State but not trait measures of vividness relate to memory accuracy

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ARTICLE INFO

ABSTRACT

Vivid mental imagery is often assumed to relate to memory accuracy, but recent empirical findings from studies of mental imagery and aphantasia have found conflicting results regarding this association. Recent literature has found the modality of stimulus may influence this association, and that vividness and confidence of memories may change over the lifespan. Therefore, the present study investigates the relationship between mental imagery vividness and memory for scenes, with a focus on modality-specific and age-related effects, and relationships with confidence. Using a novel experimental procedure, young and older participants memorised objects within scenes and later identified whether specific changes had occurred. Results indicated that while trait-level and averaged measures of vividness did not predict memory accuracy, trial-by-trial state measures were significantly related to subsequent performance. Additionally, results provided evidence that mental imagery may relate to visual aspects of memory more than spatial aspects. Older adults reported higher vividness ratings but performed worse on average than young adults. Confidence and vividness were highly correlated but remained distinct subjective experiences. Re-analysis of an existing related dataset involving people with aphantasia confirmed state-level findings regarding vividness and memory accuracy, highlighting limitations of previous research relying on averaged and trait-level measures. Results identify the need for future research to analyse vividness on a trial-by-trial basis to appropriately investigate the relationship between mental imagery vividness and memory accuracy.

1. Introduction

Mental images are a familiar aspect of conscious experience for most people; however, a small proportion of individuals report a lack of mental imagery entirely. This phenomenon has been defined as 'aphantasia' by Zeman et al. (2015) and characterises reduced or absent voluntary imagery, often evidenced by responses to a trait-level measure such as the 'Vividness of Visual Imagery Questionnaire' (VVIQ) (Marks, 1973). Despite no apparent conscious access to mental images, aphantasics, on the whole, are able to perform almost indistinguishably from people who report experiencing vivid mental images across a range of cognitive and mental tasks (Keogh et al., 2021; Pounder et al., 2018, 2022; Siena and Simons, 2024). Visual memory is considered to be closely related to visual mental imagery (Keogh et al., 2021; Palombo et al., 2015) with phrases such as being able to 'vividly see' or 'picture' a previous episode typically being used when referring to accurate memory recall (Cambridge Dictionary, 2025). However, some have argued for a separation between visual perception and internally

generated images, even prior to aphantasia's definition (Borst et al., 2012; Cornoldi et al., 1998). As few distinct differences have been observed between aphantasics and typical imagers' memory performance, the question of how mental imagery relates to memory is posed. How are those who report weak mental imagery able to accurately recall memories when compared to those who report vivid mental imagery? To what extent does conscious access to imagery improve our memory recall? Recent studies have begun to investigate these questions, with conflicting results.

Regarding the relationship between mental imagery vividness and memory, findings would suggest that imagery is not essential for accurate memory recall. Research often finds no correlation between mental imagery vividness and episodic memory performance across participants (Keogh et al., 2021; Siena and Simons, 2024), highlighting a disconnect between the subjective experience of remembering and objective performance. A vivid mental image may not necessarily suggest an accurate episodic memory, and the converse, a lack of mental imagery may not equate to memory inaccuracies. Furthermore, a key

review of the cognitive neuroscience of mental imagery by Pearson (2019) suggests that imagery may not be as fundamental to completing cognitive tasks as many assume, and the cognitive mechanisms underlying memory abilities may vary between vivid and weak imagers. The common strategy of creating detailed mental imagery to aid our memories, in experiments and daily life, may just be one of several strategies available in our cognitive toolkit. In cases of a total absence of mental imagery, aphantasics are able to form and recall episodic events (Dawes et al., 2022; Jacobs et al., 2018), and are able to complete tasks thought to rely on constructing and manipulating imagery in one's mind (Kay et al., 2024; Keogh et al., 2021; Zeman et al., 2010), further supporting the idea that mental imagery may not be essential for accurate memory recall. When including hyperphantasics (those who experience extremely vivid mental imagery) performance on standard memory tasks is equivalent to those with typical, and even absent, mental imagery (Azañón et al., 2025; Milton et al., 2021; Reeder et al., 2024).

