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Memories with a blind mind: Remembering the past and imagining the future with aphantasia

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ABSTRACT

Our capacity to re-experience the past and simulate the future is thought to depend heavily on visual imagery, which allows us to construct complex sensory representations in the absence of sensory stimulation. There are large individual differences in visual imagery ability, but their impact on autobiographical memory and future prospection remains poorly understood. Research in this field assumes the normative use of visual imagery as a cognitive tool to simulate the past and future, however some individuals lack the ability to visualise altogether (a condition termed "aphantasia"). Aphantasia represents a rare and naturally occurring knock-out model for examining the role of visual imagery in episodic memory recall. Here, we assessed individuals with aphantasia on an adapted form of the Autobiographical Interview, a behavioural measure of the specificity and richness of episodic details underpinning the memory of events. Aphantasic participants generated significantly fewer episodic details than controls for both past and future events. This effect was most pronounced for novel future events, driven by selective reductions in visual detail retrieval, accompanied by comparatively reduced ratings of the phenomenological richness of simulated events, and paralleled by quantitative linguistic markers of reduced perceptual language use in aphantasic participants compared to those with visual imagery. Our findings represent the first systematic evidence (using combined objective and subjective data streams) that aphantasia is associated with a diminished ability to re-experience the past and simulate the future, indicating that visual imagery is an important cognitive tool for the dynamic retrieval and recombination of episodic details during mental simulation.

1. Introduction

The link between mental imagery and autobiographical memory has historically proved an attractive subject of enquiry for philosophers of science. Francis Galton first recorded interindividual variation in memory phenomenology by administering self-report questionnaires to his peers on their ability to visualise while remembering the past (Galton, 1880). He noted with surprise that although most people relied heavily on visual imagery to mentally 'picture' and re-experience their memories, others appeared to remember life events without forming visual representations. Galton's surprise is testament to a common theoretical assumption about mental imagery dating as far back as Aristotle – that it is a requisite and universal format for human memory and cognition (Aristotle, c. 350 BC).

This assumption that imagery plays a central role in remembering the past largely prevails today, and few have since followed up on Galton's observations despite significant methodological advances in the measurement of mental imagery (Pearson, 2019) and despite new evidence that strongly challenges the presumed universality of visual imagery ability (Dawes, Keogh, Andrillon, & Pearson, 2020; Keogh & Pearson, 2018; Pearson & Keogh, 2019; Zeman et al., 2020; Zeman, Dewar, & Della Sala, 2015, 2016). Although behavioural and neuropsychological research has offered great insight into individual differences in autobiographical memory, scarce literature has focused on the specific contribution of visual imagery to episodic processes. The consensus view is that visual imagery is somehow important for remembering the past – although the "how" remains unclear. Whether or not autobiographical memory is reliant on, supported by, or entirely dissociable from visual imagery, is an open question. Research on this question has revealed fascinating individual differences in naturalistic cognition, but is marked by some inconsistency in the measurement and operationalisation of mental imagery.

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Early results suggested that individuals who report more subjectively vivid imagery on a common questionnaire (the Vividness of Visual Imagery Questionnaire, or VVIQ; Marks, 1973 & 1995) appear to generate a greater number of visual and sensory details when recalling past events and imagining future events (D'Argembeau & Van der Linden, 2006). However, other work has shown that VVIQ scores do not appear to predict the subjective vividness of memories themselves, nor the sense of reliving them (Greenberg & Knowlton, 2014; although Greenberg and Knowlton do demonstrate that two individuals with impoverished visual imagery reported a lower sense of reliving past events compared to those with intact imagery). More recently, studies on the role of visual imagery in autobiographical memory processes have focused on the differential contributions of two divergent imagery domains: object imagery (e.g. imagining the low-level sensory features of scenes such as colours or shapes) and spatial imagery (e.g. internally representing the layout of scenes and the relation of elements within a scene; Aydin, 2017; Kozhevnikov, Kosslyn, & Shephard, 2005). This line of enquiry is driven by findings of shared hippocampal involvement across scene construction, future thinking and spatial memory processes (Addis & Schacter, 2012; Bird, Bisby, & Burgess, 2012; Hassabis, Kumaran, Vann, & Maguire, 2007), as well as by an untested hypothesis that the functional dissociation between object and spatial perceptual processing in the brain (via the ventral and dorsal streams, respectively) might also exist for visual imagery (Farah, 1989; Goodale & Milner, 1992; Pearson, 2019). Some data suggests that high 'object imagers' (characterised by high self-report scores on the object sub-scale of the Object and Spatial Imagery Questionnaire; Blajenkova, Kozhevnikov, & Motes, 2006) are capable of more efficiently remembering a greater number of autobiographical memories, accompanied by increased sensory detail (Vannucci, Pelagatti, Chiorri, & Mazzoni, 2016). Other evidence, however, indicates that object imagery is only correlated with the phenomenological experience of remembering, whilst spatial imagery is responsible for facilitating the retrieval of specific episodic event details (Aydin, 2017; Sheldon, Amaral, & Levine, 2017).

This series of mixed results paints a diffuse picture of mental imagery's involvement in episodic cognition. In part, this reflects the complexity of human memory processes (Palombo, Sheldon, & Levine, 2018; Pearson, 2019) and indicates that the qualitative experience of remembering and the successful recall of event details are dissociable components of autobiographical memory (Aydin, 2017). However, it also reflects the complexity of mental imagery as a heterogenous collection of time, task, and stimulus-dependent cognitive processes, rather than a unitary trait (Aydin, 2017; Pearson, 2019; Vannucci et al., 2016). Many of the aforementioned studies therefore suffer from a simple measurement problem – that is, metacognitive ratings of trait imagery ability may not consistently predict autobiographical memory performance because they do not objectively measure task-specific imagery strength. There are now established behavioural measures of sensory imagery strength (which can help to eliminate reliance on self-reports) that may go some way to resolving this measurement problem (Chang & Pearson, 2018; Keogh & Pearson, 2018; Pearson, 2014). Nevertheless, individual differences in self reports of imagery ability can only be marginally informative if imagery is still a dominant task strategy amongst those individuals. Given the proposed ubiquity of visual imagery in the general population, inter-individual variance in trait imagery ability can tell us what imagery domains (e.g. object or spatial) may be most useful for completing certain cognitive tasks (like remembering the details of a past event), but cannot tell us what performance on these same tasks would look like without imagery altogether.

One approach to answering the latter question is to focus on cases where visual imagery ability is disrupted or impaired. Anderson, Dewhurst, and Dean (2017) showed that using dynamic visual noise (a form of visual interference thought to selectively interfere with spatial imagery processes; McConnell & Quinn, 2004) seems to disrupt the number of specific memories participants are able to recall under test conditions. A more recent body of work demonstrates that dynamic visual noise also impairs the overall quality and accuracy of event representations, irrespective of whether participants are asked to remember real memories, imagine atemporal scenes, or recall details from experimental video stimuli (Sheldon et al., 2017; Sheldon, Cool, & El-Asmar, 2019). However, data from dynamic visual noise paradigms often do not suggest a consistent mechanism of action (Chubala, Ensor, Neath, & Surprenant, 2020; Valenti & Galera, 2020) and are contingent on an assumption that perceptual interference stimuli selectively disrupt visual imagery recruitment, rather than other sensory processes (e.g. working memory) or cognitive resources (e.g. attention) additionally involved in constructing event representations (Andrade, Kemps, Werniers, Jon, & Szmalec, 2002; Avons & Sestieri, 2011).

Clinical cases of visual imagery impairment can offer valuable insight into the potential shared brain networks that might support mental imagery and autobiographical memory, but this evidence is often anecdotal and complicated by multiple comorbidities. Ogden (1993) describes a case of cortical blindness due to occipital infarctions where the patient reported simultaneous visual imagery loss and autobiographical amnesia. Similarly, visuospatial imagery impairment often seems to be reported alongside deficits in event recall in cases of posterior cortical atrophy (Ahmed et al., 2018; Gardini et al., 2011; Ramanan et al., 2018). This dovetails with general evidence that damage to occipital regions results in visual imagery impairment and coinciding retrograde amnesia for autobiographical events (Conway & Fthenaki, 2000; Rubin & Greenberg, 1998; Rubin, Schrauf, & Greenberg, 2003). However, the majority of these case reports infer visual imagery impairment based on clinician anecdotes or outdated drawing recall tasks, rather than established measures of visual imagery ability. Additionally, the neural networks underpinning mental imagery extend far beyond the occipital cortex (Dijkstra, Bosch, & van Gerven, 2019; Dijkstra, Mostert, de Lange, Bosch, & van Gerven, 2018; Pearson, 2019), and whilst coinciding visual imagery and autobiographical memory deficits might indicate common occipital involvement in these processes, they do not necessarily imply a causal role for visual imagery in remembering past events. Furthermore, clinical cases present obvious methodological limitations aside from low sample sizes – cognitive impairment resulting from neurological damage or disease is rarely limited to acquired visual imagery loss alone, making it difficult to isolate the selective contribution of visual imagery to autobiographical memory.

However, special cases exist which allow researchers to bypass some of these design limitations. Some individuals (approximately 2–5% of the general population) experience a total inability to visualise in the absence of any acquired neurological damage or coinciding psychopathology – a condition termed "aphantasia" (Zeman et al., 2015, 2016). Importantly, aphantasia does not seem to be explained by self-report bias or poor metacognitive insight (Dawes et al., 2020; Keogh & Pearson, 2018; Wicken, Keogh, & Pearson, 2021), and aphantasic participants do not just score at floor on self-report imagery scales, but perform significantly worse than participants with typical visual imagery ability on an objective behavioural measure of sensory imagery strength (Keogh & Pearson, 2018). Interestingly, aphantasia also appears to be associated with weak object imagery, but typical spatial imagery (Bainbridge, Pounder, Eardley, & Baker, 2019; Dawes et al., 2020; Keogh & Pearson, 2018) and may be marked by reduced physiological responses to imagery-dependent emotional stimuli (such as flat skin conductance responses during fear-inducing stories (Wicken et al., 2021). By presenting a natural "knockout" model for visual imagery, aphantasia offers a unique opportunity to investigate the impact of visual imagery absence on episodic processes, and to deconstruct the complex relations between visual imagery and autobiographical memory (Palombo et al., 2018). In recent work (Dawes et al., 2020), we demonstrated that individuals with aphantasia report general deficits in episodic memory, future prospection, and semantic memory (but not spatial memory), and report a significantly reduced ability to visualise elements of scenes during autobiographical memory recall. That study presented the first evidence that aphantasia might be associated with a general reduction in the ability to mentally simulate events – irrespective of whether these events occurred in the past (when remembering life events), in the future (when constructing novel scenarios) or even during sleep (when dreaming). These preliminary findings offer some support for a mechanistic role of mental imagery in the construction of episodic events – and a role which is not selective to autobiographical memory specifically, but to multiple forms of event simulation.

