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Preprint · May 2025

DOI: 10.21203/rs.3.rs-6675918/v1

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Article

Keywords: P300, working memory, visual imagery, delta oscillations, cognitive neuroscience

Posted Date: May 26th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-6675918/v1

Additional Declarations: No competing interests reported.

Abstract

Aphantasia is characterized by a diminished or absent capacity for visual imagery, affecting an estimated 3–4% of the population. While functional MRI research has linked visual imagery to regions such as the hippocampus and occipital lobes, it reveals little about the temporal dynamics underlying this phenomenon. Electroencephalography (EEG), with its millisecond resolution, is well-suited for capturing such activity but has only been applied to aphantasia in two case studies, leaving a critical gap in our understanding. We conducted the first group EEG study comparing individuals with aphantasia (n = 62) to controls (n = 59) during rest and tasks probing attention and working memory. Aphantasic participants showed reduced P300 signals—an neural response linked to attention and memory updating—during a visual oddball task, suggesting decreased attentional engagement and impaired episodic memory updating. Lower frontal delta power during a high-load n-back task further suggested reduced reliance on internal imagery and a decreased need to suppress external distractions. Despite these neural differences, behavioral performance remained comparable, indicating possible compensatory strategies. Our findings provide the first electrophysiological evidence that individuals with aphantasia exhibit distinct neural signatures during cognitive tasks, contributing to a growing body of work that redefines how the absence of visual imagery shapes cognition and perception.

Introduction

Close your eyes and picture a red apple—its glossy skin and deep red hue. For some, this mental image is vivid and detailed; for others, there is only darkness, a sense of the concept without any visual form. The term *aphantasia* was introduced less than a decade ago to describe this reduced capacity for voluntary visual imagery—the inability to "see with the mind's eye"[1]. Recent estimates suggest that 3–4% of the population experiences aphantasia[2], revealing that the absence of mental imagery may be more common than previously assumed. This recognition has sparked growing interest in how individuals with aphantasia engage in cognitive functions typically thought to be supported by imagery, including episodic memory and working memory[3–6].

Behavioral studies have found both similarities and differences between aphantasic and control participants in cognitive tasks. For instance, aphantasics tend to recall fewer perceptual details during episodic memory retrieval[3–4] and exhibit slower but more accurate performance on mental rotation tasks[7]. Yet, performance on visual working memory tasks often remains comparable to that of controls, with evidence indicating a shift toward semantic labelling over sensory-based representation[8]. One possibility then is that individuals with aphantasia utilize alternative, non-imagery-based strategies to achieve their task goals, thus adapting to their limited mental imagery by employing different cognitive processes. However, this explanation remains debated; some propose that unconscious imagery may still support performance in aphantasia[9–10].

Despite growing behavioral research, the neural correlates of aphantasia remain comparatively understudied. To date, only a small number of functional magnetic resonance imaging (fMRI) studies

have sought to identify brain regions potentially involved in this phenomena[13]. During visual imagery tasks, individuals with low imagery vividness appear to activate broader and distinct neural networks, including regions linked to object recognition (fusiform gyrus), memory recall (posterior cingulate), and spatial processing (parahippocampal gyrus)[13]. Aphantasics also show reduced hippocampal engagement and increased activity in visual perception areas during autobiographical memory retrieval[4], along with weaker connectivity between prefrontal and visual cortices at rest[14–15].

Both behavioral and neural results suggest that people with aphantasia experience differences in autobiographical memory, supporting the theory that aphantasia results from differences in the episodic memory system[11–12]. However, episodic memory is a complex system, and differences in recall rates observed during recall phases could be due to either retrieval or encoding processes. Current studies have not teased these possibilities apart, and we have yet to determine the extent to which potential differences in memory encoding processes versus memory retrieval processes contribute to the behavioural results of lower perceptual detail retrieval. A particular gap exists in the literature, as no studies to date have investigated the processes that support memory encoding in aphantasia, such as attentional allocation.

Electroencephalography (EEG) complements fMRI by capturing neural activity with millisecond-level precision, making it well-suited to detect rapid neural events that hemodynamic signals cannot measure[16]. EEG is used to record event-related potentials (ERPs), which are brain responses directly triggered by specific stimuli, providing insight into the timing and sequence of cognitive processes[16]. In particular, the P300 ERP, which peaks around 300 ms after a novel stimulus, reflects attention and memory updating processes[17]. Its P300b subcomponent is closely linked to episodic encoding, with larger amplitudes observed during the successful retrieval of contextual details[18]. In addition to time-locked ERPs, EEG can be analyzed in the frequency domain to examine ongoing oscillatory dynamics associated with cognitive states[19]. Frequency-based analyses reveal changes in power across specific bands, such as theta (4–7 Hz), which have been associated with episodic memory encoding and retrieval[20–22], as well as increased working memory load[23].

