation of attention resources, indicating bottom-up attention capture. In contrast, the increased N2 amplitude indicates enhanced cognitive control and conflict monitoring required when encountering mismatched information, reflecting top-down attentional modulation.

Therefore, the ERP results of this study emphasize the role of attention in working memory tasks during encoding and retrieval phases, and how attention influences the processing of internal representations in working memory through bottom-up attention capture and top-down modulation during visual search tasks. Next, in the next chapter, we will explore the brain regions involved in goal orienting and stimulus-driven attentional selection processes based on resting-state fmri data, as well as the functional connectivity of these brain regions.

Chapter 4: Investigating Brain Regions Related to Resting-State fMRI

The ERP results of Chapter 3 showed that the role played by salient stimuli in internal representation selection varied according to their role in the search task. During the memory encoding phase, frontal and parietal electrodes in the pro condition showed stronger P1 and N3 components than those in the anti condition; In this chapter, we will utilize resting-state functional MRI (rs-fMRI) data to explore the brain regions involved in goal-directed and stimulus-driven attentional selection processes, as well as their functional connectivity brain regions, focusing on individual differences.

4.1 Data Preprocessing

This study utilized MATLAB (version 2020b) and the DPARSF toolbox ^[133] (V5.4_230110, <http://rfmri.org/DPARSF>) for preprocessing the resting-state functional MRI (rs-fMRI) data. The preprocessing steps included: (1) Discarding the initial five time points to stabilize the magnetic field and improve image quality. (2) Slice timing correction to account for the staggered acquisition times of different slices in the interval-layer scanning method used in this experiment. The 43rd slice was selected as the reference slice to correct for time differences between slices. (3) Head motion correction to eliminate spatial displacement issues caused by involuntary head movements and equipment vibrations during the experiment. (4) Coregistration and segmentation of T1 images with functional images. (5) Regression of Friston-24 motion

parameters and three additional nuisance signals (white matter, cerebrospinal fluid, and global signal) to remove confounding variables. (6) Spatial normalization to the Montreal Neurological Institute (MNI) space and resampling to $3 \times 3 \times 3$ mm³. (7) Temporal band-pass filtering (0.01-0.1 Hz) and spatial smoothing to obtain REHO values.

4.2 Data Statistical Analysis

4.2.1 Whole-brain voxel-wise analysis of rs-fMRI activities

The preprocessed resting-state data were subjected to second-level group analysis using the SPM 12 toolbox (<https://www.fil.ion.ucl.ac.uk/spm/>). First, a design matrix was constructed to specify the model for group comparisons. The primary behavioral data analyzed in this study included angle error during the working memory task, and reaction time (RT) and accuracy (ACC) during the visual search task. Since the neutral condition served as the baseline in the experimental setup, the behavioral data were calculated by subtracting the baseline (neutral) from the pro and anti conditions, resulting in pro-neutral and anti-neutral differences to highlight the related brain activity induced by these conditions. Additionally, because the interaction effect between condition and position in the angle error of the working memory task was primarily driven by significant differences between ipsilateral and contralateral positions in the anti condition, the anti_ips-anti_contr difference was also calculated as a behavioral measure. These three behavioral measures were then correlated with one

feature: ReHo (Regional Homogeneity). To account for individual differences in resting-state data, age and gender were included as covariates in the regression analysis to mitigate potential confounding effects and enhance the generalizability and interpretability of the results. During the second-level group analysis, T-tests were used to compare the means between groups, identifying brain regions associated with performance in working memory and visual search tasks. A significance level of $p < 0.05$ FWE-corrected at the cluster level and cluster size > 30 voxels was set for group-level analysis.

4.2.2 Resting state functional connectivity (rsFC)

Subsequently, we analyzed seed-based voxel-wise using DPARSF 5.3 (Data Processing Assistant for Resting-State fMRI (DPARSF) | The R-fMRI Network (rfmri.org)) to compute resting state functional connectivity (rsFC), and the rsFC calculation without band-pass filter. The process included the following steps: First, picking the brain areas identified in the previous voxel-wise analysis as the seed for further rsFC analysis. Second, extracting and calculating time courses of all voxels for each seed region. Third, computing Pearson correlations between mean time course and all other voxels in the whole brain. At last, to promote the normality and strengthen the quality of the analysis of the statistics, using a transform Fisher from r to z to convert all rsFC maps into z -maps.