However, self-reports of general trait abilities (such as autobiographical memory) do not allow for an objective, task-based approach to measuring episodic memory performance or content. Moreover, it is not clear that self-reported memory deficits reliably predict objective memory capacity, given that episodic autobiographical memory is likely underpinned by a variety of interconnected cognitive processes that may in turn be related to visual imagery in complex ways (Palombo et al., 2018). Typically, the subjective vividness of memory and the behavioural retrieval of specific episodic event details appear to be well correlated dimensions of remembering (Bainbridge et al., 2019; Moscovitch, Cabeza, Winocur, & Nadel, 2016; Yonelinas, 2002), suggesting that self-report ratings of trait episodic memory ability (as previously reported in aphantasia; Dawes et al., 2020) should be a reliable indicator of episodic memory task performance. However, neuroscientific evidence often challenges this assumption, showing that the neural networks underpinning autobiographical memory recall may diverge along different sub-systems which separately support episodic detail retrieval, and metacognitive or self-reflective dimensions of remembering, respectively (Andrews-Hanna, Saxe, & Yarkoni, 2014; Aydin, 2017). Similarly, this dissociation is matched by behavioural evidence of either impaired subjective recollection with intact memory performance (Fandakova, Johnson, & Ghetti, 2021; Huron et al., 1995), or impaired memory performance with intact subjective recollection (Addis, Roberts, & Schacter, 2011). These counter-examples highlight the need for careful examination of each individual's subjective experience of remembering alongside traditional behavioural measures of autobiographical memory capacity. In the case of aphantasia, it is crucial to investigate whether self-reported memory deficits (accompanying visual imagery absence) extend to altered performance on behavioural measures of episodic autobiographical memory and future prospection (as early findings suggest; Milton et al., 2021). In the current study, we therefore compare a sample of participants with aphantasia against a sample of control participants (with visual imagery) on an adapted autobiographical memory test to ask the question: how do individuals without visual imagery remember the past and construct possible futures?

2. Method

2.1. Participants

The study was approved by the UNSW Human Research Ethics Advisory Panel in line with National Health and Medical Research Council (NHRMC) guidelines on ethical human research. All participants gave informed consent before completing the study. Aphantasic participants were recruited from a pool of individuals who had signed up to an internal database. Aphantasic participants were remunerated for completing the study. 31 aphantasic participants in total completed the study, one of whom was excluded for study incompletion. Our final sample of aphantasic individuals included for analysis thus comprised of 30 participants (19 female and 11 male; mean age = 35.73 years, *SD* = 12.42 years, range = 18–68 years). Participants in our control group all reported intact visual imagery ability and were recruited from a variety of sources. 15 participants who were affiliated with individuals from the aphantasic sample (such as spouses, friends, or colleagues) directly contacted the lab to express their interest in research participation. These participants were remunerated for study completion. To achieve matched sample size, 11 participants were also recruited using Amazon Mechanical Turk (MTurk) and remunerated for participation. An additional eight participants were then recruited from a pool of undergraduate psychology students at the university who completed the study in exchange for course credit. This totaled 34 participants, four of whom (from the MTurk sub-sample) were excluded from analysis due to missing data or non-compliance with task instructions (such as recollection of non-specific memories on the autobiographical memory assessment). Our final control sample thus consisted of 30 participants (19 female, 10 male, and 1 with gender identity undisclosed; mean age = 35.77 years, *SD* = 12.04 years, range = 18–60 years).

Participants from the aphantasic sample and the control sample were matched on both age ($M_D = 0.033$ years, $SE_{D,}t_{58} = 0.011$, $p = .992$) and gender (Pearson $\chi^2_{1,58} = 0.031$, $p = 1.000$). Additionally, there were no significant differences between aphantasic participants ($n = 30$) and a subset of the control group (who completed an additional questionnaire battery; $n = 18$) on a range of mood and affective outcome measures (analysed using two-tailed, independent samples Kolmogorov-Smirnov tests), including reported depression ($Z = 1.230$, $p = .097$), anxiety ($Z = 1.155$, $p = .139$), and stress ($Z = 1.043$, $p = .226$) on the 21-item Depression Anxiety Stress Scale (DASS; Lovibond & Lovibond & Lovibond, 1995), trait anxiety ($Z = 0.783$, $p = .573$) on the State Trait Anxiety Inventory (STAI, Form Y; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), and positive affect ($Z = 1.342$, $p = .055$) and negative affect ($Z = 0.894$, $p = .400$) on the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988).

2.2. Experimental design, procedure, and materials

Participants completed a set of self-report questionnaires on visual imagery, followed by an adapted version of the Autobiographical Interview (Addis, Wong, & Schacter, 2008). The experiment was administered online using Qualtrics. All participants were subject to the same study design irrespective of experimental group.

2.2.1. Questionnaires

The Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973 & 1995) is a 16-item scale which asks participants to imagine a person as well as several scenes and rate the vividness of these mental images using a 5-point scale ranging from 1 ("No image at all, you only 'know' that you are thinking of the object") to 5 ("Perfectly clear and <as> vivid as normal vision"). A single mean score on the VVIQ was computed for each participant. The Object and Spatial Imagery Questionnaire (OSIQ; Blajenkova et al., 2006) is a 30-item scale which requires participants to indicate how well each of several statements on object imagery ability (e.g. "When I imagine the face of a friend, I have a perfectly clear and bright image") and spatial imagery ability (e.g. "I am a good Tetris player") applies to them on a 5-point scale ranging from 1 ("Totally disagree") to 5 ("Totally agree"). There are 15 items each comprising the Object and Spatial imagery domains of the OSIQ. A mean object imagery score, and a mean spatial imagery score, were computed for each participant by averaging raw scores across the total number of items in each domain. The Episodic Memory Imagery Questionnaire (EMIQ) is a custom designed, 16-item self-report questionnaire which aims to assess the subjective vividness of episodic memory. Items on the EMIQ were derived from the VVIQ scale (Marks, 1995) and modified for context. The EMIQ asks participants to remember several events or scenes from their life and rate the vividness of these scenes using a 5-point scale (similar to the VVIQ) ranging from 1 ("No image at all, I only 'know' that I am recalling the memory") to 5 ("Perfectly clear and as vivid as normal vision"). A single mean score on the EMIQ was computed for each participant.

2.2.2. *Adapted Autobiographical Interview*

2.2.2.1. Administration. Participants completed an online version of the adapted Autobiographical Interview (Addis et al., 2008). Participants were asked to remember six life events (real memories) and imagine six hypothetical future events in response to standardised word cues matched on imageability (e.g. "Book" or "Garden"; Clark & Paivio, 2004). Task instructions specified that these events must be specific (occurring at a specific time or place) and occur within a precise 24-hour period. Trials were blocked into sets of two and counterbalanced (e.g. two memory trials in a row, followed by two future trials). On each trial, participants generated a detailed written description of the event in question. Internal survey logic ensured that at least 3.5 minutes were spent describing each event, with a minimum limit of 150 characters. 12 written event descriptions were obtained in total for each participant, yielding 720 event descriptions in total.

2.2.2.2. Scoring protocol. These descriptions were then scored using a standardised protocol (Addis et al., 2008; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002) which parses and partitions event descriptions into discrete information segments characterised as 'internal details' (episodic details specific to the event, such as event, place, time, perceptual, cognitive, and emotion details) and 'external details' (including semantic or factual details, repetitions, extraneous events, and other metacognitive or irrelevant information). The number of internal and external details were then tallied for each event, in addition to the number of details within each internal and external detail subcategory (e.g. the number of perceptual internal details, or the number of semantic external details). In accordance with the original scoring protocol (Levine et al., 2002), internal details were sub-coded as event, time, place, thought, emotion, or perceptual details. Additionally, we also tallied the number of sensory details (visual, auditory, tactile, olfactory, gustatory, and kinesthetic details) within the perceptual subcategory of internal details for each event description. External details were sub-coded into four categories: semantic details, extraneous event details, repetitions, and "other" details (such as metacognitive or editorial statements).

Whilst the uncorrected tallies of internal and external details provide the most valuable information about the episodic richness of remembered and future events, they are also subject to within-participant variance in performance across trials, as well as between-participant differences in the total number of event details produced. We therefore computed an additional 'episodic ratio' score by averaging the number of internal details over the total number of event details for each event trial. An episodic ratio score of 0.95, for example, denotes that 95% of the total scored details were internal details. This would typically indicate autobiographical memory recall that was rich in event-specific episodic detail, and low in semantic content not directly pertaining to the event (or other erroneous information). Episodic ratio scores yield a complementary measure of episodic richness to be considered alongside internal and external detail tallies, allowing us to partially control for individual differences in the total number of event details generated (which is correlated with total word count, and therefore potentially attributed to other extraneous factors such as typing speed, attention, verbosity, or writing competency). By the same logic, we operationalised detail sub-categories as within-participant proportions of the overarching detail category – that is, we computed within-event ratios of perceptual details to internal details, visual details to internal details, semantic details to external details, and so on. An internal detail tally, external detail tally, episodic ratio score, and ratio score for each detail sub-category, were thus produced for every event description (yielding 720 data points per dependent variable, or 360 per group).

2.2.2.3. Scoring agreement. The total event descriptions were randomised and scored by an independent external rater blind to the experimental hypothesis and blind to group and condition labels. Interrater reliability was assessed for 20% of the data (144 event descriptions), which was also scored by A.J.D (blind to group and condition labels). Interrater reliability was assessed independently for the internal and external detail scores using two intra-class correlational analyses (under two-way random effects, absolute agreement parameters). ICC values are reported for the composite internal and external details only (not the detail sub-types). Interrater reliability was excellent for internal details (ICC = 0.910, 95% CI [0.834, 0.946,]) and very good for external details (ICC = 0.878, 95% CI [0.821, 0.915]).

2.2.2.4. Details across time periods. For each event, participants also reported its temporal remoteness – that is, how 'recently' each event occurred (or might occur) in time. For past events, participants freely chose between four possible temporal distance ratings (e.g. whether the memory occurred "Greater than three years ago"; "Longer than one year ago, but less than three years ago"; "Within the last year, but longer than one month ago"; or "Less than one month ago"). Similarly, participants reported how far into the future each imagined hypothetical scenario might take place (e.g. whether the event might occur "Less than one month from now"; "Within the next year, but greater than one month from now"; "Greater than one year from now, but less than three years from now"; or "Greater than three years from now"). This yielded eight time period categories in total (see Fig. 2f).

2.2.2.5. Phenomenological ratings. On each trial, after providing a written description of the recalled or imagined event, participants also rated their subjective experience of the event on a phenomenological scale, reporting their agreement with a range of statements on a 7-point Likert-type scale (ranging from 1: "Not at all" to 7: "To a very high degree"). These statements assessed participants' qualitative experience of each event's vividness (e.g. "This future event is vivid"), sensory details (e.g. "I can see and hear in my mind where it will take place"), spatial details ("I can clearly see the arrangements of the objects/people"), field perspective (e.g. "I primarily see what happened from a perspective of my own eyes"), observer perspective (e.g. "I primarily see what happened as if I am a fly on the wall"), emotion (e.g. "The emotions I have when I imagine the episode are intense"), personal importance (e.g. "This event is important to me"), and coherence (e.g. "When imagining the event, it comes to me as a coherent story and not as an isolated scene"). Self-report questions were derived from the literature (Berntsen & Jacobsen, 2008; D'Argembeau & Van Der Linden, 2004; D'Argembeau & Van der Linden, 2006; Johnson, Foley, Suengas, & Raye, 1988) and combined into a 12-item phenomenological scale. Participants completed this scale after each event, and item scores were then averaged into the eight variables listed above (see Table S2 in Supplementary Information). All variable scores were then averaged across time (six past events, and six future events), such that each experimental group had a single past event score and a single future event score on each of the phenomenological variables.

2.2.2.6. Linguistic analysis. Naturalistic language expression (such as during verbal speech or written text) often contains rich information about an individual's emotional affect, cognitive state and general psychological wellbeing (Pennebaker, Mehl, & Niederhoffer, 2003). Similarly, participant descriptions of remembered or imagined events might yield useful linguistic markers of between-group differences in cognition (Kahn, Tobin, Massey, & Anderson, 2007; Peters, Wiehler, & Bromberg, 2017). We chose to conduct supplementary, exploratory analyses of participant event descriptions using the commercially available text processing and analysis software program Linguistic Inquiry and Word Count (LIWC 2015; Pennebaker, Booth, Boyd, & Francis, 2015). LIWC has been used to assess autobiographical memory impairment in pediatric patients as a function of verbal fluency (Sekeres et al., 2018), as well as to demonstrate robust differences in language use between depressed and non-depressed individuals (Himmelstein, Barb, Finlayson, & Young, 2018), and between older and younger adults during recall of emotionally valenced autobiographical memories (Schryer, Ross, St. Jacques, Levine, & Fernandes, 2012). There is also some evidence that linguistic features derived from Linguistic Inquiry and Word Count (along with other manual text features) are robust predictors of summed internal and external scores on the Autobiographical Interview during episodic memory and prospection (Peters et al., 2017).