Despite the clear utility of this method, EEG research on aphantasia is still in its early stages, with limited findings drawn from single-subject case studies. Furman and colleagues observed atypical temporal activation—rather than the expected frontal and occipital patterns—during a mental imagery task in their aphantasic subject[24]. Similarly, Zhao et al.[25] reported a normal ERP response, specifically the rotation-related negativity (RRN), during standard mental rotation tasks. However, atypical patterns for mirror-reversed stimuli were observed, suggesting that spatial processing in aphantasics may vary with task complexity. Yet, without larger sample sizes, it remains impossible to determine if these insights are purely due to individual variability and thus cannot be generalized to aphantasics as a whole.

To address this gap, we conducted a novel EEG study comparing neural activity in individuals with aphantasia and control participants during cognitive tasks, including the visual oddball and n-back, as

well as during resting state. Participants were assigned to two groups using the Vividness of Visual Imagery Questionnaire (VVIQ)[26]. Informed by prior fMRI[13–15] and EEG case studies[24–25], we broadly hypothesized that the groups would differ in neural activity during both rest and task conditions. More specifically, given the P300 component's established role in attention and episodic memory encoding[17–18], we anticipated to find reduced P300 amplitudes in the aphantasia group during the oddball task. However, given the limited prior work on the electrophysiology of aphantasia, our frequency-domain analyses were exploratory. As such, we examined group differences across all frequency bands (delta, theta, alpha, and beta) during both resting-state and n-back tasks, aiming to identify EEG patterns that could inform future research.

Results

Participants

One participant failed to complete the Vividness of Visual Imagery Questionnaire (VVIQ) and, as a result, could not be classified into either group, leading to their exclusion from all analyses. This left 62 participants scoring 32 or below in the aphantasia group and 59 in the control group. A two-tailed independent samples t-test revealed no significant age differences between the aphantasia and control groups ($t(119) = 1.088$, $p = .139$). Demographic details such as sex, gender, and handedness are provided in Table 1.

Table 1. *Group Characteristics*

Characteristic	Control (n=59)	Aphantasia (n=62)
Age (years)	35 [31, 38]	37 [33, 40]
VVIQ (score)	63 [60, 66]	19 [18, 20]
Sex (n; female, male, prefer not to say)	43, 16, 0	42, 19, 1
Gender (n; woman, man, other)	43, 16, 0	37, 19, 4
Handed (n; left, right, ambidextrous)	6, 51, 3	7, 51, 4

Note. Age and VVIQ score values are presented as means ± 95% confidence intervals. For gender, the 'other' category refers to genderfluid or non-binary individuals.

In the Survey of Autobiographical Memory (SAM), the aphantasia group demonstrated significantly lower scores in both episodic memory ($t(118)=2.33$, $p = .011$, $\eta^2= .04$) and future prospection ($t(118) = 6.450$, $p < .0001$, $\eta^2 = .26$) subcategories (see Extended Data Table 1). There were no significant differences in either semantic or spatial memory categories. Furthermore, the Plymouth Sensory Imagery Questionnaire (PSI-Q) results showed significantly lower scores for the aphantasia group across

all subcategories: visual, olfactory, auditory, taste, touch, bodily sensation, and feeling (all p < .0001; see Extended Data Table 2).

No significant differences were observed in the State-Trait Anxiety Inventory (STAI) between the groups for either state anxiety (t(118) = 0.79, p = .126) or trait anxiety (t(118) = 0.57, p = .283).

Behavioural

No accuracy or reaction time differences were found between the aphantasia and control groups across all tasks (oddball, 2-back, and 3-back; see Extended Data Table 3).

Electroencephalography

Event Related Potentials

In the oddball task, the aphantasia group exhibited significantly lower P300 amplitude values (M = 2.73 μV, 95% CI [2.11, 3.36]) compared to the control group (M = 3.78 μV, 95% CI [3.02, 4.41]), t(118) = 2.139, p = .07, η^2 = 0.37. See Figures 1 and 2. For grand average conditional waveforms, see Extended Data Figure 1. No differences were observed in P300 latency (t(118) = 1.30, p = .097).

Frequency Activity

2-Back

For the delta band, there was a significant main effect of brain region, $F(2, 236) = 145.20$, $p < .001$, partial $\eta^2 = .55$, while the main effect of group was insignificant, $p = .282$. The interaction effect between brain region and group was significant, $F(2, 236) = 4.72$, $p = .010$, partial $\eta^2 = .04$. Bonferroni-adjusted post hoc tests revealed a significant group difference only in the frontal region, where the control group showed significantly greater delta activity than the aphantasia group ($t(118) = 2.52$, $p = .003$, Cohen's $d = 0.27$). In contrast, there were no significant differences between groups in the central region ($p = .056$), nor in the parietal region ($p = .450$). See Extended Data Table 4, Figure 3.

For the theta, alpha, and beta bands, significant mains effects were identified for brain region, indicating differences in power in frontal, central, and parietal regions. However, no effects of group, or interactions were identified. See Extended Data Table 4.