Furthermore, multiple regression analyses were performed to assess the brain regions associated with high-risk and low-risk in rsFC individuals. Again, FWE

corrected $p < 0.05$ with uncorrected p value < 0.001 and cluster size > 30 voxels were set as the significance level.

4.3 Resting state results

4.3.1 Whole-brain voxel-wise analysis of rs-fMRI activities

The angle difference (angleerror) of the working memory task in the Anti-ips-anti_contr condition was correlated with the left superior occipital gyrus (L. SOG). The results showed that the REHO values of the left superior occipital gyrus (-24, -84, 36) were positively correlated ($r = 0.666$, $p < 0.001$, 1000 bootstrap confidence interval of [0.423, 0.827]) with the angleerror in the Anti_ips-anti_contr condition (Figure 4-1(a)) (see Table 4-1 for details). However, the relevant cluster value for the left superior occipital gyrus was FWE-corrected $p = 0.078$, with a cluster size > 30 for cluster group elements at the group level. included in the calculations because it involves a key brain region that elicits a significant interaction between condition and location in working memory angular disparity.

Table 4-1 Brain regions associated with working memory tasks

Behavioral Measure	Resting State feature	Brain Regions	Cluster size	Peak MNI coordinates			r
				x	y	z	
Anti_ips-contr angleerror	REHO	L. SOG	34	-24	-84	36	0.666***

Note: Cluster FWE-corrected $p < 0.05$ at the group level and Cluster size > 30 at the group level were set as the level of significance. l. SOG superior occipital gyrus.

Anti_ips-anti_contr_angleerror vs. Resting state fMRI
(a) Left superior occipital gyrus

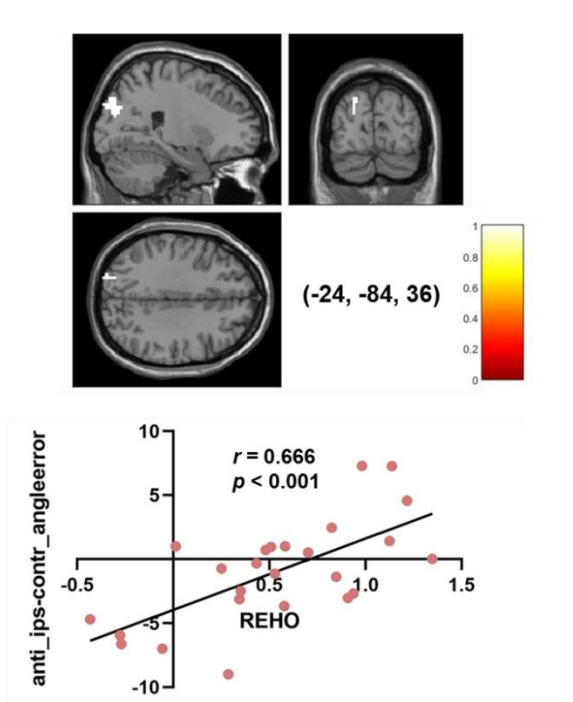


Figure 4-1 Brain regions correlated with angular differences in the anti_ips-anti_contr condition under the working memory task. (a) REHO eigenvalues in the left supraoccipital gyrus are positively correlated with the anti_ips-anti_contr condition. Note: angleerror is the angular difference

4.3.2 Seed-based functional connectivity

In order to assess the association between functional connectivity and the working memory performance in the Anti_ips-anti_contr_angleerror condition, we performed a seed-based functional connectivity analysis using the brain regions identified in the analysis in 4.3.1 as seed regions.

We examined the connectivity of L.SOG, a brain region whose REHO was correlated with the Anti_ips-anti_contr_angleerror condition. Seed-based function

connectivity analysis revealed that left superior parietal lobule (L. SPL) (x, y, z = -33, -54, 36, Fig. 4-2 (b) was negatively correlated with Anti_ips-anti_contr_angleerror condition ($r = 0.596$, $p = 0.0016$, 1000 bootstrap confidence interval [0.239, 0.754]) and left superior frontal gyrus (L. SFG) (x, y, z = -21, 0, 54, Fig. 4-2(c) was negatively correlated with Anti_ips-anti_contr_angleerror condition ($r = 0.623$, $p < 0.001$, 1000 bootstrap confidence interval [0.452, 0.871]) are functional connectivity with L. SOG (see details in Table 2).