Linguistic Inquiry and Word Count conducts an automated linguistic analysis using pre-existing validated dictionaries to classify and 'score' each text on a wide range of grammatical, syntactic, and semantic features. It computes each feature score by tallying the number of words in each body of text which fall under a certain feature category, and normalising this tally over the text's total word count. Although our analyses using the Linguistic Inquiry and Word Count program were exploratory, we nevertheless limited our focus to hypothesis-driven variables of interest, being specifically interested in potential group differences in visuo-spatial imagery use during episodic cognition. We therefore targeted domains which captured information that might reflect the extent to which participants recruited sensory and spatial representations during episodic simulation.

We analysed six main Linguistic Inquiry and Word Count feature categories of interest representing these domains: A Perceptual Processes category (which averages three sub-categories: "see", "hear", and "feel"), a "body" sub-category (e.g. *arm*, *shoulder, thirsty*), and a Spatial sub-category ("space", e.g. *above, underneath, near*). We also analysed three Linguistic Inquiry and Word Count feature categories reflecting cognitive language use (Cognitive; e.g. *thought, know*), emotional language use (Affective; e.g. *happy, love, worried*), and temporal language use (Time, e.g. *Spring, sunset, Sunday, October*), in addition to three Linguistic Inquiry and Word Count feature categories (Past Focus, Present Focus and Future Focus) which capture temporal language use through tense structure (e.g. the imperfect tense use in "I *went* to the beach" would contribute to the Past Focus dimension, whilst "I *will* go to the beach *tomorrow*" would map onto the Future Focus dimension).

We derived raw scores on all 12 feature categories for each individual event description, yielding 720 scores per feature category (or 360 scores per group). These were all collapsed across time (resulting in a single total score per group on each feature category), with the exception of the three time-oriented language domains (Past, Present and Future Focus) for which we computed both a past event score and a future event score for each participant. We also used Linguistic Inquiry and Word Count to assess general language comprehension and writing competency by computing a single total score per group on a range of general linguistic markers including: word count, words per sentence, number of words used of six letters or more, punctuation use (e.g. periods, commas, question marks, dashes, apostrophes), pronouns (e.g. *I*), articles (e.g. *the*), prepositions (e.g. *above*), auxiliary verbs (e.g. *have*), adverbs (e.g. *very*), conjunctions (e.g. *but*), negations (e.g. *never*), verbs (e.g. *swim*), adjectives (e.g. *happy*), and informal language use (including non-fluencies such as *umm*, *aah*, or *hmm*; and filler words such as *dunno*, or *you know*).

2.3. Data analysis

All analyses were carried out in SPSS 27.0 for Mac OS. Analyses were blocked into six chronological Results sections, beginning with the self-report questionnaire data and followed by five outcome measures from the adapted Autobiographical Interview: internal details; external details; episodic ratio scores; subjective event ratings; and linguistic analyses.

2.3.1. Self report questionnaires

Between-group differences in self-reported imagery were analysed using non-parametric independent samples Kolmogorov-Smirnov tests, with the family-wise error rate controlled using a Bonferroni adjusted alpha criterion of $\alpha = 0.0125$ (0.05/4 where 4 is the number of scale variables analysed; see Fig. 1).

2.3.2. Autobiographical interview detail scores

Assumptions of normality for parametric analyses were assessed using Shapiro-Wilk tests. The internal detail tallies ($W_{720} = 0.987$. $p < .001$), external detail tallies ($W_{720} = 0.656$. $p < .001$), and episodic ratio scores ($W_{720} = 0.649$. $p < .001$) all showed a significant departure from normality (as did all sub-categories of the internal and external detail scores; all $W_{720} < 0.948$, all $p < .001$). We therefore analysed detail scores on the adapted Autobiographical Interview using a series of generalized linear mixed effects models (GLMM) with varying distributions and link functions (based on optimal model fits for each detail category or sub-category). For each analysis, detail scores for individual events ($n = 720$) were modelled as a function of imagery group (controls, aphantasia), time (past, future), and the group-time interaction (fixed effects), with intercepts varying by participant (random effect). *p*-values and confidence intervals were derived via the Kenward-Roger approximation for degrees of freedom (Kenward & Roger, 1997). Note that for each generalized linear mixed effects model in the Results sections, we primarily report planned pairwise contrasts (controlled for within tests using the sequential Bonferroni adjustment) corresponding to our a priori hypotheses of differences in detail scores between groups (at each level of time), and within groups (across time).

Internal details were modelled using a Gaussian distribution (power link), while external details and episodic ratio scores were modelled using Gamma distributions (with power links). The family-wise error rate across these three main analyses was controlled for using a Bonferroni adjusted alpha criterion of $\alpha = 0.016$ (~0.05/3). We then fit independent models for each sub-category of the internal details (event, time, place, thought, emotion, perceptual, visual, auditory, tactile, kinesthetic, olfactory, and gustatory), and for each sub-category of the external details (semantic, "other", extraneous event, and repetitions), controlling the alpha criterion across these analyses at $\alpha = 0.003$ (~0.05/16, where 16 is the total number of detail sub-categories). All detail sub-category scores were fit with Gamma distributions and power link functions (with the exception of internal event details, which were fit with a Gaussian distribution and power link). Where supplementary models appear in Results (such as during model comparison, or in Fig. 2f – where the two-level past-future time predictor is substituted by an eight-level time period predictor), the distributions and link functions were otherwise fitted to data using the same model parameters as those above.

2.3.3. Phenomenological ratings

Between-group differences in phenomenological event ratings were analysed independently for past and future events with 16 non-parametric, independent samples Kolmogorov-Smirnov tests (two-tailed), while overall differences in phenomenological event ratings across time (averaged across groups) were analysed using 8 non-parametric, matched-pairs Wilcoxon signed rank tests (two-tailed). The family-wise error rate across this series of tests was controlled using a Bonferroni adjusted alpha criterion of $\alpha = 0.002$ (~0.05/24, where 24 is the total number of tests conducted; see Fig. 3).

2.3.4. Linguistic analysis

We first assessed between-group differences in language use when describing mentally simulated events using a multivariate (2 × 12) repeated measures analyses of variance (RMANOVA), entering the effects of imagery group (controls, aphantasics) and Linguistic Inquiry and Word Count feature category (Perceptual, See, Hear, Feel, Body, Space, Cognitive, Affective, Time, Past Focus, Present Focus, Future Focus) as independent variables. We then conducted three follow-up mixed model (2 × 2) ANOVAs to assess the effect of imagery group (controls, aphantasics) and time (past events, future events) on three LIWC domains measuring time-oriented language use (Past Focus, Present Focus, and Future Focus). Across these analyses, we controlled the family-wise error rate using a Bonferroni-adjusted alpha criterion of $\alpha = 0.004$ (0.05/12; see Fig. 4). To assess between-group differences in verbosity and writing competency/style, we next conducted a series of two-tailed independent samples *t*-tests on 19 grammatical feature variables extracted from LIWC (with a single total score calculated per group on each linguistic domain; see Linguistic Analysis). Across these tests, the family-wise error rate was controlled using a Bonferroni adjusted alpha criterion of $\alpha = 0.0025$ (~0.05/19 where 19 is the number of independent tests conducted). Finally, we sought to explore the potential association between automated linguistic feature categories (derived from Linguistic Inquiry and Word Count) and detail score sub-categories on the adapted Autobiographical Interview. Both outcome variables were operationalised as proportion scores (linguistic scores as a percentage of the text in each event description corresponding to each feature category, and detail sub-categories on the adapted Autobiographical Interview as a proportion of either the internal or external detail tally for each event description). Spearman's rho correlations were used to assess the relationship between 9 linguistic feature categories (excluding only the Past Focus, Present Focus, and Future Focus linguistic scores, as they target grammatical tense rather than content) and all sub-categories of the internal detail scores (event, time, place, thought, emotion, perceptual, visual, auditory, tactile, kinesthetic, olfactory, gustatory) and external detail scores (semantic, other, extraneous, repetitions) on the adapted Autobiographical Interview. Although we only present a sub-section of the full correlation matrix (see Fig. 5), we controlled for multiple comparisons using a Bonferroni adjusted alpha criterion of $\alpha = 0.00008$ (~0.05/625, where 625 is the total number of possible cell combinations in the full correlation matrix).

2.3.5. *Effect size estimates*

Approximate estimates of effect size are reported in Results sections where appropriate. For non-parametric tests, we estimated effect sizes *r* for independent samples Kolmogorov-Smirnov tests and matched pairs Wilcoxon signed ranks tests using the formulae below (left and right, respectively):

$$r = \frac{Z}{\sqrt{\frac{n1*n2}{(n1+n2)}}} \qquad \text{and} \qquad r = \frac{Z}{\sqrt{N}}$$

where Z is the standardized non-parametric test statistic, N the total sample size of the combined groups, $n1$ and $n2$ the sample size of the independent groups, and r the output effect size estimates (comparable with Cohen's d effect size interpretations; Rosenthal, 1994).

3. Results

3.1. *Self-report questionnaires*

Aphantasic participants reported significantly lower overall visual imagery vividness on the VVIQ (17.27 ± 0.42) than control participants (63.50 ± 1.94; $Z = 3.873$, $p < .001$, $r \rightarrow 1$, two-tailed; see Fig. 1), reinforcing previous findings (Dawes et al., 2020; Keogh & Pearson, 2018; Zeman et al., 2020). The distribution of aphantasic subjects' object imagery scores was significantly lower than that of controls ($Z = 3.873$, $p < .001$, $r \rightarrow 1$, two-tailed; see Fig. 1). Interestingly, Fig. 1 also highlights that there were no significant differences between groups in the distributions of scores on the spatial imagery component of the OSIQ ($Z = 0.387.0$, $p = .998$, $r = 0.1$, two-tailed), replicating previous findings of intact spatial imagery in aphantasic samples (Dawes et al., 2020; Keogh & Pearson, 2018; Zeman et al., 2010; Bainbridge et al., 2019). Lastly, aphantasic participants in our study reported diminished visual imagery compared to controls when remembering past events ($Z =$ 3.873, $p < .001$, $r \rightarrow 1$, two-tailed; see Fig. 1 EMIQ section), indicating that self-reported imagery deficits in aphantasia are not limited to atemporal imagery contexts (measured by the VVIQ).

3.2. *Internal details*

Fig. 2a depicts internal detail scores on the adapted Autobiographical Interview across groups and time. Aphantasic participants generated significantly fewer internal details than control participants for both past events (Fig. 2a left panel; $\beta = 6.176$, $SE = 2.162$, $t = 2.857$, $p =$ .006, 98.4% CI_D [0.835, 11.518]) and future events (Fig. 2a right panel; $\beta = 7.197$, $SE = 2.005$, $t = 3.590$, $p = .001$, 98.4% CI_D [2.248, 12.147]). Whilst control participants produced an equivalent number of internal details across time (Fig. 2a left and right panels; $\beta = 1.302$, $SE = 0.727$, $t = 1.789$, $p = .074$, 98.4% CI_D [−0.455, 3.058]), aphantasic individuals produced significantly fewer internal details when imagining hypothetical future events compared to past events ($\beta = 2.322$, $SE = 0.746$, $t = 3.112$, $p = .002$, 98.4% CI_D [0.521, 4.124]).