Three Back Task

Delta

Significant main effects emerged for both brain region, $F(2, 236) = 116.80$, $p < .001$, partial $\eta^2 = .52$, and group, $F(1, 118) = 10.28$, $p = .002$, partial $\eta^2 = .09$. Furthermore, the interaction effect between brain

region and group was also significant, $F(2, 236) = 5.19$, $p = .006$, partial $\eta^2 = .05$. Post-hoc comparisons with bonferroni corrections indicated that the Control group had significantly higher delta activity compared to the Aphantasia group in the frontal region ($t(118) = 3.22$, $p < .001$, $d = 0.72$) and in the central region ($t(118) = 2.56$, $p = .007$, $d = 0.49$). However, in the parietal region, the difference between groups was not statistically significant ($p = .078$). See Extended Data Table 5, Figure 3.

For the theta, alpha, and beta bands, significant mains effects were identified for brain region, indicating differences in power in frontal, central, and parietal regions. However, no effects of group, or interactions were identified. See Extended Data Table 5.

Correlations

Weak positive correlations were observed between VVIQ scores and 3-back frontal delta (r = .30, p = .001). See Supplementary Information Table S3.

In addition, age significantly negatively correlated with VVIQ (r = - .42, p < .0001), PSIQ (r = -.40, p < .0001) and SAM scores (r = -.23, p = .002). See Supplementary Information S3, S4, S5.

Discussion

Our findings reveal distinct electrophysiological neural differences during cognitive tasks between aphantasic and control groups. Specifically, compared to the control group, individuals with aphantasia demonstrated significantly reduced P300 amplitudes during the visual Oddball task and decreased frontal delta oscillations under high cognitive load conditions in the n-back task. Despite these electrophysiological differences, behavioural task performance remained comparable between groups.

The reduced P300 amplitudes observed in individuals with aphantasia suggest that the differences between groups stem not from behavioral performance but rather from distinct underlying neural mechanisms. As established, the P300 component reflects attentional resource allocation and memory updating, with amplitude scaling to the amount of contextual information retrieved during episodic tasks[17–18]. Unlike clinical populations such as individuals with temporal lobe epilepsy, where reduced P300 amplitudes coincide with memory impairments[27], aphantasia appears to represent a non-pathological variation in how cognitive tasks are neurally supported. Crucially, our finding is consistent with the interpretation of aphantasia as consisting of symptoms arising from differences in the episodic memory system, as both attentional resource allocation and memory updating are relevant to encoding information into episodic memory.[11]

Previous studies have established behavioural findings showing that aphantasics recall fewer perceptual details during memory tasks[3–4] but have not been able to discern whether the observed differences in retrieval levels are due to differences in information processing at the encoding stage or the retrieval stage. By studying the P300, our research suggests that there may be differences between aphantasics and controls at the neural level during the encoding stage. Thus, lower amplitudes in the aphantasia

group may indicate reduced engagement processes associated with memory encoding, such as attentional resource allocation and memory updating. This, in turn, suggests that some of the differences reported in other studies measuring memory retrieval may be due to different neural processing observed at a stage relevant to encoding memories. Future research should further investigate the hypothesis that there are neural differences between aphantasics and controls in processes that are relevant to memory encoding.

Exploratory analysis revealed that individuals with aphantasia exhibited decreased frontal delta power compared to controls during the n-back working memory task, specifically in the 3-back condition and to a lesser extent in the 2-back condition. Harmony[28] reviewed the functional significance of delta band power, noting that its increase, especially in frontal regions during cognitive tasks, is important for suppressing irrelevant sensory information and enhancing focus on internal thoughts and complex cognitive processes. Simply put, delta activity may help the brain concentrate by filtering out distracting environmental stimuli, which could otherwise impede task performance. Harmony also discovered a link of frontal delta power to *functional cortical deafferentation*—a mechanism that temporarily reduces incoming sensory information to the cortex. This reduction is thought to preserve the integrity of internally generated mental content by minimizing interference from external signals. Such a mechanism proves valuable during tasks that require sustained attention, like working memory challenges, by helping individuals "tune out" unnecessary sensory input and maintain goal-directed mental activity with fewer disruptions[28].

Functional cortical deafferentation may be particularly relevant in the context of aphantasia, as individuals with this condition report absent or weaker visual imagery[1]. In contrast, in individuals with typical imagery, working memory tasks such as the n-back often involve the active maintenance and manipulation of internally generated visual representations. Supporting these internal processes likely requires the suppression of irrelevant sensory input, particularly because perception and visual imagery share common mechanisms[29]. Thus, irrelevant sensory stimuli may interfere with internal visual representations. This suppression may be associated with the increased frontal delta activity we observed in controls[28,30–31]. By contrast, aphantasics may have relied on non-sensory strategies for solving the n-back tasks, such as the internal labeling of the stimuli. One possibility is that irrelevant sensory input interferes less with non-sensory verbal representations, given that they recruit different mechanisms, thus requiring less effort on the part of aphantasics to suppress external stimuli. Hence, the lower frontal delta power activity observed in this group.