**Table 4-2 Resting state functional connectivity results in brain
regions associated with behavioral performance**

Brain Regions	Cluster size	Peak MNI coordinates			r
		x	y	z	
Seed Region: L.SOG					
L. SPL	75	-33	-54	36	0.596**
L. SFG	52	-21	0	54	0.632***

Note: Cluster FWE-corrected $p < 0.05$ at the group level and Cluster size > 30 at the group level were set as the level of significance. L. SPL superior parietal gyrus. L. SFG superior frontal gyrus.

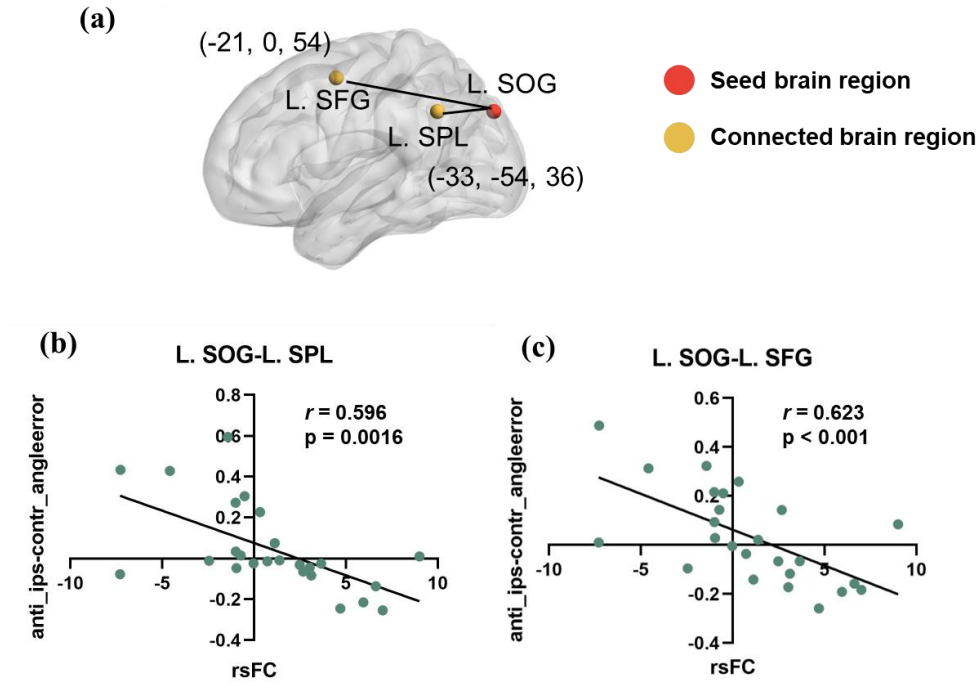


Figure 4-2 Results of seed-based resting state FC analysis after controlling age and gender. (a) When the L. SOG serving as a seed, L. SOG was negatively correlated with L.SPL and L.SFG. (b) L. SOG–L. SPL FC strength was negatively correlated with the Anti_ips-anti_contr_angleerror. (c) L. SOG–L. SFG FC strength was negatively correlated with the Anti_ips-anti_contr_angleerror.

4.4 Discussion of Resting-State fMRI Results

The resting-state fMRI analysis in this study reveals that brain regions associated with attention-guided working memory are distributed across the frontal, parietal, and occipital lobes. These regions support the process of attention-guided working memory

through their specific functions and interconnections: the frontal lobe's role in information maintenance and regulation, the parietal lobe's spatial processing capabilities, and the occipital lobe's visual information processing function.

In the working memory task, the difference between ipsilateral and contralateral positions in the anti condition, which drives the interaction between condition and position, was linked to the left superior parietal lobule. Studies have shown that the superior parietal lobule is highly sensitive to various visual features of stimuli, including shape^[113, 114] and color^[115, 116], and is essential for object recognition^[117], particularly in spatially locating objects^[118, 119]. This region is also crucial for the temporary storage of visual information, making it key for processing visual information^[120]. In this study, the greater the difference between ipsilateral and contralateral positions in the anti condition, the stronger the correlation with the superior parietal lobule, indicating its significant role in visual information processing and spatial updates.