Subsequent analysis of internal detail sub-categories revealed a reduction in perceptual information amongst aphantasic participants (see Fig. 2b), with a significant fixed effect of imagery group found for the perceptual detail model ($F_{1,\,62} = 14.750$, $p < .001$, $\eta_P^2 = 0.19$). There was no significant fixed effect of imagery group for any of the models fitted to the other internal detail sub-categories (all $F_{1,\,62} < 3.682$, all $p > .060$). Moreover, pairwise contrasts suggested that the aphantasic reduction in perceptual information occurred predominantly during future event simulation (where aphantasic participants produced approximately 7.6% fewer perceptual details than controls; $\beta = 7.693$, $SE = 2.109$, $t = 3.648$, $p < .001$, 99.7% CI_D [1.304, 14.081]), with weaker between-group differences observed in the within-event ratios of perceptual details to internal details when participants were remembering life events ($\beta = 6.330$, $SE = 2.227$, $t = 2.843$, $p = .005$, 99.7% CI_D [−0.423, 13.083], non-significant after Bonferroni correction).

Breaking down these group differences further, Fig. 2c demonstrates that aphantasic participants' reduction in perceptual details may have been selectively driven by a reduction in visual detail retrieval relative to controls ($F_{1,\,62} = 9.670$, $p = .003$, $\eta_P^2 = 0.13$). There was no significant reduction in aphantasic participants' proportion of internal details in any other sensory modality, compared to controls (including auditory, tactile, kinesthetic, olfactory, or gustatory details; all $F_{1,\,62} < 4.716$, all $p > .014$, all non-significant after Bonferroni correction). Paralleling the between-group difference observed in perceptual details, this reduction

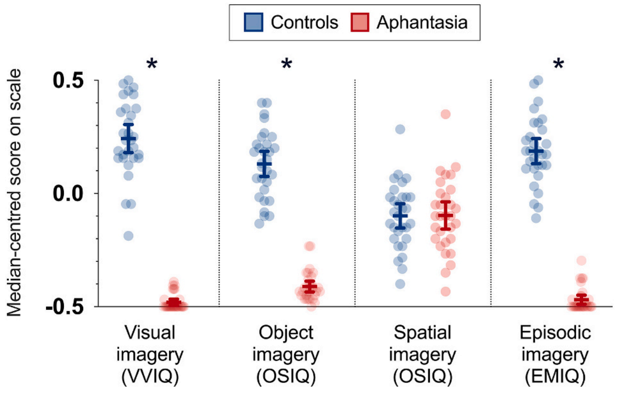
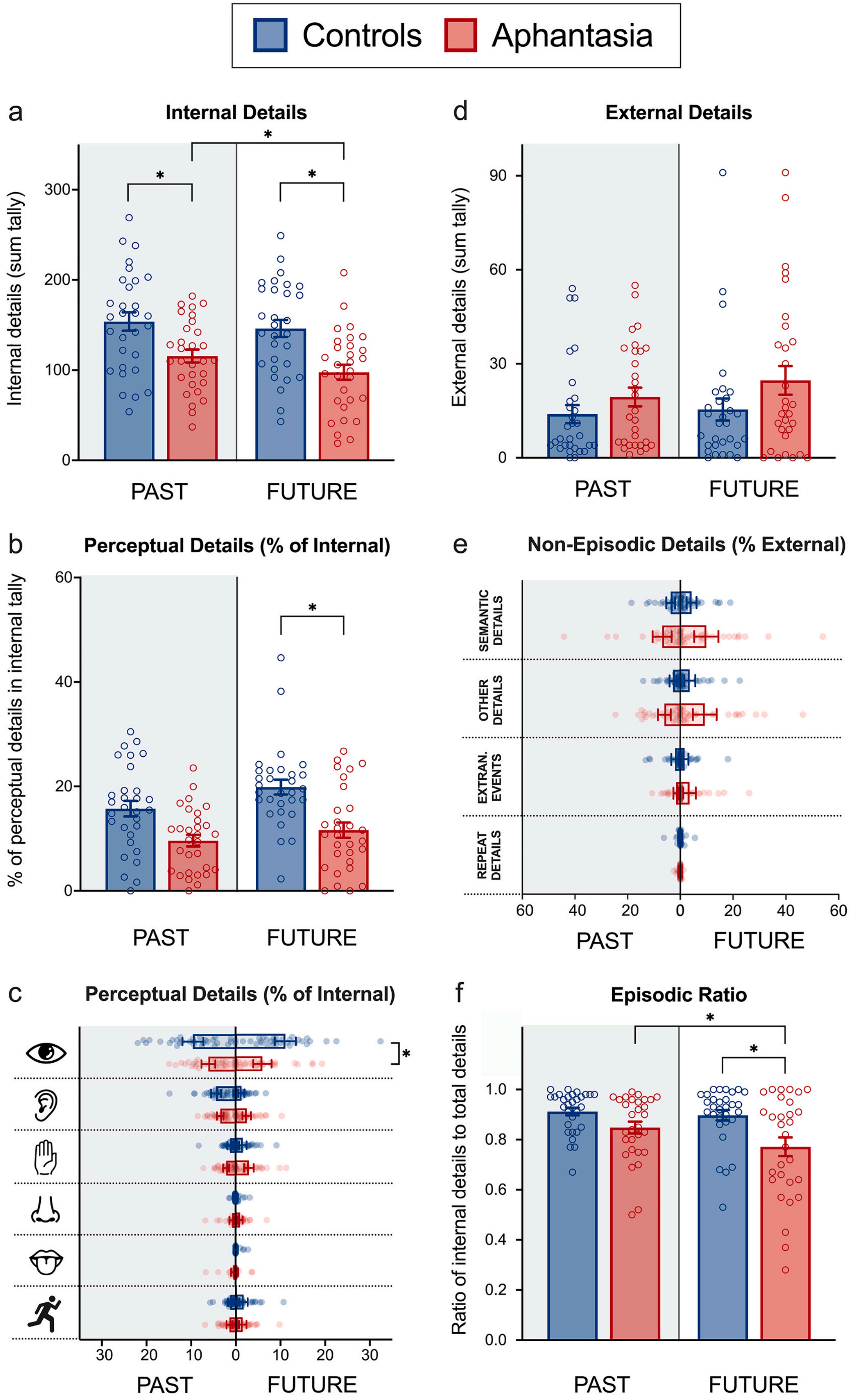


Fig. 1. Summary of self-report questionnaires for individuals with aphantasia (red, $n = 30$) and controls (blue, $n = 30$). Scatter plots depict median-centred scores on each scale, coloured by group. Solid lines represent mean scores (± 95% *C.I.s*). On the vertical axis, 0.0 represents the median score, −0.5 the lowest possible score, and 0.5 the maximum possible score on each scale. Stars denote significance at a Bonferroni corrected alpha criterion of $p < .0125$. For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



(caption on next page)

Fig. 2. Detail scores for past and future events on the adapted Autobiographical Interview for control participants (blue, $n = 30$) and aphantasic participants (red, $n = 30$). Panels **a** and **d** depict sum tallies of internal details and external details, respectively. Panel **f** depicts the within-event ratios of internal details to total details. Panel **b** depicts within-event ratios of perceptual details to internal details, whilst panel **c** depicts sensory sub-categories of perceptual details (from top to bottom: visual, auditory, tactile, olfactory, gustatory, kinesthetic) as within-event proportions of internal details. Panel **e** depicts within-event ratios of non-episodic detail sub-categories to external details. All panels depict mean condition scores (± *SEM*), with the exception of panels c and e (which depict 95% *C.I.s*). Circles on all graphs depict mean individual scores. Stars denote significance at corrected alpha thresholds using the Bonferroni adjustment (see Data Analysis and Results sections). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in visual detail was most prominent during future event simulation (where aphantasic participants produced approximately 5.1% fewer visual details than controls; $\beta = 5.165$, $SE = 1.630$, $t = 3.168$, $p = .002$, 99.7% CI_D [0.218, 10.111]), and was not statistically significant during episodic autobiographical memory ($\beta = 3.604$, $SE = 1.654$, $t = 2.179$, $p = .031$, 99.7% CI_D [−1.416, 8.624], non-significant after Bonferroni correction).

3.3. External details

Fig. 2d depicts the number of external (or non-episodic) details scored on the adapted autobiographical memory task. There were no significant differences between aphantasic participants and controls in the number of external details produced for either past events (Fig. 2d left panel; $\beta = 0.987$, $SE = 0.870$, $t = 1.135$, $p = .259$, 98.4% CI_D [−1.149, 3.124]) or future events (Fig. 2d right panel; $\beta = 1.601$, $SE = 0.848$, $t = 1.888$, $p = .062$, 98.4% CI_D [−0.481, 3.683]). Similarly, there were no significant effects of time on external detail scores within either the control group ($\beta = 0.242$, $SE = 0.506$, $t = 0.478$, $p = .632$, 98.4% CI_D [−0.979, 1.463]) or the aphantasic group ($\beta = 0.856$, $SE = 0.486$, $t = 1.761$, $p = .079$, 98.4% CI_D [−0.318, 2.029]; see Fig. 2d both panels). Additionally, there were no significant fixed effects of imagery group on the proportion of non-episodic details in each external detail sub-category (see Fig. 2e, top to bottom), including semantic details ($F_{1,\ 62} = 0.408$, $p > .05$), "other" details ($F_{1,\ 62} = 2.563$, $p > .05$), extraneous event details ($F_{1,\ 62} = 0.288$, $p > .05$), or repetitions ($F_{1,\ 62} = 1.527$, $p > .05$). Similarly, there were no significant effects of time (past, future) on the proportion of external details in each sub-category (all $F_{1,\ 662} < 2.141$, all $p > .05$).

3.4. Episodic ratio scores

On average, aphantasic participants' event descriptions contained approximately 10.6% less episodic information than control participants' event descriptions ($\beta = 0.106$, $SE = 0.036$, $t = 2.983$, $p = .004$, 98.4% CI_D [0.018, 0.194]). Fig. 2f demonstrates that the overall deficit in episodic information produced by aphantasic participants was most pronounced when imagining hypothetical future events. Although the distribution of episodic ratio scores were not significantly different between groups for past events (Fig. 2f left panel; $\beta = 0.068$, $SE = 0.041$, $t = 1.655$, $p = .101$, 98.4% CI_D [−0.033, 0.169]), aphantasic participants' descriptions of future events contained a 14.1% lower episodic ratio compared to controls (Fig. 2f right panel; $\beta = 0.141$, $SE = 0.039$, $t = 3.652$, $p < .001$, 98.4% CI_D [0.046, 0.236]). Aphantasic participants also produced 9.1% less episodic information when imagining future events (Fig. 2f right panel) than they did when remembering past events ($\beta = 0.091$, $SE = 0.024$, $t = 3.767$, $p < .001$, 98.4% CI_D [0.033, 0.149]), whereas controls' episodic ratio distributions did not differ significantly across time ($\beta = 0.018$, $SE = 0.027$, $t = 0.651$, $p = .515$, 98.4% CI_D [−0.048, 0.083]).