This interpretation aligns with previous findings that aphantasics may show comparable behavioral performance on working memory tasks while engaging different neural pathways or cognitive strategies[5]. It also suggests that delta power might serve not only as a marker of cognitive load or attention generally but specifically as an index of the brain’s effort to protect internally generated sensory representations from perceptual disruption. In the absence of internal sensory representations —such as imagery in aphantasics—the neural demand for this protective inhibition may be lower, resulting in

attenuated delta oscillatory activity during cognitively demanding tasks. Although we did not explicitly investigate different cognitive strategies for task performance in this study, our interpretation is supported by previous research[7,8]. Specifically, people with aphantasia reported using more analytical strategies to complete a mental rotation task, whereas controls used more imagery-based strategies[7,32].

To further investigate the functional significance of delta activity, we examined the correlation between delta power during the 3-back task and VVIQ scores. Here, we found a positive relationship, suggesting that individuals with greater imagery vividness engage stronger delta oscillations to manage cognitive load effectively. Higher delta activity may reflect a stronger need for inhibitory control on the part of vivid imagers, as irrelevant sensory input can interfere with the visual imagery they use to solve the task. Conversely, under the assumption that aphantasics employ non-sensory strategies for solving the n-back tasks, such as verbal representations of the stimuli, the lower delta activity observed in this population may indicate a reduced need for inhibiting irrelevant sensory information. Therefore, task-related delta oscillations could serve as a neural biomarker for visual imagery vividness, offering an objective measure complementary to subjective self-report instruments such as the VVIQ.

Several limitations of this study merit consideration. Firstly, reliance on self-reported VVIQ scores to classify participants introduces potential subjectivity, as individuals may vary in their self-assessment of voluntary imagery vividness. Recent research employing objective measures such as binocular rivalry[5], pupillary light responses[33], and galvanic skin responses[34] offers promising avenues to complement subjective ratings and improve classification accuracy. It is also worth noting that the definition of 'aphantasia' as limited to voluntary visual imagery has received criticism[35,36] and that involuntary imagery ability ought to be assessed further. Our study was limited to assessing the vividness of voluntary visual imagery using the VVIQ and voluntary imagery in other modalities using the PSI-Q, but it did not investigate involuntary imagery. Furthermore, we did not investigate the self-reported cognitive strategies employed by participants during task performance, which limited our understanding of the precise compensatory mechanisms. Explicitly examining whether individuals rely on visual versus non-sensory strategy (such as phonological or semantic)[37] would provide deeper insights into these compensatory processes. Our group's ongoing research aims to address this limitation by including targeted self-report measures designed to elucidate strategy differences. Furthermore, similar to most studies on aphantasia, our study combined the groups reporting no imagery with the groups reporting reduced visual imagery. This could potentially obscure differences between these groups in task performance and neural mechanisms[12]. Recent studies have advocated separate analyses for aphantasics (defined as the complete absence of voluntary visual imagery, VVIQ = 16) and hypophantasics (defined as reduced voluntary visual imagery, VVIQ 17–33)[38].

Conclusion

Our findings provide new evidence that individuals with aphantasia exhibit distinct neural signatures during cognitive tasks. In the aphantasic group, reduced P300 amplitudes during a visual oddball task

indicate diminished engagement of episodic encoding processes. Additionally, lower slow-wave delta activity during a high-load working memory task suggests a reduced reliance on internally generated imagery and a lesser need to suppress external distractions, thereby reducing the demand on frontal control systems. Delta power positively correlated with VVIQ scores, suggesting its potential as a neural marker of imagery vividness and linking stronger mental imagery to greater engagement of these inhibitory processes. Despite these neural differences, task performance remained consistent across groups. These findings suggest that aphantasia involves more than a deficit of visual imagery—it reflects the brain's remarkable capacity for adaptation.

Methods

Participants

A total of 122 healthy participants were recruited for this study. The sample size was determined with the aim of maximizing recruitment while ensuring adequate compensation for participants within our funding constraints. Given the rarity of aphantasia, extensive recruitment methods were used to access this population, including the University of Glasgow's psychology pool, campus posters, lecture announcements, and targeted social media ads on platforms such as Instagram, Facebook, and Reddit. Additional outreach included newspaper advertisements in the Glasgow Herald and posts in aphantasia-specific online groups. Eligibility criteria included being between 18 and 65 years old, having no visual impairments, no diagnosed neurological conditions, and being native or having high proficiency in English. Participants received a £35 Love2Shop voucher as compensation. All participants provided informed consent, in line with the Ethics Board of the University of Glasgow's College of Arts and Humanities, and adhered to the standards of the Declaration of Helsinki (1964). Participants signed a Participant Agreement Form and a Plain Language Statement before testing and were reminded of their right to withdraw from the study at any time.