When investigating mental imagery vividness and memory performance, the nature of the measure used to assess vividness appears to modulate its predictive power. One's mental imagery vividness is primarily measured by the self-reported "Vividness of Visual Imagery Questionnaire" (Marks, 1973), generating a score out of 80 for an individual's trait-level, general vividness of mental imagery. In parallel, to capture state-level vividness on each trial, subjective rating scales can be included on a trial-by-trial basis to assess vividness within the moment. Two meta-analyses by Runge et al. (2015, 2017) identified that trial-by-trial self-reported vividness has higher predictive value and effect sizes than the VVIQ alone, indicating the importance of state trial-by-trial measurements over state VVIQ measurements. Additionally, more recent research has found limited effects of VVIQ on behavioural measures, with a large proportion of variation of vividness failing to be captured by the VVIQ when compared to trial-by-trial ratings (Dijkstra and Fleming, 2023). Experimental studies have found trial-by-trial vividness reports relate to subsequent task performance (D'Angiulli et al., 2013; Dijkstra et al., 2017; Pearson et al., 2011), indicating a trait measure such as the VVIQ may smooth over and fail to identify vividness effects. The present study therefore includes a trial-by-trial measure of vividness to accurately assess relationships between mental imagery and memory, and any trait versus state distinctions.

While it is common across the literature to find weak or no relationships between vividness and memory, there are some associations between the two factors. For example, greater mental imagery strength has been found to relate to greater recollection of autobiographical details (Aydin, 2018), and greater visual working memory capacity (Keogh and Pearson, 2011, 2014). However, some findings also suggest advantages to less vivid imagery, such as reduced binocular rivalry priming (Keogh and Pearson, 2018), potentially protecting against distraction from one's mind's eye, and protection against irrelevant visual information during visual memory tasks (Keogh and Pearson, 2011, 2014). Additionally, there may be a spatial advantage to less vivid imagery, as aphantasics and weak imagers often demonstrate greater spatial accuracy and ratings (Bainbridge et al., 2021; Keogh et al., 2021; Keogh and Pearson, 2018; Pearson, 2019), with some researchers arguing for a separation between 'object' and 'spatial' aphantasia (Blazhenkova and Pechenkova, 2019; Palermo et al., 2022). Therefore, there may be a spatial benefit to less vivid imagery, according to previous findings. In the case of a total lack of imagery, when recalling autobiographical events and imagining future events, aphantasics have been found to generate significantly fewer episodic (Dawes et al., 2022), internal (Milton et al., 2021) and emotional (Monzel et al., 2024) details than controls. When drawing pictures from memory, aphantasics, when compared to controls, may recall significantly fewer objects, their drawings can have less colour, and they may rely on verbal scaffolding (Bainbridge et al., 2021). Aphantasics can also take longer to complete mental rotation tasks, but are not significantly less accurate (Pounder et al., 2022). Therefore, there may be noticeable differences in memory

ability between those with vivid and weak mental imagery. While some research may suggest there are disadvantages to less vivid imagery, there are findings to suggest benefits in some regards, perhaps in part due to alternative cognitive strategies and mechanisms being used by weaker imagers, as suggested by Pearson (2019) and Reeder et al. (2024). Investigating several aspects of memory, such as object and spatial modalities, is therefore in need of more research within the context of mental imagery.

Recent research also suggests that age may modulate the relationship between mental imagery vividness and memory accuracy. A review of the literature by Folville et al. (2021) found that, in general, older individuals rate their vividness on a trial-by-trial basis more highly than younger individuals (Devitt et al., 2024; Faul et al., 2025; Folville et al., 2020), despite objectively worse memory performance (Dror and Kosslyn, 1994; Kemps and Newson, 2005). Moreover, older individuals sometimes appear to rate their confidence as higher, but with poorer performance (Folville et al., 2020). This would suggest that older adults subjectively experience memories differently to younger adults, and that memory vividness, and in some circumstances confidence, may change across the lifespan. Research also often finds that aphantasics have reduced confidence in their memory ability (Monzel et al., 2023, 2024). However, others have found stable relationships between trial-wise vividness, confidence, and memory performance across the lifespan (Mojescik et al., 2024). Significant correlations have also been observed between vividness ratings and accuracy for both memory gist and details of memories (Cooper and Ritchey, 2022). For visual mental imagery, some find that age does not significantly correlate with VVIQ scores (Floridou et al., 2022), with others finding a decrease of mental imagery vividness as we age (Gulyás et al., 2022). Further research into mental imagery and memory within the context of aging is therefore required, as it is unclear if age is a moderator of mental imagery vividness. Most findings suggest a potential double dissociation between vividness and memory performance between young and older adults may be present, but it may be important whether analysis focuses on trait or state measures of vividness. The relationship between confidence and vividness is also not currently understood, and may also change across the lifespan, therefore, the present study includes measurements of confidence.