Moreover, the superior occipital gyrus (SOG) demonstrates functional connectivity with both the SPL and the superior frontal gyrus (SFG), forming a network that integrates visual, spatial, and attentional processes. The SOG, known for its involvement in early visual processing, communicates with the SPL to relay visual information crucial for spatial processing and object recognition. This connection underscores the role of the SPL in integrating visual features into a coherent spatial framework. Furthermore, the functional connectivity between the SOG and the SFG

supports the top-down regulation of visual attention, where the SFG modulates the visual processing occurring in the SOG based on the demands of the working memory task. This interaction highlights the dynamic interplay between frontal executive control and occipital visual processing, mediated through the parietal lobe's spatial functions, particularly in conditions that require attentional shifts and spatial updates.

Overall, these findings emphasize the importance of the SOG-SPL-SFG network in coordinating the various components of attention-guided working memory, ensuring that visual information is efficiently processed, maintained, and regulated according to task demands.

4.5 Chapter Summary

In the working memory task, the angle error differences between ipsilateral and contralateral positions in the anti condition highlighted the functional role of the left superior parietal lobule (L.SPL) in maintaining visual information and its sensitivity to spatial locations. Stronger correlations indicated larger differences between ipsilateral and contralateral positions. Additionally, the left superior occipital gyrus (SOG) demonstrated functional connectivity with the left superior parietal lobule (L.SPL) and the left superior frontal gyrus (L.SFG). The SOG plays a crucial role in early visual processing, transmitting vital visual information to the L.SPL for spatial processing and object recognition. The L.SPL is responsible for processing and integrating spatial information, while the L.SFG contributes to attention regulation and allocation,

enhancing the efficiency of L.SPL in handling spatial data. The connectivity between SOG, L.SPL, and L.SFG facilitates efficient information transfer and coordination, supporting precise working memory operations. This dynamic interaction reflects the brain's ability to adapt to varying cognitive demands, highlighting the specialized functions of these regions in spatial information processing and task execution.

Chapter 5: Summary and Prospects

5.1 Summary and Discussion

This study explored the neural mechanisms underlying attention-guided working memory by integrating behavioral, EEG and resting-state fMRI data. The research findings are as follows:

(1) Behavioral Data Analysis Results: The analysis indicated that top-down and bottom-up attention mechanisms have different impacts on attention-guided working memory tasks. In the working memory task, the pro (positive cue) condition resulted in more precise angle memory for the colored bars, indicating that the cue significantly enhanced working memory representation. Conversely, the anti (negative cue) condition produced an interference effect, impairing working memory representation. When spatial location information was included, a complex interaction between condition and location was observed. Notably, memory for the colored bars was more precise when the salient distractor was presented contralaterally rather than ipsilaterally to the working memory target, suggesting that internal representations at the salient distractor location were suppressed. These findings emphasize the differential impact of attention mechanisms on working memory representation and how internal information can influence the efficiency of working memory processing.

(2) Event-Related Potential Analysis Results: The ERP analysis demonstrated that activity in the frontal, parietal, and occipital regions is crucial in attention-guided

working memory tasks, particularly in the allocation of attentional resources and regulation of internal working memory representations. During the encoding phase of working memory, the pro condition showed stronger P1 and N3 components at fronto-parietal electrodes compared to the anti condition, reflecting adjustments in top-down visual processing and information processing strategies directly related to behavioral performance. During the maintenance phase, search stimuli elicited N1, P2, and N3 components in the frontal lobe, showing ipsilateral and contralateral differences under the anti condition, indicating early processing, memory indexing, and cognitive control over mismatched information. Additionally, the occipital P2 component during the retrieval phase exhibited differences between ipsilateral and contralateral conditions in both pro and anti conditions, highlighting changes in visual attention and cognitive control. These components suggest that the role of salient stimuli in selecting internal representations is linked to their role in the search task, mainly involving the frontal-parietal-occipital regions in regulating attention on working memory representation.

(3) Resting-State fMRI Analysis Results: The resting-state fMRI analysis highlighted the collaborative role of the frontal, parietal, and occipital lobes in executing attention-guided working memory tasks. The results showed that the left superior parietal lobule was significantly associated with memory accuracy differences between anti ipsilateral and anti contralateral conditions in the working memory task, indicating their roles in maintaining memory information and spatial orientation. The study emphasizes the comprehensive role of the frontal, parietal, and occipital lobes in

visual information processing, spatial localization, and task strategy adjustment, revealing the correlation between brain regions and behavior in complex cognitive tasks.