Materials

Participants completed several standardized questionnaires to evaluate cognitive and sensory characteristics. The Vividness of Visual Imagery Questionnaire (VVIQ)[26] measured visual imagery vividness across scenarios on a 5-point scale, with higher scores indicating more vivid imagery. The Survey of Autobiographical Memory (SAM)[39] assessed general memory abilities and included subcomponents for episodic memory, semantic memory, spatial memory, and future prospection, each rated on a 5-point scale. The Plymouth Sensory Imagery Questionnaire (PSI-Q) 40 assessed multi-sensory imagery vividness, with participants rating sensory experiences across visual, auditory, tactile, gustatory, bodily sensation, feeling, and olfactory domains on a 10-point scale. To evaluate anxiety levels, participants completed the State-Trait Anxiety Inventory (STAI)[41], which assessed both state and trait anxiety on a 4-point scale.

Brain activity was recorded using a portable EEG device (Xon; Brain Products, Germany) in conjunction with the ios app PEER (Brainwave Software, Victoria, Canada) on an iPad Pro (11-inch, 4th generation, ios 17.6.1). EEG data were collected at a sampling rate of 250 Hz using electrodes placed at seven positions covering the frontal, central, and parietal regions (F3, F4, C3, Cz, C4, P3, and P4), with A2 (right earlobe) serving as both ground and reference (see https://xon-eeg.com/ for complete technical specs). The study included two cognitive tasks during EEG recording: a Visual Oddball task[42] and the n-back task with 2- and 3-back versions[43]. The Visual Oddball task reliably elicits the P300 event-related potential (ERP), which reflects attentional engagement and context updating during stimulus evaluation[19]. In this task, participants viewed a series of blue and green circles on a dark gray background at the center of the screen. The goal was to tap the screen whenever a blue circle appeared. Each circle appeared for 800 ms, followed by a yellow fixation cross for 400 to 600 ms. The blue circle (oddball) appeared randomly 25% of the time, while the green circle (control) appeared 75% of the time, with no more than two blue circles presented consecutively. The n-back task is a commonly used test that assesses working memory[44,45]. In the task, participants viewed a continuous presentation of letters on a dark gray background at the center of the screen. The goal was to identify and tap the screen when the current letter matched one shown two or three items earlier, depending on the task version (2-back or 3-back). Each letter was displayed for 1200 ms, followed by a yellow fixation cross for 400–600 ms. Target letters appeared in 20% of the trials.

Procedure

All testing took place at the XR Lab in the Advanced Research Centre (ARC-XR) at the University of Glasgow. Upon arrival, participants provided informed consent before beginning the session. Resting-state EEG recordings were then taken under two conditions, each for 2 minutes: eyes open and eyes closed. For the eyes-closed condition, participants were instructed to close their eyes and relax without focusing on any specific thought. For the eyes-open condition, they were asked to softly fixate on a cross positioned approximately one meter in front of them. Following the resting state recordings, participants completed the Visual Oddball task. They were instructed to tap anywhere on the screen when they saw a blue circle (the oddball) and not respond to green circles. Next, participants proceeded to the n-back task, starting with the 2-back version and progressing to the 3-back version. For both versions, they tapped anywhere on the screen whenever the current letter matched the one presented two or three steps back, respectively. Each task consisted of four blocks of 100 trials, with self-paced breaks provided between blocks and tasks as needed. Tasks were completed while participants were seated at a desk, with stimuli presented on an iPad placed on a stand at a comfortable viewing distance. Finally, participants completed a demographics survey and questionnaires via the Qualtrics research platform. These questionnaires were presented in a randomized order to reduce potential response bias.

Data Processing & Analysis

Survey data were processed by averaging scores within each questionnaire and categorizing participants based on their VVIQ scores. Participants scoring 32 and under on the VVIQ were classified as aphantasic[1-2], with all other participants in the control group. Scores on the SAM were aggregated across its four memory domains: Episodic, Semantic, Spatial, and Future. Similarly, PSI-Q scores were averaged across the following sensory modalities: Visual, Olfactory, Auditory, Taste, Touch, Bodily Sensation, and Feeling. STAI scores were summed separately for the state and trait questions, providing overall scores for each anxiety dimension.

EEG data processing followed our standardized lab processing pipline[45]. Artifact rejection rates were 17.9% for resting state, 33.69% for the 2-Back task, and 33.72% for the 3-Back task. Data were further decomposed using Fast Fourier Transformations (FFT) to remove the time domain, allowing analysis of frequency bands. For resting state data, we segmented the signal into distinct frequency bands: delta (1-3 Hz), theta (4-7 Hz), alpha (8-12 Hz), and beta (13-30 Hz) at the frontal, central, and parietal regions. Reaction time was calculated as the interval between the appearance of the target stimulus and the participant's response. Accuracy was determined by the ratio of correctly identified targets to the total number of targets presented.

In ERP analysis of the oddball task, epochs of data were extracted from 200 ms before to 800 ms after stimulus onset, followed by baseline correction using the 200 ms preceding stimulus onset. Segments with a gradient exceeding 10 μv/ms or an absolute difference greater than 100 μv were excluded, resulting in an artifact rejection rate of 22.0% of the trials. Grand average difference waveforms were calculated by subtracting control waveforms from the oddball waveforms, as difference waves are considered more informative than control waveforms[16]. P300 peak amplitudes were quantified by averaging the voltage within a ±25 ms window around the peak of the difference wave, using combined P3/P4 electrodes. These window and filter settings were selected to align with laboratory standardization protocols, ensuring consistency across EEG studies[46,47]. Latencies were identified as the time corresponding to the maximal voltage within the specified window. Reaction time for the oddball task was measured as the interval between the appearance of a target (oddball) stimulus and the participant’s response, and accuracy was calculated as the number of correctly identified target stimuli divided by the total number of target stimuli presented.