Taking the above research into account, questions regarding relationships between mental imagery and memory, age, modalities, and confidence require further experimentation. While most of the current literature suggests no relationships between mental imagery vividness and memory, other studies suggest the possibility that effects may be present under certain circumstances, such as whether trait or state-level measures are examined. Further experimentation is required to test what factors may or may not relate to mental imagery vividness. Hypotheses therefore include:

H_1 – State-level measure of vividness have greater predictive power than trait-level measurements.
H_2 – Less vivid mental imagery relates to greater spatial memory accuracy.
H_3 – Older adults report greater vividness than younger adults.
H_4 – Older adults have poorer memory accuracy than younger adults.
H_5 – Confidence and mental imagery vividness are related to one another.

Bayesian statistics will be utilised to test evidence for null hypotheses only, to investigate absences of relationships between variables.

The present experiment sought to investigate these hypotheses through a novel online experimentation procedure, in which participants viewed objects within scenes and subsequently identified visual or spatial changes when the scenes were presented again.

2. Methods

2.1. Participants

60 participants (30 male, 30 female) were recruited from the online research platform Prolific. An additional 3 participants were recruited but were excluded due to failing attentional checks. Written informed consent was obtained in a manner approved by the University of Cambridge Psychology Research Ethics Committee.

30 of the participants were aged 18-30 (Mean = 25.6), and 30 aged 60-72 (Mean = 64.9), with even gender distributions in each age category. Participants were recruited from the United Kingdom and the United States of America, and were screened for full colour vision and normal, or corrected to normal, vision.

2.2. Materials

40 stimuli were created via the videogame The Sims 4 due to its ease of use and ability to create high quality scenes. Stimuli consisted of images of scenes, such as rooms, parks, and gardens, with a variety of objects within them, see Fig. 1 for examples. Scenes each contained a single 'target' object within them, which would be highlighted with a red circle during the task. The target was then either moved elsewhere in the scene (spatial condition), its colour changed (visual condition), or the target was unaltered (no-change condition), and another screenshot taken.

Scenes varied in their complexity, viewing angle, style, and location. Each scene and target were used only once. To create isolated, greyscaled images of targets, screenshots of each target object were taken, the background removed, and saturation set to 0. In total there were 14 visual, 13 spatial, and 13 no-changes.

Participants were required to complete the 'Vividness of Visual Imagery Questionnaire' (VVIQ) (Marks, 1973) to assess individual differences in trait-level mental imagery vividness. Graphics were acquired with permission from *aphantasia. com* to explain the concept of mental imagery to participants, see Appendix A.

2.3. Design

The experiment followed a quantitative design. Dependent variables included memory performance, VVIQ score, trial-by-trial vividness, and trial-by-trial confidence. Independent variables included age and change modality (visual, spatial, or none). Measurements allowed for both between group and repeated measures analyses.

2.4. Procedure

An 'incidental encoding' approach was taken to ensure participants relied primarily on visual processing for their subsequent memory performance. Participants therefore were not instructed that their memory would be tested until after the Encoding phase, instead they were told that the experiment investigated scene processing.

During each Encoding trial, participants were presented with an image of a scene for 5 s, after which a red circle appeared to highlight a target object for a further 5 s. A schematic representation of testing procedures can be found in Fig. 2. Participants were then pseudo randomly asked one of four yes/no visual questions, and one of four yes/no spatial questions regarding the target object or scene, see Appendix C. Accuracy for these questions was not of analytical interest and instead served as a means for incidental encoding. A total of 40 images were presented across the encoding block. Stimuli were split into 4 blocks of 10 images, with each block having a pseudorandomised order of stimuli. There were no breaks between blocks. A fixation cross appeared between stimuli with a 500 ms pre-stimulus onset, 1000 ms display, and 500 ms post-stimulus onset. To check participants' attention, the fixation cross turned red 20% of the time, after which participants had 3000 ms to respond by pressing the Space Bar.