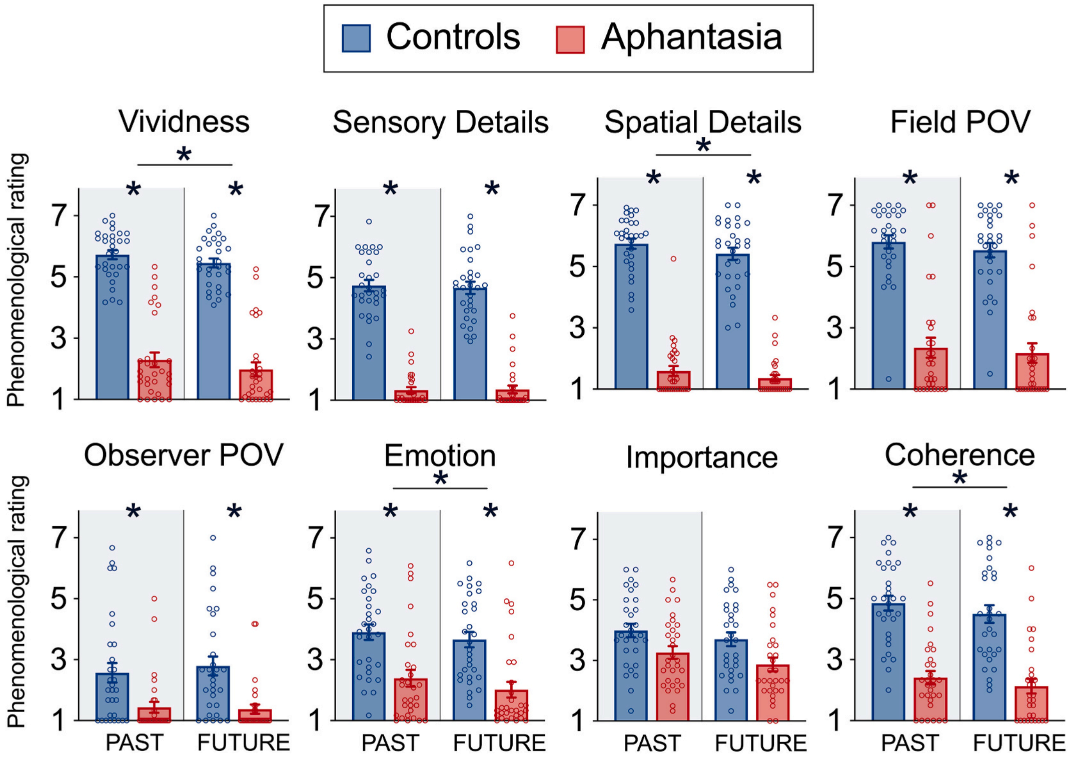


Fig. 3. Phenomenological ratings of remembered and imagined events as a function of imagery group (controls = blue; aphantasia = red) and time (past, future; bottom X axis). Bars represent mean scores (± 95% C.Is) on 7-point Likert-type agreement scale. Dots represent individual data; stars denote significance at Bonferroni-corrected alpha criterion of $p < .002$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

We were next interested in whether episodic detail scores varied as a function of the temporal remoteness of remembered and imagined events. Although the number of reported events was not equivalent across time periods, a chi squared test of independence on participants' free choices of time period revealed no significant interaction between time period and imagery group ($\chi^2_{1,7} = 12.385$, $p > .05$). This indicates that aphantasic participants and control participants chose a similar number of past and future events to report at each time period. Further, the reduced model for episodic ratio scores (with only imagery group, time, and the group-time interaction term as fixed effects) showed better model fit compared to an equivalent model with the temporal remoteness of events included as an additional fixed factor ($\chi^2_1 = -43.169$, $p > .05$), as well as compared to a model with temporal remoteness and the three-way group-time-remoteness interaction term included as additional fixed factors ($\chi^2_2 = -165.977$, $p > .05$). This indicates that the main pattern of between-group and within-group effects in episodic ratio scores reported earlier (see Fig. 2f) held irrespective of how long ago in the past (or how far away in the future) these mental events occurred in time.

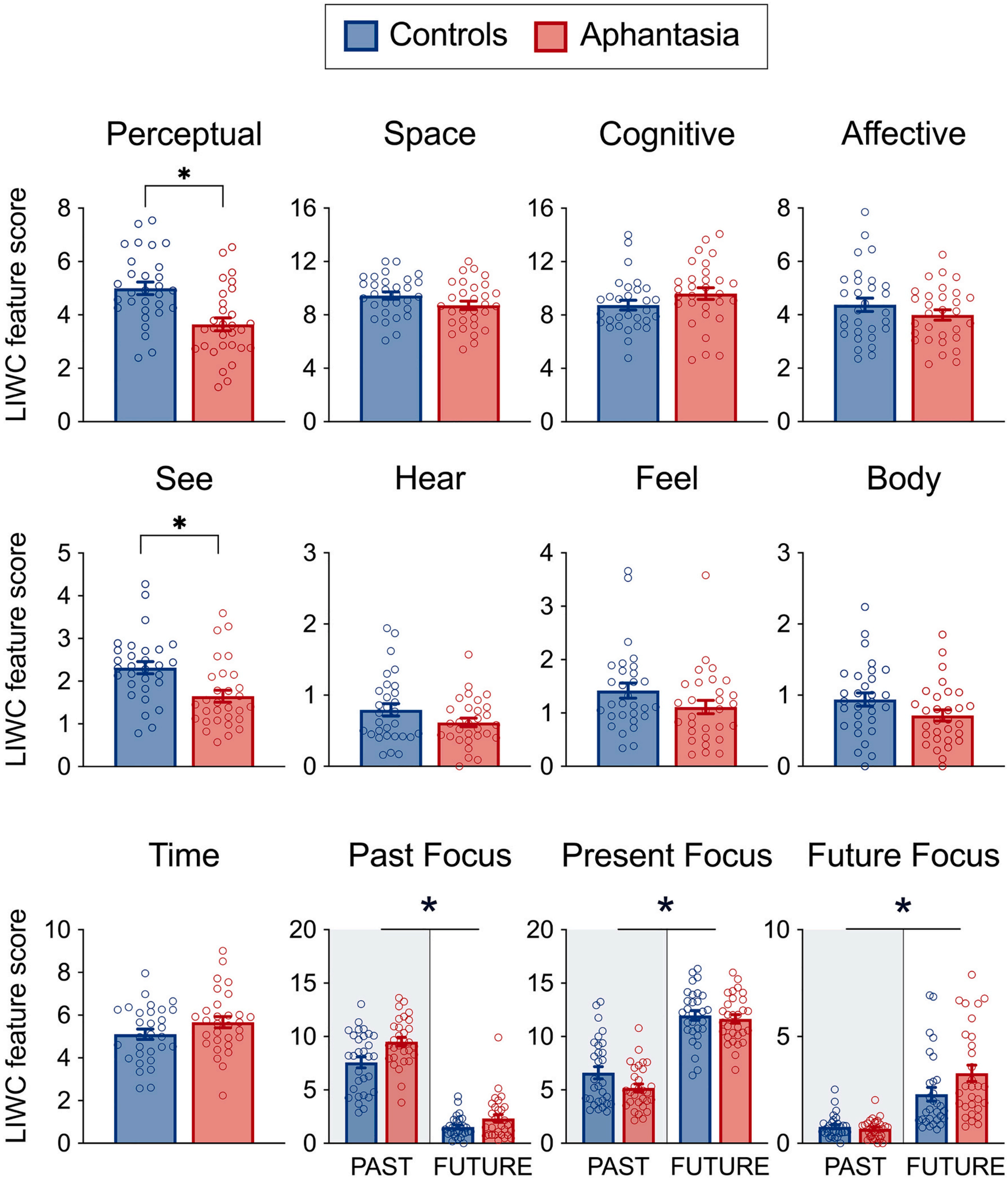


Fig. 4. Mean linguistic feature category scores (± 95% *C.I.s*) as a function of imagery group (blue = control participants; red = aphantasic participants). Extracted LIWC scores reflect sensory (Perceptual, Visual, Auditory, Tactile, Spatial, Kinesthetic), cognitive (Cognitive), emotional (Affective), and temporal (Time, Past Focus, Present Focus, Future Focus) language use. Stars denote significance at corrected alpha criterion of $p < .004$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.5. Phenomenological ratings

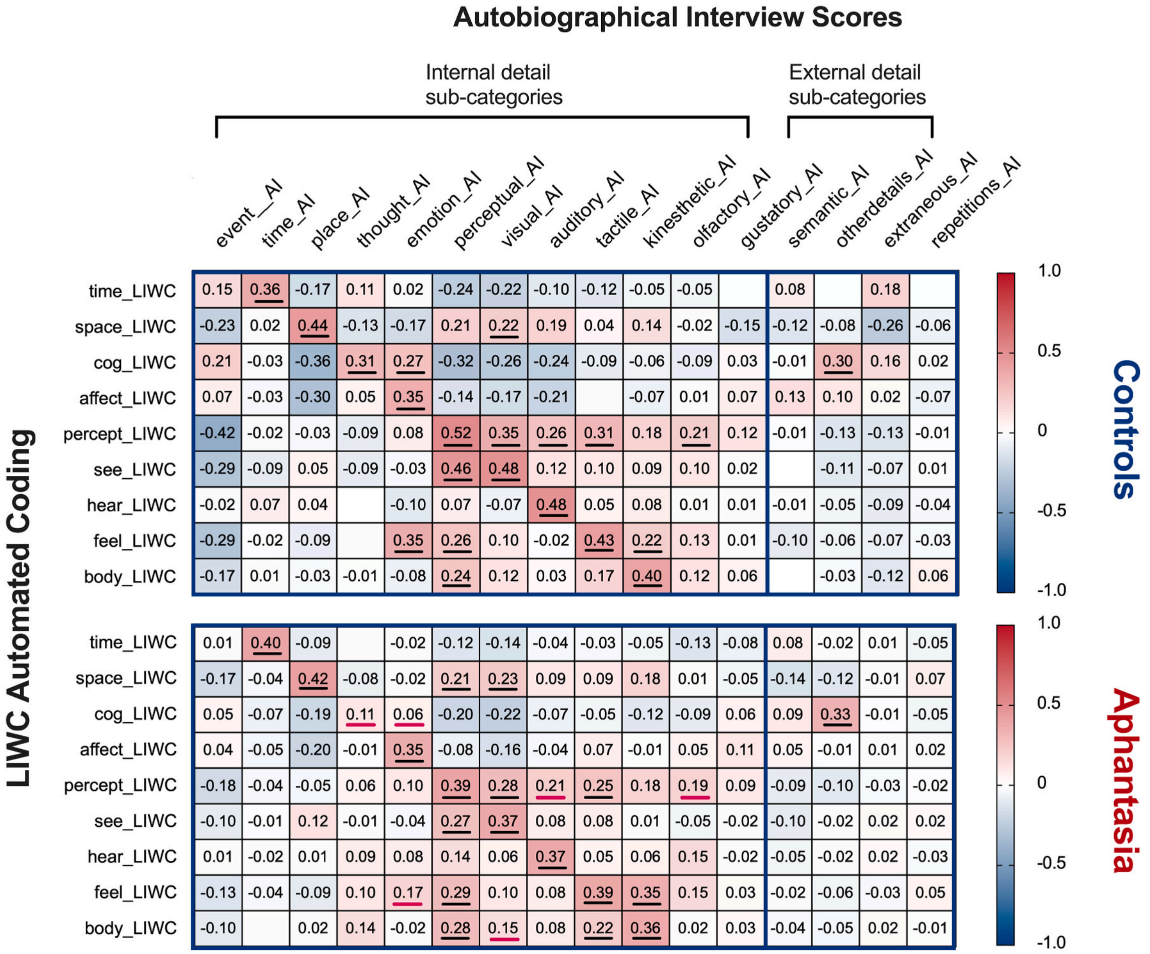
Fig. 3 shows that aphantasic participants rated their episodic events as being significantly less vivid overall compared to controls (past events: $Z = 3.227$, $p < .001$, $r = 0.833$; future events: $Z = 3.615$, $p < .001$, $r = 0.933$), as well as being comparatively lower in both sensory details (past events: $Z = 3.615$, $p < .001$, $r = 0.933$; future events: $Z = 3.615$, $p < .001$, $r = 0.933$) and spatial details (past events: $Z = 3.744$, $p < .001$, $r = 0.967$; future events: $Z = 3.744$, $p < .001$, $r = 0.967$). On average, aphantasic participants scored significantly lower than controls on both the field perspective (past events: $Z = 3.098$, $p < .001$, $r = 0.800$; future events: $Z = 3.098$, $p < .001$, $r = 0.800$) and observer perspective (past events: $Z = 1.678$, $p = .007$, $r = 0.433$; future events: $Z = 2.066$, $p < .001$, $r = 0.533$) items (see Fig. 3, Field POV and Observer POV panels). Since scoring highly on the "Field" perspective rating for an event implies a low score on the "Observer" perspective rating, it is likely that aphantasic participants' low ratings on both of these variables reflects a generally diminished ability to internally "see" or imagine events visually. Lastly, aphantasic participants rated their episodic events as being significantly less emotional (past events: $Z = 2.066$, $p < .001$, $r = 0.533$; future events: $Z = 2.582$, $p < .001$, $r = 0.667$) and coherent (past events: $Z = 2.582$, $p < .001$, $r = 0.667$; future events: $Z = 2.582$, $p < .001$, $r = 0.667$) compared to control participants, but did not rate these events as significantly less important or personally relevant compared to participants with typical visual imagery ability (past events: $Z = 1.291$, $p = .071$, $r = 0.333$; future events: $Z = 1.549$, $p = .016$, $r = 0.400$; non-significant after Bonferroni correction).