Statistical Analysis

All statistical analyses were conducted using JASP (version 0.16.4; JASP Team, Amsterdam, Netherlands; JASP Team, 2022). Figures were created in GraphPad Prism, version 10.2.3 (GraphPad Software, San Diego, California, USA). An alpha level of 0.05 was used for significance testing. A two-way mixed analysis of variance (ANOVA) was conducted to examine the effects of Group (Control, Aphantasia; between-subjects) and Region (Frontal, Central, Parietal; within-subjects) on neural activity. Significant interaction and main effects were followed up with Bonferroni-adjusted post-hoc t-tests to compare regional activity within each group. Partial eta squared (η_p^2) was calculated as an indicator of

effect size for each fixed effect, and Cohen's *d* was used to quantify effect sizes for pairwise comparisons. Statistical assumptions for normality and homogeneity of variances were tested using the Shapiro-Wilk and Levene's tests, respectively. Spearman's rank two-tailed correlations were used to examine the relationships among survey scores (VVIQ, PSI-Q, SAM) and neural measures (FFT activity, ERP characteristics, behavioural) as well as demographic data (age, gender, sex). All error bars on graphs represent 95% between-subject confidence intervals.

Declarations

This study was reviewed and approved by the Ethics Board of the University of Glasgow's College of Arts and Humanities. All participants provided informed consent in accordance with the Declaration of Helsinki.

Competing Interests:

none.

Funding:

This project was supported by Duke University's Summer Seminars in Neuroscience and Philosophy (Grant ID: TWCF-2019-20384). AB was additionally supported by a UKRI Future Leaders Fellowship (Grant Ref: MR/W00741X/1), a British Academy Postdoctoral Fellowship (Grant Ref: PFSS23\230115), and a Lord Kelvin/Adam Smith Fellowship from the University of Glasgow. KB was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through a Canada Graduate Scholarships – Doctoral (CGS-D) award [Grant Number 579262–2023] and an NSERC Discovery Grant [Grant Number 0943–2016]. OEK was also supported by the NSERC Discovery Grant [Grant Number 0943–2016].

Author Contribution

KB, AB, RK, and EW designed the study. AB supervised the research, trained research assistants, and assisted with data collection. KB trained research assistants in EEG methodology and performed all data processing and analysis. KB and AB drafted the initial manuscript. RK and EW provided revisions to the manuscript. AB and RK recruited participants for the research. AB, RK, and KB prepared the manuscript tables. HL and LM collected the data for the experiments. OEK provided senior guidance and reviewed the final manuscript. All authors reviewed and approved the final manuscript.

Acknowledgement

Thank you to Felipe De Brigard and Walter Sinnott-Armstrong for the opportunity, support and encouragement in this collaborative effort.

Data Availability

All data and codes are available at https://osf.io/qdz8m/

Supplementary Information is available for this paper.