Following Encoding, participants completed the VVIQ (Marks, 1973) before moving onto the Test phase. In the Test phase, participants were instructed that their memory of previously seen stimuli would be tested,
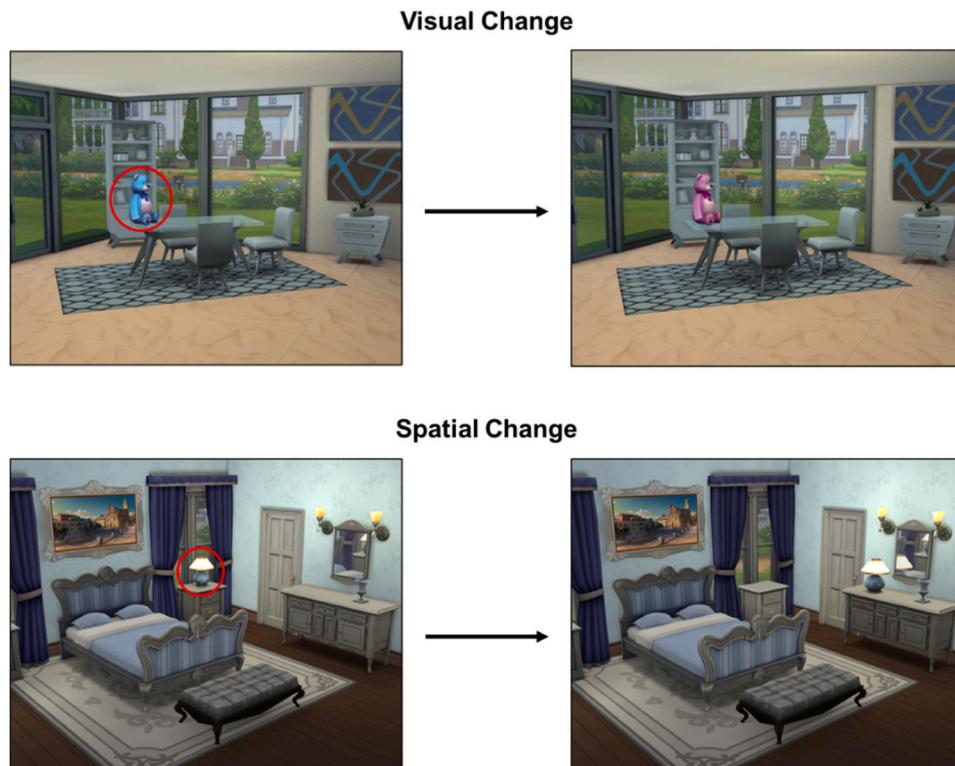

Fig. 1. Example visual (top) and spatial (bottom) stimuli.
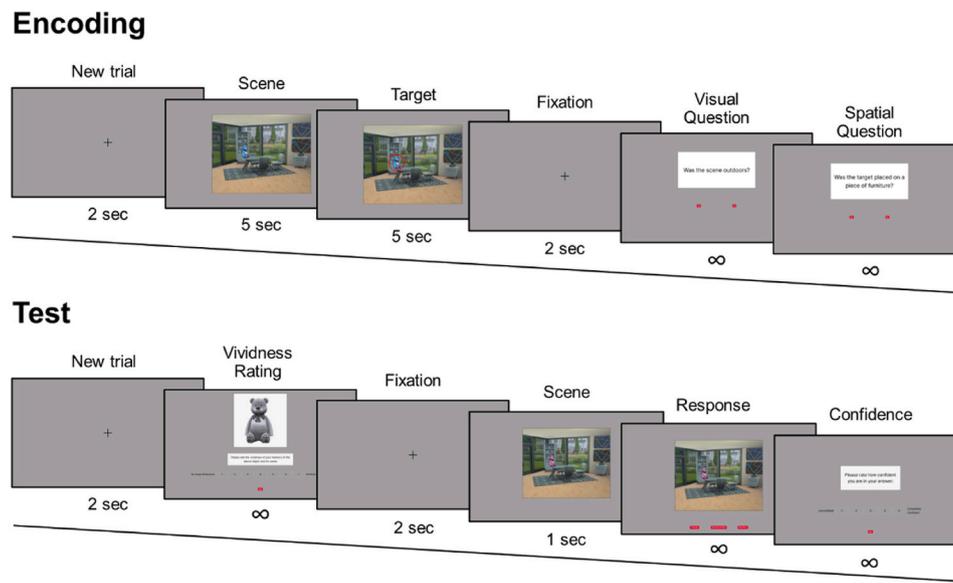
Encoding