Fig. 3 also demonstrates that irrespective of imagery group, past events were rated as being significantly more vivid ($Z = 3.340$, $p < .001$, $r = 0.431$), richer in spatial details ($Z = 3.945$, $p < .001$, $r = 0.509$), more emotional ($Z = 3.373$, $p < .001$, $r = 0.435$), and more coherent ($Z = 2.974$, $p = .003$, $r = 0.394$) than future events. However, there were no significant differences between past and future events in overall ratings of sensory details ($Z = 0.146$ $p > .05$, $r = 0.019$), field perspective ($Z = 2.158$, $p = .031$, $r = 0.279$, non-significant after Bonferroni correction); observer perspective ($Z = 0.500$, $p > .05$, r 0.065) or the personal importance of events ($Z = 2.436$, $p = .015$, $r = 0.314$, non-significant after Bonferroni correction).

3.6. Linguistic analysis

3.6.1. Verbosity and writing style

Aphantasic participants' event descriptions did not differ significantly from those of controls on any of our extracted grammatical variables from Linguistic Inquiry and Word Count (all $p > .0025$, all non-significant after Bonferroni correction), including verbosity (word



	event__AI	time_AI	place_AI	thought_AI	emotion_AI	perceptual_AI	visual_AI	auditory_AI	tactile_AI	kinesthetic_AI	olfactory_AI	gustatory_AI	semantic_AI	otherdetails_AI	extraneous_AI	repetitions_AI
time_LIWC	0.15	0.36	-0.17	0.11	0.02	-0.24	-0.22	-0.10	-0.12	-0.05	-0.05		0.08		0.18	
space_LIWC	-0.23	0.02	0.44	-0.13	-0.17	0.21	0.22	0.19	0.04	0.14	-0.02	-0.15	-0.12	-0.08	-0.26	-0.06
cog_LIWC	0.21	-0.03	-0.36	0.31	0.27	-0.32	-0.26	-0.24	-0.09	-0.06	-0.09	0.03	-0.01	0.30	0.16	0.02
affect_LIWC	0.07	-0.03	-0.30	0.05	0.35	-0.14	-0.17	-0.21		-0.07	0.01	0.07	0.13	0.10	0.02	-0.07
percept_LIWC	-0.42	-0.02	-0.03	-0.09	0.08	0.52	0.35	0.26	0.31	0.18	0.21	0.12	-0.01	-0.13	-0.13	-0.01
see_LIWC	-0.29	-0.09	0.05	-0.09	-0.03	0.46	0.48	0.12	0.10	0.09	0.10	0.02		-0.11	-0.07	0.01
hear_LIWC	-0.02	0.07	0.04		-0.10	0.07	-0.07	0.48	0.05	0.08	0.01	0.01	-0.01	-0.05	-0.09	-0.04
feel_LIWC	-0.29	-0.02	-0.09		0.35	0.26	0.10	-0.02	0.43	0.22	0.13	0.01	-0.10	-0.06	-0.07	-0.03
body_LIWC	-0.17	0.01	-0.03	-0.01	-0.08	0.24	0.12	0.03	0.17	0.40	0.12	0.06		-0.03	-0.12	0.06

	event__AI	time_AI	place_AI	thought_AI	emotion_AI	perceptual_AI	visual_AI	auditory_AI	tactile_AI	kinesthetic_AI	olfactory_AI	gustatory_AI	semantic_AI	otherdetails_AI	extraneous_AI	repetitions_AI
time_LIWC	0.01	0.40	-0.09		-0.02	-0.12	-0.14	-0.04	-0.03	-0.05	-0.13	-0.08	0.08	-0.02	0.01	-0.05
space_LIWC	-0.17	-0.04	0.42	-0.08	-0.02	0.21	0.23	0.09	0.09	0.18	0.01	-0.05	-0.14	-0.12	-0.01	0.07
cog_LIWC	0.05	-0.07	-0.19	0.11	0.06	-0.20	-0.22	-0.07	-0.05	-0.12	-0.09	0.06	0.09	0.33	-0.01	-0.05
affect_LIWC	0.04	-0.05	-0.20	-0.01	0.35	-0.08	-0.16	-0.04	0.07	-0.01	0.05	0.11	0.05	-0.01	0.01	0.02
percept_LIWC	-0.18	-0.04	-0.05	0.06	0.10	0.39	0.28	0.21	0.25	0.18	0.19	0.09	-0.09	-0.10	-0.03	-0.02
see_LIWC	-0.10	-0.01	0.12	-0.01	-0.04	0.27	0.37	0.08	0.08	0.01	-0.05	-0.02	-0.10	-0.02	0.02	0.02
hear_LIWC	0.01	-0.02	0.01	0.09	0.08	0.14	0.06	0.37	0.05	0.06	0.15	-0.02	-0.05	-0.02	0.02	-0.03
feel_LIWC	-0.13	-0.04	-0.09	0.10	0.17	0.29	0.10	0.08	0.39	0.35	0.15	0.03	-0.02	-0.06	-0.03	0.05
body_LIWC	-0.10		0.02	0.14	-0.02	0.28	0.15	0.08	0.22	0.36	0.02	0.03	-0.04	-0.05	0.02	-0.01

Fig. 5. Spearman's rho correlation matrices ($n = 360$ data points per group) for controls ($n = 30$, top matrix) and aphantasic participants ($n = 30$, bottom matrix) assessing correlations between automated LIWC linguistic feature categories (Y axis; from top to bottom: time, space, cognitive, affect, perceptual, see, hear, feel, body) and detail score sub-categories on the adapted Autobiographical Interview (X axis; from left to right: event, time, place, thought, emotion, perceptual, visual, auditory, tactile, kinesthetic, olfactory, gustatory, semantic, other details, extraneous events, repetitions). Strength of correlation is indicated by heatmap (key to right of figures). Significant coefficients (at a Bonferroni-corrected threshold of $p < .00008$) are indicated (for positive correlations only) by solid black lines. Solid pink lines on second matrix indicate correlations that are significant for controls but not for aphantasic participants. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

count, number of words per sentence, or number of words of six letters or more), grammar use (within-even proportion of: common verbs, common adjectives, auxiliary verbs, common adverbs, total pronouns, personal pronouns, impersonal pronouns, articles, prepositions, conjunctions, or negations), and writing style (informal language, nonfluencies, and filler words).

3.6.2. Perceptual, spatial, and temporal language use

We next compared aphantasic participants to controls on our primary feature categories of interest derived from Linguistic Inquiry and Word Count: Perceptual Processes (language expressing sensory processes, including the See, Hear, Feel, and Body domains), Space (language expressing spatial relations, e.g. *over*, *next to*, or *sideways*), Cognitive (e.g. *thought, know*), Affective (e.g. *happiest*, or *worried*), and temporal (Time) domains. A multivariate repeated measures ANOVA revealed a significant interaction between imagery group and linguistic category ($F_{1,\ 11} = 2.701$, $p = .009$, $\eta^2_\text{p} = 0.382$), with planned pairwise comparisons revealing group differences in linguistic feature scores selectively in the Perceptual and See domains. Specifically, Fig. 4 shows that compared to controls, the overall event descriptions of participants with aphantasia (when remembering the past and imagining the future) were characterised by a significantly lower proportion of perceptual language (Perceptual: $M_\text{D} = 1.344$, $SE_D = 0.342$, 99.6% CI_D [0.318, 2.371], $p < .001$, $\eta^2_\text{p} = 0.210$; see Fig. 4, top row) and visual language (See: $M_\text{D} = 35.967$, $SE_D = 0.342$, 99.6% CI_D [0.039, 1.228], $p = .002$, $\eta^2_\text{p} = 0.150$; see Fig. 4, second row), with no other significant between-group differences in language use in any other linguistic category (including the Hear, Feel, Body, Space, Cognitive, Affective, and Time domains; all $p > .05$, all non-significant after Bonferroni correction for multiple comparisons).

Fig. 4 also shows that participants relied on past tense use (e.g. "I saw a great storm cloud"; "a long time ago") to describe event memories, evidenced by a main effect of time on Past Focus linguistic scores (Fig. 4, Past Focus; $F_{1,\ 58} = 360.649$, $p < .001$, $\eta_p^2 = 0.861$). The same was true for future events, where participants primarily used future tense to describe hypothetical episodic events (Fig. 4, Future Focus; $F_{1,\ 58} = 63.725$, $p < .001$, $\eta_p^2 = 0.524$). These effects demonstrate that participants correctly followed task instructions on the adapted Autobiographical Interview and used language conventions that reflected the direction of mental time travel in each condition. Interestingly, participants overall used more present-oriented (or atemporal) language (e.g. "I'm running across the beach", or "Now I can see it") to describe future events than they did for past events (Fig. 4, Present Focus; $F_{1,\ 58} = 260.936$, $p < .001$, $\eta_p^2 = 0.818$). We hypothesised that differences in present tense use between aphantasic's and controls' event descriptions might reflect participants' qualitative sense of "re-experiencing" memories or "pre-experiencing" hypothetical events. However, planned multiple comparisons revealed no significant group differences between aphantasic participants and controls in their use of past, present, or future tense, either when describing episodic autobiographical memories or when describing novel future events (all $p > .004$, all non-significant after Bonferroni correction).

3.6.3. Correlations between automated linguistic analysis and detail scoring on the adapted Autobiographical Interview

Finally, we computed Spearman's rho correlations to explore potential overlap between automated linguistic markers of cognitive processes and information captured by the Autobiographical Interview scoring protocol. Here, we were interested in whether the low-level linguistic features of an event description might be sufficient to meaningfully predict its episodic richness. Overall, we observed moderate to strong, domain-specific correlations between automated linguistic feature scores (derived from Linguistic Inquiry and Word Count) and internal detail sub-categories (scored using the Autobiographical Interview protocol; Levine et al., 2002). This is evidenced by the red diagonal pattern of positive correlation coefficients in Fig. 5 (top panel: Controls), which illustrates a significant association between linguistic feature scores and corresponding content-specific internal detail sub-categories (e.g. between the Space domain from Linguistic Inquiry and Word Count and the Place sub-category of internal details on the Autobiographical Interview: $r = 0.436$, $p = 4.001\text{e}^{-18}$, $\text{CI}_r = [0.346, 0.518]$; or between the Perceptual Processes linguistic category and perceptual internal details on the Autobiographical Interview: $r = 0.519$, $p = 3.233\text{e}^{-26}$, $\text{CI}_r = [0.437, 0.593]$).