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Figures

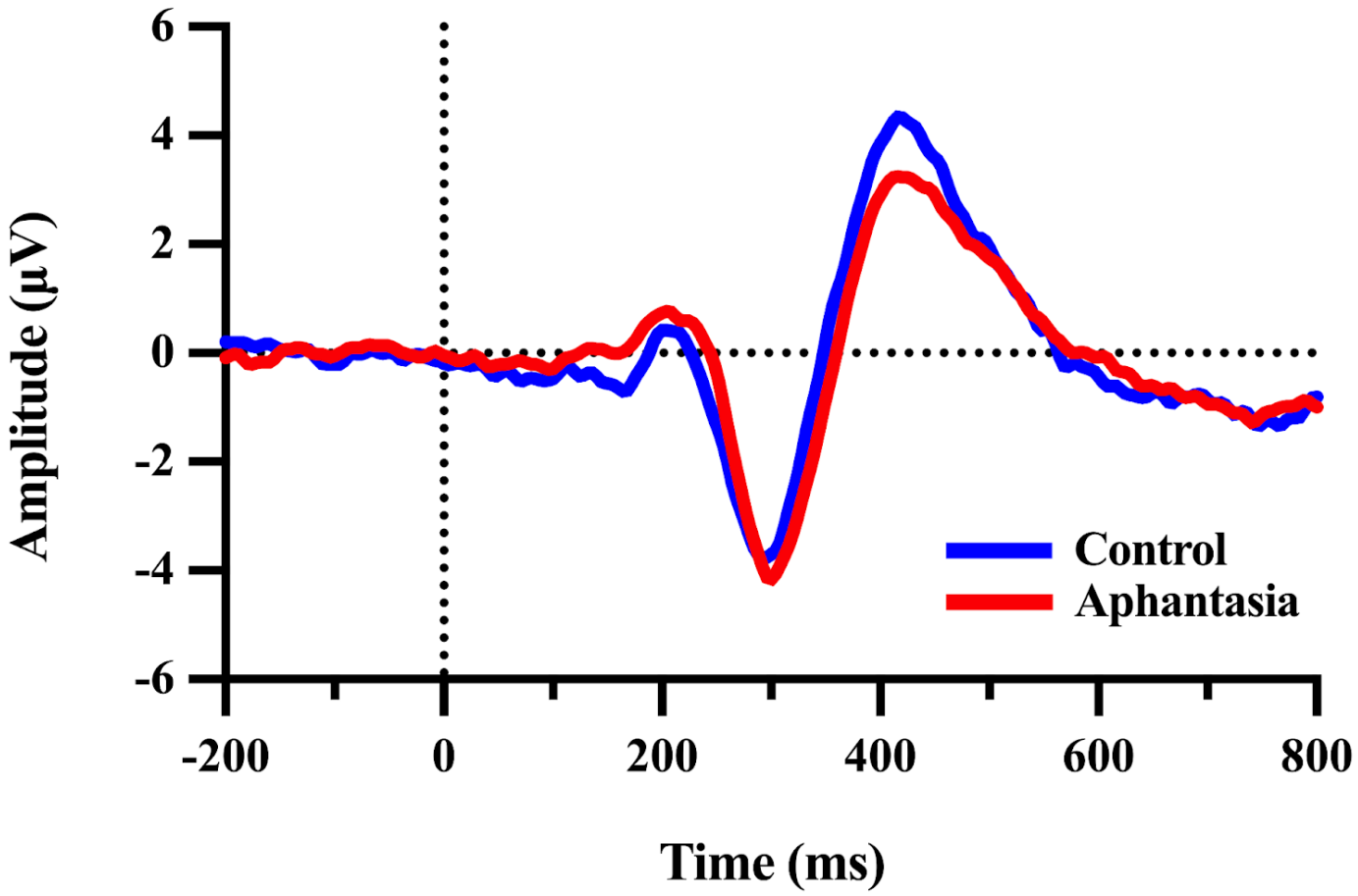

Figure 1

Grand average ERP waveforms for control and aphantasia groups

Figure 1 Caption: P300 responses to target stimuli are shown for control (blue) and aphantasia (red) participants, time-locked to stimulus onset (0 ms). The P300 peak amplitude is reduced in the aphantasia group.