Test

Fig. 2. Diagram of Encoding (top) and Test (bottom) procedures.

with vividness and confidence ratings being required before and after each scene respectively. Several screens explaining what constitutes a mental image were used to act as a standard, ensuring participants understood the concept of mental imagery, anchoring their judgements, and to minimise potential conflation with confidence, see Appendix A. Next, participants were instructed that the target object in each scene may have changed colour, be in a different part of the room, or be unaltered from the first presentation. Once the instructions were completed, participants were presented with a fixation cross with the same timing as in the Encoding phase, followed by a greyscale image of the original target object. Participants were asked to rate the vividness of their memory of the relevant object and its scene, using a 7-point rating scale ranging from 1 (*No image whatsoever*) to 7 (*Perfectly vivid*). Following another fixation cross, the test stimulus was presented comprising of the full-colour object in its scene, with visual, spatial, or no changes applied. Three buttons indicating 'No Changes', 'Object Colour Changed', and 'Object Moved' appeared after 1000 ms. Participants had unlimited time to select their answer, and once chosen, rated their confidence on a 5-point scale, ranging from 1 (*Unconfident*) to 5 (*Completely Confident*), see Fig. 2 for a schematic diagram of procedures. Note that a 5-point scale was chosen to discourage participants from simply repeating their response to the previous 7-point vividness rating scale. This procedure was repeated for all 40 previously encoded stimuli, following the same block order, ie. stimuli in Encoding block 1 were presented in Test block 1. This ensured an approximate 15-minute gap between seeing stimuli in Encoding and the subsequent Test phase. Participants were then fully debriefed, including reasoning for not disclosing the memory aspect of the task, and given a brief overview of the topic area and aphantasia. For descriptive statistics of participants' knowledge of aphantasia see Supplementary Materials.

3. Results

3.1. Data preparation

Analyses were performed using R Statistical Software (v4.4.2; R Core Team, 2024)., with a focus on relationships between subjective vividness ratings and objective memory performance, age effects, differences in modalities, and confidence effects.

Data outputs from Gorilla Experiment Builder were cleaned, organised, and combined using the 'tidyverse' package (v2.0.0; Wickham et al., 2019) within R Statistical Software (v4.4.2; R Core Team, 2024).

Two datasets were generated, the first dataset of participants' mean scores on memory metrics, VVIQ scores, descriptives, and other additional information, and the second, a long form dataset of participants' performance on a trial-by-trial basis (SBNT_Anon_Data_Master.csv and SBNT_Anon_Trials.csv respectively in Supplementary Materials).

For mean data, the total percentage of questions correct was calculated for each participant, alongside their average vividness and confidence ratings across all trials. Total percentage scores were also calculated separately for visual, spatial, and no-change trials respectively.

Upon inspection, distributions of total percentage memory scores were non-normal ($W = 0.94$, $p = .004$) following a Shapiro-Wilk test. To correct for negative skew, a common heuristic transformation (Kassambara, 2019) was applied using the equation below:

$$10 - sqrt(max(x+1) - x)$$

where x = Individual participant's total percentage memory score.

The transformation resulted in data being scaled on a 0-10 scale, where 10 represents 100% accuracy, and 0 represents 0% accuracy. The resulting transformed data passed normality checks ($W = 0.98$, $p = .429$). As a result, all further data analysis used transformed memory scores. VVIQ scores ($W = 0.97$, $p = .200$) and average vividness ratings ($W = 0.99$, $p = .748$) were normally distributed.

To consider the effect of extreme response times, trials with <500 msec or >10,000 msec response times for vividness ratings, changes, and confidence ratings were removed during exploratory analysis. These exclusions did not alter significance levels when compared to the original data, therefore, all further analyses reported below used the whole, original dataset with no exclusions. Furthermore, as there were 3 possible options to select during the test phase (Visual, Spatial, None), the chance level is 33%. After excluding stimuli below chance, all previously found significant effects remained significant, therefore no stimuli were excluded from the analyses reported below. See Supplementary Materials for details of reaction time exclusions, chance exclusions, individual stimuli performances, and style effects.

3.2. Knowledge of aphantasia

Upon completion of the experiment, participants were asked to choose one of the following to indicate their prior knowledge of aphantasia: '*Yes, I was aware of what aphantasia was and what it meant*', '*I had a vague knowledge of aphantasia, but wasn't sure exactly what it was*',

and *'I had not heard of aphantasia prior to this experiment'*. 39 (65%) of participants indicated they had no prior knowledge of aphantasia, 13 (21.7%) had some vague knowledge, and 8 (13.3%) knew what aphantasia was prior to the experiment.