Interestingly, this content mapping appeared to be domain-specific for many linguistic feature categories. For example, the Hear linguistic feature category was selectively correlated with auditory internal details ($r = 0.479$, $p = 4.5671\text{e}^{-22}$, $\text{CI}_r = [0.393, 0.557]$), as was the Time linguistic feature category with internal time details ($r = 0.364$, $p = 1.002\text{e}^{-12}$, $\text{CI}_r = [0.268\ 0.453]$). However, broader overlap was observed in other more semantically nuanced categories – for example, Fig. 5 (top panel: Controls) illustrates that the Feel linguistic category was significantly correlated with perceptual, tactile, and kinesthetic internal details (all $p < .00008$), but also with emotional details on the Autobiographical Interview ($r = 0.350$, $p = 7.761\text{e}^{-12}$, $\text{CI}_r = [0.253, 0.440]$). Likewise, Cognitive linguistic scores were significantly correlated with both cognitive (thought) and affective (emotion) internal details (both $p < .00008$), but also with "other" external details (which include metacognitive and editorial statements) on the Autobiographical Interview ($r = 0.300$, $p = 6.0481\text{e}^{-9}$, $\text{CI}_r = [0.200, 0.394]$).

Importantly, Fig. 5 demonstrates that the domain-specific pattern of correlations between linguistic scores and Autobiographical Interview coding observed for control participants (top panel) also largely held for aphantasic participants (bottom panel: Aphantasia), with few exceptions (marked by pink lines; see Fig. 5). Because our correlation analyses were conducted on within-event proportion scores for each individual participant (for both the linguistic feature categories and the internal detail sub-categories), this general consistency in correlation patterns across groups provides additional support for evidence of selective reductions in perceptual and visual language amongst aphantasic participants compared to controls when describing past and future events (see Fig. 4). In general, our results also provide reasonable evidence that automated linguistic analysis (using Linguistic Inquiry and Word Count) captures meaningful information in naturalistic descriptions of remembered and imagined events that is commonly encoded by internal details (scored by human raters using the traditional Autobiographical Interview protocol).

4. Discussion

Here we compared participants with aphantasia and controls (who reported experiencing visual imagery) on a range of self-report imagery questionnaires, phenomenological ratings of past and future events, and a behavioural memory test adapted from the Autobiographical Interview (Addis et al., 2008). We found marked differences when comparing the two groups across all outcomes. Firstly, our results demonstrate that aphantasic participants reported significantly weaker visual imagery (VVIQ), object imagery (OSIQ) and scene imagery when remembering past events (EMIQ) than the control group (see Fig. 1). However, their reports indicated spatial imagery ability (OSIQ) on par with that of controls (see Fig. 1). This expected pattern of results is consistent with previous indicators of visual imagery absence in aphantasia (Keogh & Pearson, 2018; Pearson, 2019; Zeman et al., 2020) and closely replicates our recent self-report findings (Dawes et al., 2020), suggesting good generalisability of self-reported cognition across independent aphantasic samples. Aphantasic reports of weak imagery for objects and scenes (with simultaneously intact spatial imagery) align well with a "what" vs. "where" division in visual perception (marked by ventral processing of objects, and dorsal processing of spatial locations, respectively) hypothesised to be mirrored in top-down visual imagery processes (de Borst et al., 2012; Farah, 1989; Goodale & Milner, 1992; Keogh & Pearson, 2018). It is possible that only the ventral (object) pathway is "affected" in aphantasia (such as via differential functional connectivity or reduced top-down control, rather than any acquired brain damage), leaving spatial imagery processes preserved. More complex explanations may instead prove correct – for example, aphantasia may result from some impaired integration of "what" and "where" information in frontal regions (such as the mesial superior frontal gyrus; de Borst et al., 2012), or more generally from reduced connectivity between prefrontal cortex and early visual cortex. Neuroimaging paradigms will help to answer these important questions. More generally, our current findings reinforce the importance of accounting for the emerging heterogeneity of imagery domains when investigating individual differences in visual imagery and autobiographical memory abilities (Aydin, 2017; Sheldon et al., 2017; Vannucci et al., 2016).

Most importantly, the current study provides robust behavioural evidence that visual imagery absence is associated with a significantly reduced capacity to simulate the past and construct the future (as measured by the adapted Autobiographical Interview). Aphantasic participants generated significantly fewer internal details than controls, irrespective of temporal direction, indicating that their event descriptions were less episodically rich and specific than participants with visual imagery. Importantly, this diminished retrieval of episodic detail amongst aphantasic individuals was driven selectively by a reduction in perceptual and visual internal details (see Fig. 2b and c), and not by significantly reduced episodic detail in other internal detail subcategories (such as event, time, place, emotion, thought, or non-visual sensory details), compared to controls. Good caution is required in interpreting the size of these effects relative to other studies with differing methodologies and population samples. For some indication, however, the magnitude of the mean difference in freely recalled internal details between aphantasic participants and controls is comparable to that seen between young and older adults on similar versions of the task (Addis et al., 2008; St. Jacques & Levine, 2007) and comparable to the observable mean difference in internal details between control participants and patients with posterior cortical atrophy, Alzheimer's disease, or semantic dementia (particularly for future prospection; Ahmed et al., 2018; Irish, Addis, Hodges, & Piguet, 2012). Whilst there is clearly no indication of any clinical or cognitive impairment amongst aphantasic individuals (counter to these example populations), the comparative reduction in internal details produced by aphantasic participants does provide good evidence that visual imagery is important for the mental construction of events in rich, sensory detail – whether these events take the form of personal autobiographical memories or novel imagined scenarios.

Interestingly, the reduction in internal details amongst aphantasic participants did not appear to be matched by a significant relative increase in external details. This may be a good first indicator that the aphantasic deficit in episodic detail is not attributable to group differences in written output, or to the type of memory "semanticisation" effect that often accompanies age-related changes in autobiographical memory recall (Addis et al., 2008). Indeed, there were no significant group differences in the within-event proportions of external details made up by each non-episodic detail sub-category (including semantic details). However, participants with aphantasia did produce a slight increase in external details relative to controls at most time periods, which (albeit non-significant at those individual time periods) was sufficient to yield a significant group difference in episodic ratio scores for future events overall (see Fig. 2c and f). This suggests that whilst visual imagery is an important precursor for episodic construction processes in general, it may contribute to the mental simulation of future scenarios proportionally more than it does to the mental simulation of autobiographical memories. Importantly, the low external detail tallies revealed by our results may also be attributable to our online study paradigm, since written event descriptions likely allow participants to self-monitor and omit language features prevalent in natural speech which reliably contribute to the external detail scoring category (such as verbal repetitions, non-fluencies, and semantic information; Addis et al., 2008; Levine et al., 2002). More work is needed to elucidate whether the robust reduction in specific episodic information produced by individuals with aphantasia is also accompanied by alterations to the semantic scaffolding processes commonly thought to be involved in constructing mental events.

Our current findings offer additional evidence that visual imagery facilitates the phenomenological experience of remembering and imagining events. Our results firstly align well with a known "temporal gradient" of event phenomenology whereby remembered past events are rated overall as being more vivid, rich in spatial detail, emotional and coherent compared to imagined future events (particularly by participants with strong visual imagery; Addis et al., 2008; D'Argembeau & Van der Linden, 2006; D'Argembeau & Van Der Linden, 2004). Importantly, aphantasic participants in our study reported a greatly altered subjective experience of trial-by-trial memory and imagination phenomenology compared to participants with visual imagery. Irrespective of temporal direction, aphantasic participants rated their remembered and imagined events as being significantly less vivid, emotional and coherent compared to controls, as well as being lower in both sensory and spatial details (see Fig. 3). Initially, this latter reduction in the subjective richness of spatial details reported by aphantasic participants during episodic simulation may seem to contradict aphantasic reports of intact spatial imagery on the OSIQ (see Fig. 1), as well as previous findings of intact spatial imagery and spatial navigation abilities on both self-reports (Dawes et al., 2020; Keogh & Pearson, 2018; Zeman et al., 2020) and behavioural tasks (Bainbridge et al., 2019). However, this anomalous result is likely attributed to item wording on the phenomenological ratings used in the current study (e.g., "*I can clearly see the arrangements of objects*", or "*I can clearly see the location*"). Such ratings do not require any mental rotation, spatial transformation, or location-based judgments (which are common features of spatial imagery tasks that aphantasic individuals typically perform well on; Bainbridge et al., 2019; Keogh, Wicken, & Pearson, 2021). Instead, aphantasic participants in the current study may have simply used these "spatial" phenomenological items to subjectively rate the vividness of the perceptual or sensory elements of their remembered event locations, rather than the clarity of the scene's spatial arrangement itself.

This is evidenced by the way in which aphantasic participants evaluated their visual perspective during autobiographical memory and future prospection. Whilst participants with visual imagery tended to "view" events from a field (first-person) perspective in the current study, aphantasic participants predictably appeared to lack visual perspective altogether. Interestingly, however, individuals with aphantasia did not rate their memories or imagined future scenarios as being significantly less personally meaningful to them than control participants (see Fig. 3), highlighting the importance of differentiating between the subjective relevance of autobiographical memories to personal identity, and the objective accuracy or specificity of these memories. In recent work, we demonstrated that individuals with aphantasia commonly report general deficits in episodic memory and future prospection on standardised questionnaires (Dawes et al., 2020). Here, these reports are reinforced by subjectively weak phenomenological ratings of specific events remembered and imagined by participants with aphantasia during a behavioural task. Whilst previous work has shown that individuals with strong visual imagery report more vivid episodic events (D'Argembeau & Van der Linden, 2006), our findings here help depict the lower tail of this effect – that individuals without visual imagery report qualitatively impoverished event representations during naturalistic episodic simulation tasks.

Interpreting our overall set of results requires acknowledging relevant methodological differences between our online experimental paradigm and conventional Autobiographical Interview administration. For example, it was not possible for us to implement some procedural elements of the traditional protocol, including the addition of supplementary verbal prompts (such as a 'general' probe condition used to encourage retrieval of specific memories, and a 'specific' probe condition used to prompt recall of additional episodic details). Such conditions are common features of the standard Autobiographical Interview (Levine et al., 2002), albeit not universal ones (Addis et al., 2008). Notably, these conditions are designed to maximise the number of internal details recalled by participants and as a consequence often alter the final pattern of results (St. Jacques & Levine, 2007). This is advantageous in most contexts but may have been counterproductive in our study, where we were specifically interested in the unassisted, naturalistic construction and description of past and future events by participants without visual imagery. To this end, we argue that our findings represent a veridical baseline measurement of naturalistic event construction and description in aphantasia. However, it is important that future studies explore the potentially dissociable effects of verbal interview prompts on Autobiographical Interview performance in aphantasic participants compared to controls, in addition to investigating whether aphantasic memory performance is improved by episodic induction manipulations which have been shown to boost internal (episodic) detail retrieval during memory and imagination (Madore, Gaesser, & Schacter, 2014; Madore, Jing, & Schacter, 2019; Sheldon, Gurguryan, Madore, & Schacter, 2019). One potential limitation of our study is that we used a written version of the Autobiographical Interview rather than the traditional verbal version. Despite this difference in administration, we believe that the current data are still informative. Importantly, our adapted memory test meets a majority of the suggested criteria for Autobiographical Interview conduct and reporting (see guidelines established by Miloyan, McFarlane, & Vásquez-Echeverría, 2019), including clarity of outcome variables, scorer blinding, interrater agreement, and control for demographic variables such as age, gender and verbal ability. Our methodology is highly similar to previous adapted versions of the Autobiographical Interview (Addis et al., 2008) including the use of cue words matched for imageability, standardised trial times, and temporal counterbalancing of past and future event conditions. We argue that the efficiency of written Autobiographical Interview protocols (which ameliorate the significant time commitment of audio-transcription) warrants consideration by future researchers. It is nevertheless important to emphasise the need for more systematic comparison between written and verbal administrations of the Autobiographical Interview, which may target episodic memory behaviour in significantly different ways, and which may present meaningfully different sets of experimental confounds.