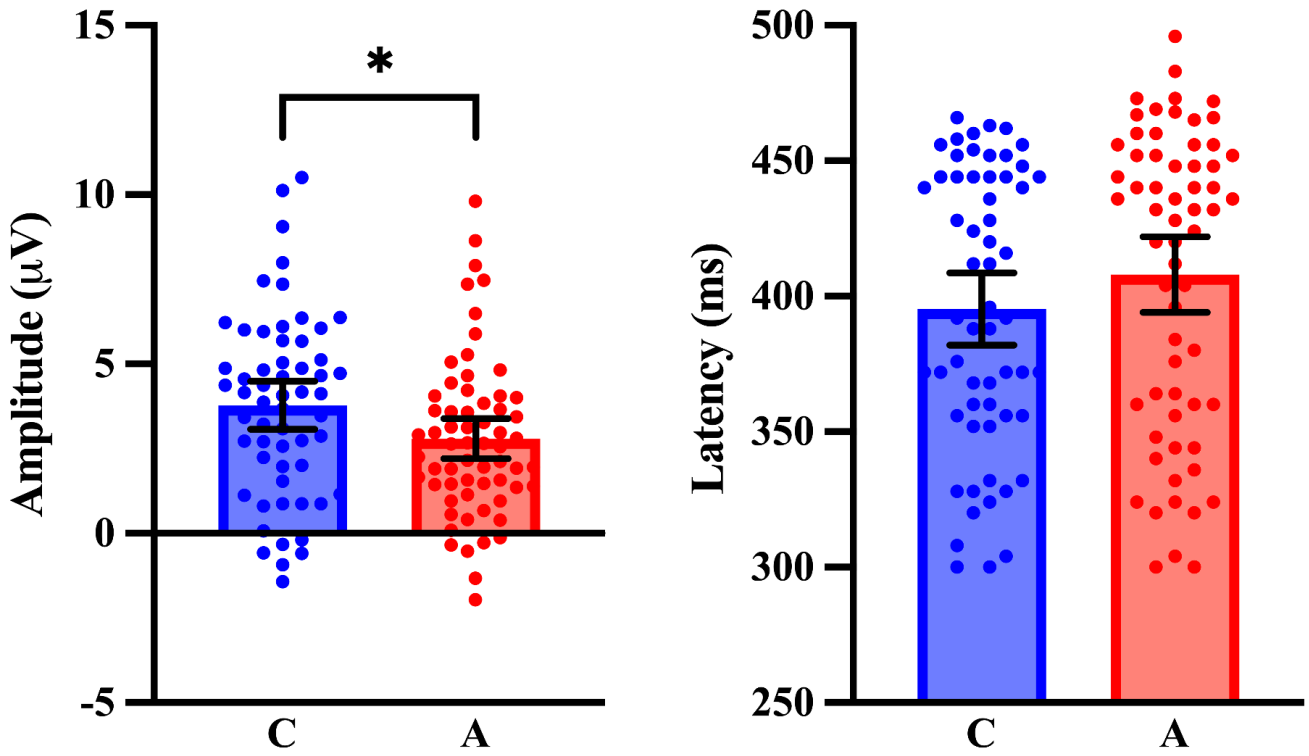

Figure 2

Group differences in P300 amplitude and latency during the visual oddball task

Figure 2 caption: Left: Mean P3 amplitude (μV) was significantly lower in individuals with aphantasia (A) compared to controls (C), $p < .05$. Right: Mean P3 latency (ms) was descriptively higher in the aphantasia group, although this difference did not reach statistical significance. Error bars represent ± 95% confidence intervals. Dots represent individual data points.

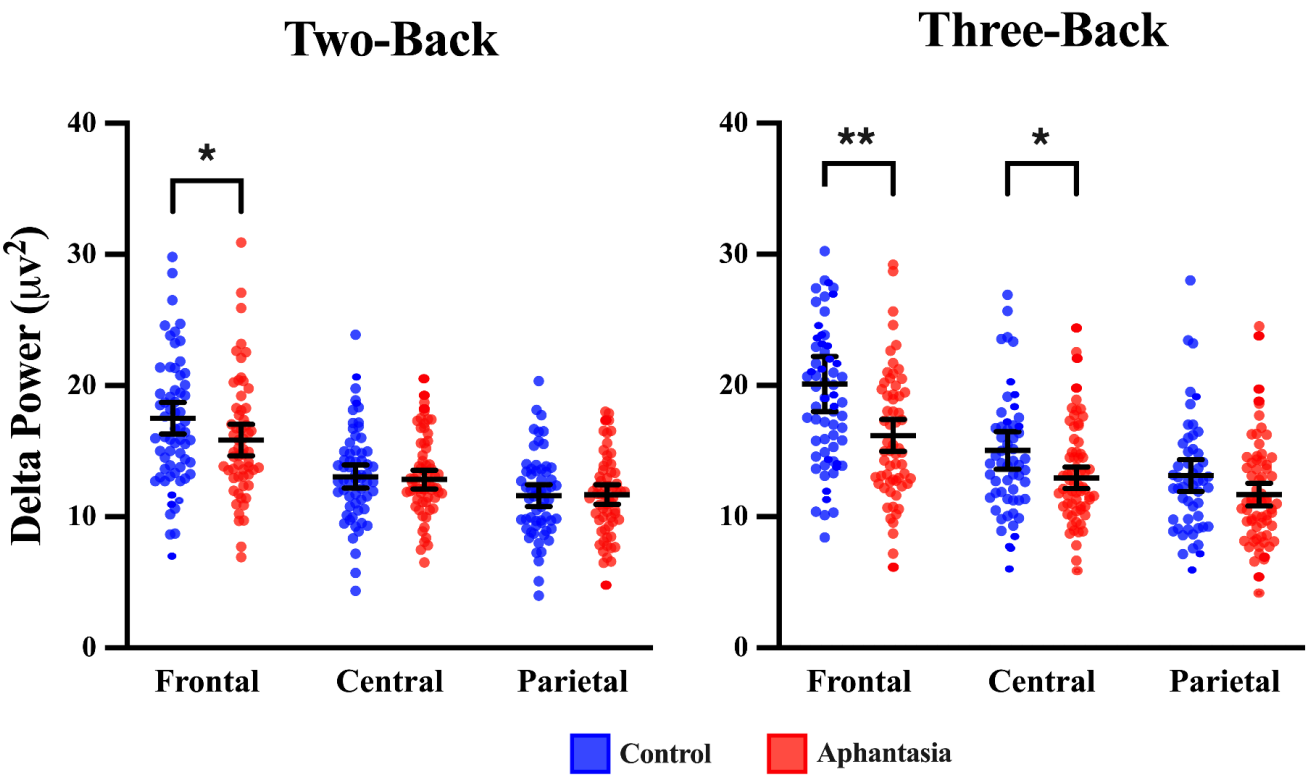

Figure 3

Group differences in delta power across brain regions during 2-back and 3-back tasks.

Figure 3 caption: Delta power (μV²) is shown for control (blue) and aphantasia (red) groups at frontal, central, and parietal electrode sites during the 2-back (left) and 3-back (right) working memory tasks. Black bars represent group means ± 95% confidence intervals. Asterisks denote significant group differences: $p < .05$ (*), $p < .01$ (**). Individuals with aphantasia exhibited significantly lower frontal delta power in both task conditions, with additional central differences emerging during the 3-back.

Supplementary Files

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