In conclusion, the study's findings suggest that the role of salient stimuli in selecting internal representations is linked to their role in the search task. Salient stimuli as positive cues aid in selecting internal representations in working memory, while as negative cues, they impair working memory representation. When stimulus-driven and goal-directed selections are consistent, the selection effect is more pronounced, whereas when they conflict, the selection of internal representations relies more on goal-directed selection. Although salient stimuli are initially captured by bottom-up attention, top-down regulation becomes stronger when completing task-related demands. The neural mechanisms of goal-directed and stimulus-driven influences on working memory representation differ, and the spatial location of salient stimuli also affects representation. Activity in the frontal-parietal-occipital regions is crucial for allocating attention resources, regulating internal working memory information, processing visual information, spatial localization, and task strategy adjustment. Top-down influences primarily arise from the parieto-occipital regions, playing a key role in optimizing information processing and attention allocation. These findings underscore the interaction and coordination between brain regions in attention-guided working memory tasks and the influence of top-down and bottom-up attention mechanisms on selecting salient stimuli in internal representations.

The broader implications of this work for cognitive neuroscience lie in its

contribution to understanding the interplay between attention and memory representation. By dissecting the dynamic balance between bottom-up and top-down mechanisms, this study sheds light on how the brain prioritizes and integrates information to meet task demands, offering a neural framework for the flexibility of human cognition. These findings challenge simplistic dichotomies of attention as purely stimulus-driven or goal-directed, instead emphasizing their intricate coordination across spatial and representational dimensions. This perspective has far-reaching significance: it informs how we conceptualize the brain's adaptability in complex environments and provides a foundation for addressing real-world challenges, such as improving attentional strategies in high-stakes scenarios or designing interventions for cognitive impairments.

5.2 Prospects

This study employed electroencephalography (EEG) and resting-state functional magnetic resonance imaging (rs-fMRI) to explore the neural mechanisms underlying attention-guided working memory tasks from both high temporal and high spatial resolution dimensions. While the EEG data and rs-fMRI data provide mutual evidence supporting each other's results, there remain areas for further investigation and refinement:

1. Although this study successfully analyzed specific brain regions' activities using event-related potentials and time-frequency data, the precise mechanisms of

how these regions coordinate within the entire brain network to accomplish working memory tasks remain unclear. Future research could delve deeper into network connectivity analysis within EEG data to explore the dynamic cooperation mechanisms between these regions.

2. This study used resting-state fMRI data for individual differences-based research. Future research could combine task-based fMRI data with EEG analysis results to mutually validate and support each other, providing a more detailed and comprehensive perspective on how salient stimuli affect internal working memory representations.
3. The similarity in brain region activities revealed by EEG and fMRI data provides a theoretical basis for employing source localization techniques in EEG analysis. Source localization can help infer the specific origins of neural activities (i.e., brain regions, locations, and intensities) from EEG signals, providing more direct and conclusive evidence for understanding how brain regions coordinate, especially in high cognitive demand tasks.
4. Although EEG and fMRI data in this study were collected separately, future research could consider using simultaneous EEG-fMRI acquisition techniques. This multimodal approach can leverage the advantages of EEG's high temporal resolution and fMRI's high spatial resolution, providing more comprehensive and direct evidence on how attention guides working memory processing. Additionally, simultaneous data acquisition allows researchers to observe the

interaction between EEG activities and brain region activities in real-time during task execution, thereby deepening our understanding of attention mechanisms and their role in working memory.

Chapter 6: Bibliography

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Abbreviations

ACC - Accuracy

EEG - Electroencephalography

ERP - Event-Related Potential

fMRI - Functional Magnetic Resonance Imaging

ICA - Independent Component Analysis

MNI - Montreal Neurological Institute

P1, N1, P2, N2, N3, N2pc, Pd - Components of ERP related to different stages of brain processing

REHO - Regional Homogeneity

rsFC - Resting-State Functional Connectivity

SOG - Superior Occipital Gyrus

SPL - Superior Parietal Lobule

SFG - Superior Frontal Gyrus

TR - Repetition Time (related to MRI)

FOV - Field of View (related to MRI)

RT - Reaction Time