Irrespective of methodological variation, it is also prudent to rule out alternative explanations for the main results reported in our study. There are simple demographic factors which are known to yield substantial variation in autobiographical memory performance over and above individual difference variables. These include age (St. Jacques & Levine, 2007; St. Jacques, Rubin, & Cabeza, 2012), gender (Fuentes & Desrocher, 2013), psychopathology (Hallford, Austin, Takano, & Raes, 2018) and potential group differences in linguistic ability (Marian & Neisser, 2000; Seixas-Lima et al., 2020). Our results are unlikely to be attributed to these factors, since our control group was matched against the aphantasic group on mean age and gender identification (see Participants section in Method). Past studies with larger sample sizes have revealed no underlying differences between aphantasic individuals and participants with visual imagery in reported history of psychopathology, epilepsy, neurological damage or head trauma (Dawes et al., 2020). Likewise, there were no significant differences between participants with aphantasia and controls in the current study on standard mood and affect questionnaires (see Method). Importantly, there was also no significant difference in the length of event descriptions between aphantasic participants and controls in our study, and the event descriptions of aphantasic participants were matched against controls on every other linguistic outcome (including typical markers of written fluency such as the number of words per sentence, number of six-letters-plus words, and frequency of non-fluencies and filler words; see Linguistic Analyses in Results). Further to this, verbosity and word count are intrinsically controlled for by the analysis of episodic ratio scores, which offer a proxy measure of episodic "richness" by computing the proportion of episodic details to total details within each event (Levine et al., 2002; Miloyan et al., 2019). In our study, aphantasic event descriptions contained approximately 10.6% less episodic information, on average, compared to controls – a mean group difference in episodic ratio scores which was as large as 14.1% for imagined future events (see Fig. 2f in Results). Taking these factors into account, demographic factors and individual differences in verbal fluency are unlikely explanations for our main pattern of results.

Lastly, it is possible that the performance of participants with aphantasia on the adapted Autobiographical Interview might reflect lower task effort overall, or a 'self-hindering' bias to respond with floor scores on all questions. However, aphantasic participants provided equally detailed written event descriptions compared to controls, and demonstrated an obvious willingness to complete additional qualitative questions about their subjective experience of autobiographical memory upon study completion. Aphantasic participants also indicated intact spatial imagery, but impaired object imagery on the OSIQ (see Fig. 1). Whilst this does not rule out demand characteristics altogether, it replicates existing evidence that participants with self-described aphantasia respond with effort and authenticity, and do not score at floor on all measures of cognitive ability assumed to involve imagery (such as on the OSIQ and the Survey of Autobiographical Memory: Dawes et al., 2020; and on mental rotation tasks: Pearson, 2019; Zeman et al., 2010). Our linguistic analyses also offer good supplementary evidence supporting the veracity of written event descriptions from participants with aphantasia. Aphantasic individuals generated fewer visual internal details on the adapted Autobiographical Interview and used quantitatively less visual language than controls to describe their events (despite scoring equally to controls on non-visual linguistic markers of sensory language use, in keeping with selective impairment to visual imagery processes; see Fig. 4). These linguistic markers are unbiased by the overall effort and length of written event descriptions, providing an independent proxy measure of the descriptive content of remembered and imagined events. Moreover, we observed significant domain-specific correlations between linguistic feature scores and subcategories of internal details on the adapted Autobiographical Interview, adding to a growing body of evidence that performance on the adapted Autobiographical Interview can be tangibly approximated by low-level linguistic information contained in naturalistic descriptions of event representations (Himmelstein et al., 2018; Peters, Wiehler, & Bromberg, 2017). More importantly, the selectively reduced visual language use and cognitive retrieval of visual details in aphantasic participants suggests that our main results are unlikely to be attributable to demand characteristics or response bias. Collectively, aphantasic individuals' reduced internal detail tallies and episodic ratio scores evidenced here and in recent studies (Milton et al., 2021) are most likely to reflect a generalised reduction in the ability to retrieve and construct detailed mental representations of episodic events and scenes.

The exact mechanism of action for reduced episodic simulation processes in aphantasia cannot be elucidated from our current behavioural results, but our findings may be interpreted in light of several prominent theoretical frameworks. Interestingly, the observed reduced episodic autobiographical memory capacity in aphantasia stand in stark contrast to recent research showing that visual working memory is not reduced in aphantasia when compared to control populations or clinical norms (Keogh et al., 2021; Pounder et al., 2022). One explanation for this dissociation is that aphantasic individuals use non-imagery-based strategies (such a labelling or verbalising the images) to successfully solve lab-based visual working memory tasks (Keogh et al., 2021). It is possible that this verbal strategy used by aphantasic individuals supports performance on visual working memory tasks, but not on autobiographical memory tasks (like the Autobiographical Interview) which require the effective retrieval of rich, episodic detail. This explanation would fit predictions of the dual coding theory of memory, which suggests that individuals tend to adhere to trait-like tendencies to store information using verbal (semantic) or non-verbal (imagery) modes of representation (Paivio, 1991). This dual coding model of memory retrieval also dovetails with a historical "imagery debate" about whether or not information can be stored in the brain in multiple formats – that is, not only in a propositional (symbolic) format but also in an imagery (depictive) format (Pearson & Kosslyn, 2015). Contemporary findings indeed map differential patterns of functional connectivity during episodic memory onto trait-like differences in episodic memory "styles", distinguishing between individuals who tend to rely on visual representations to remember ("visualisers"), and those who rely on semantic or factual information ("verbalisers"; Sheldon, Farb, Palombo, & Levine, 2016). However, if participants with aphantasia represent an extreme end of this "verbaliser" trait, we might have expected a more prominent "semanticisation" of aphantasic event descriptions – an effect only weakly suggested (and not statistically supported) by their semantic (external) detail scores. An alternative explanation for the dissociation between visual working memory and autobiographical memory performance in aphantasia may be that aphantasic individuals instead rely on some form of "latent" visual imagery, or a set of sensory representations that are below some conscious threshold, which can effectively support short-term visual working memory, but not support the retrieval of phenomenally complex and perceptually rich autobiographical memories.

The fact that aphantasic participants generated fewer internal details than controls for both past and future events itself indicates considerable task overlap in the retrieval of autobiographical memories and the simulation of hypothetical future events. This aligns well with the constructive episodic simulation hypothesis, an influential re-evaluation of autobiographical memory theory which asserts that remembering the past and imagining the future are two similar variants of a common neurocognitive process enabling the dynamic and flexible construction of multimodal episodic event representations (Addis et al., 2008; Addis, Pan, Vu, Laiser, & Schacter, 2009; Addis, Wong, & Schacter, 2007). By this account, internally "re-experiencing" and "pre-experiencing" events should both involve the recombination of stored perceptual, spatiotemporal and conceptual information, and thus rely on similar cognitive processes – including mental imagery (Addis et al., 2007, 2008). This appears to be borne out by our results and those of other research groups (Milton et al., 2021), where individuals without visual imagery demonstrated diminished episodic simulation of both past and future events. Reduced episodic richness in aphantasia may also reflect a more general reduction in the hippocampally mediated capacity to construct atemporal, spatially scaffolded and perceptually rich scenes (an ability termed "scene construction"; Hassabis et al., 2007; Hassabis & Maguire, 2007; Rubin, Deffler, & Umanath, 2019). Under this account, individuals with aphantasia would exhibit deficits not only in the ability to reconstruct and imagine autobiographical events across time, but in any cognitive process (including atemporal scene construction) reliant on the simulation of complex internal visual representations – a hypothesis supported by our recent reports of reduced night dream phenomenology and intrusive memory symptomology in aphantasia (Dawes et al., 2020).

However, it is also clear from our results that participants with aphantasia show a particular reduction in episodic detail for future events, where the greatest between and within group differences in episodic richness were revealed (see Fig. 2f), and where selective group differences in perceptual and visual internal details were found (see Fig. 2b and c). This may imply that variations of episodic event simulation do not in fact rely on identical neurocognitive mechanisms, or at least that visual imagery contributes disproportionately to future event prospection over autobiographical memory. Although it requires further evidence, it is plausible that the contribution of visual imagery to episodic simulation might follow a "graded recruitment" model, whereby visual imagery becomes an especially useful cognitive tool for imagining novel events because individuals are less able to rely on other re-constructive processes that are selectively or disproportionately recruited during autobiographical memory (Addis, 2018; Irish et al., 2012). Whilst individuals with visual imagery capacity may be able to recruit imagery as a compensatory task strategy when imagining novel events without context, aphantasic individuals may lack this strategic buffer, resulting in proportionally greater disruption to the constructive processes underlying the mental simulation of future events (as observed in our data).

Understanding the precise role of visual imagery in episodic cognition will inevitably require more research. There are many outstanding questions invoked by our study, including the overarching issue of differentiating between the capacity to internally construct a complex, visuo-spatial representation of an episodic event, and the capacity to accurately recall and describe the factual details pertaining to that event. Our data support attenuation of the former capacity, but not necessarily the latter. Whilst we indeed saw stark reductions in the amount of episodic detail generated by aphantasic individuals when remembering the past and imagining the future, these reductions did not extend to a widespread inability to recall or describe episodic events altogether. Anecdotally, very few individuals with aphantasia report a complete inability to remember their personal past (and appear to show adept memory for the factual details of what occurred during specific autobiographical events). Rather, they unanimously report a reduced capacity to re-experience and 're-live' their memories in sensory detail. This inability to mentally 'simulate' past events therefore appears to be dissociable from successful autobiographical memory retrieval (in that individuals with aphantasia clearly possess intact memories of the past, and otherwise show no developmental, cognitive, or occupational impairment according to current evidence; Zeman et al., 2020).

With this in mind, further studies should demonstrate whether or not reduced episodic detail on the Autobiographical Interview is matched by reduced factual accuracy during memory retrieval, as well as use repeated retrieval paradigms to examine the internal consistency of autobiographical memories over time as a function of visual imagery ability. The use of experimental manipulations that selectively boost episodic detail retrieval (such as the episodic induction; Madore et al., 2014), in addition to replication of our results using prompted verbal interviews (Levine et al., 2002), will help to further mark the true extent of reduced episodic simulation capacity in aphantasia compared to individuals with intact visual imagery. Further work is also required to explore the potential overlap between aphantasia and a syndrome termed Severely Deficient Autobiographical Memory (SDAM; Palombo, Alain, Söderlund, Khuu, & Levine, 2015), which shares a remarkably similar aetiological profile to aphantasia, marked by selective diminishment in episodic recollection coinciding with reports of weak or absent visual imagery (Fan, Abdi, & Levine, 2020; Palombo et al., 2018; Watkins, 2018). Understanding the population overlap in aphantasia and SDAM may help to better elucidate the conditions under which visual imagery is most adaptive in facilitating memory processes.

The interactions between visual imagery, episodic event construction and autobiographical memory are likely complex, and complicated further by the myriad individual differences that moderate each of these cognitive processes. However, aphantasia offers a unique model to begin exploring these interactions and building a wider taxonomy of cognitive simulation in the human brain. Overall, our results suggest that visual imagery may be a useful depictive format for internally constructing and representing events during autobiographical memory retrieval and future prospection. This dynamic construction process appears to be altered in individuals without visual imagery, consequently reducing the overall episodic specificity and phenomenological richness of remembered and imagined events in aphantasia. Our study thus provides robust behavioural evidence that visual imagery is an important precursor for autobiographical memory and future prospection processes, and demonstrates that aphantasia is associated with a reduced capacity to mentally simulate episodic events across time.

Author contributions

All authors developed the study concept. AJD and SR built the study design. AJD collected the data and performed data analysis. AJD drafted the first manuscript, and RK, SR, and JP provided critical revisions. All the authors approved the final manuscript for submission.

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Declaration of Competing Interest

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

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Supplementary data

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