3.3. Vividness and memory scores

To investigate any relationships between mental imagery and memory (H_1, H_2), correlations between memory scores, VVIQ scores, and average vividness ratings were examined. Analyses revealed no significant relationships between memory performance and VVIQ scores ($r(58) = 0.01$, $p = .934$), or between memory performance and average vividness ratings across trials ($r(58) = 0.16$, $p = .226$), see Fig. 3. A Bayesian correlation confirmed moderate evidence (Jeffreys, 1998) to suggest that VVIQ has no relationship with memory scores ($R = 0.01$, $BF_{10} = 0.172$), with there being 5.81 times more evidence for the null than the alternative hypothesis.

To test for a relationship between VVIQ scores and average vividness ratings across trials, a Pearsons correlation revealed a significant positive relationship between the two variables ($r(58) = 0.54$, $p = <0.001$), indicating a degree of association between these two very different measures of vividness, see Fig. 4.

Analyses up until this point used averaged data across all 40 trials, which may have smoothed over potential trial-by-trial variation. To analyse the data on a trial-by-trial basis across participants, a Binomial Generalized Linear Mixed Model (GLMM) with a logit link was implemented using the *'lme4'* package (v1.1.36; Bates et al., 2015) in R. To calculate trial-by-trial vividness for each individual, centring-within-cluster (CWC) centred means were calculated by subtracting each participant's vividness rating on each trial from their overall mean trial-by-trial vividness rating. Resulting analyses examine how a higher or lower vividness rating than average, per participant, relates to subsequent memory accuracy. To investigate whether trial-by-trial, average, and trait vividness measures are associated with memory accuracy, and whether the effect differs by age, analyses were run with the following formula:

Correct ~ CWC Vividness * Age Category + Avg TBT Vividness + VVIQ Score + (1 | ID)

Where fixed effects were CWC and average vividness ratings, age category, and VVIQ scores, with participant IDs being entered as a random effect. See Table 1 for statistical outputs.

Results indicate that at the CWC trial-specific level, vividness ratings were significantly associated with correct identification of the changes during the memory task. Age category was significant, indicating that young participants were significantly more accurate than older participants. However, the interaction between vividness ratings and age
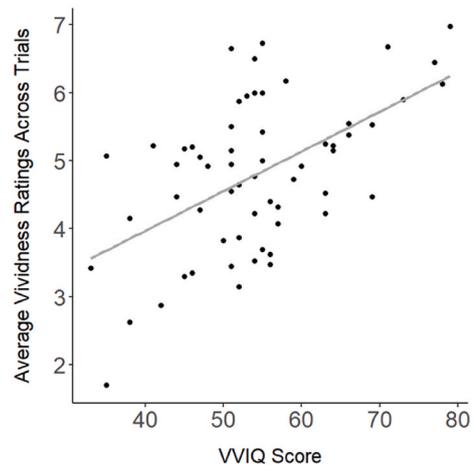

Fig. 4. Scatterplot of the relationship between VVIQ scores and average vividness ratings.

Table 1
Results of the GLMM predicting correct responses from vividness ratings, age category, and VVIQ Score.

Variable	B	SE	p
(Intercept)	0.09	0.67	0.894
CWC Trial-by-trial Vividness Rating	0.30	0.05	<0.001***
Age Category (Young)	0.64	0.23	0.006**
Average Trial-by-trial Vividness	0.21	0.12	0.082
VVIQ Score	−0.001	0.01	0.910
CWC Vividness Rating x Age Category (Young)	−0.004	0.07	0.951

categories was non-significant, indicating that the effect of vividness ratings on answering correctly did not differ between age groups. VVIQ score was not a significant predictor of memory accuracy, where averaged trial-by-trial vividness trended towards significance.

To investigate the relationship between higher vividness ratings and correct memory performance, predicted probabilities were calculated to determine the probability a participant would answer correctly for each CWC vividness rating. Analyses were run using the *'ggeffects'* (v2.2.1; Lüdecke, 2018) package in R. As demonstrated by Fig. 5, higher than average vividness ratings were associated with a higher probability of a correct response for both age groups, see Appendix D for a full table of probabilities.
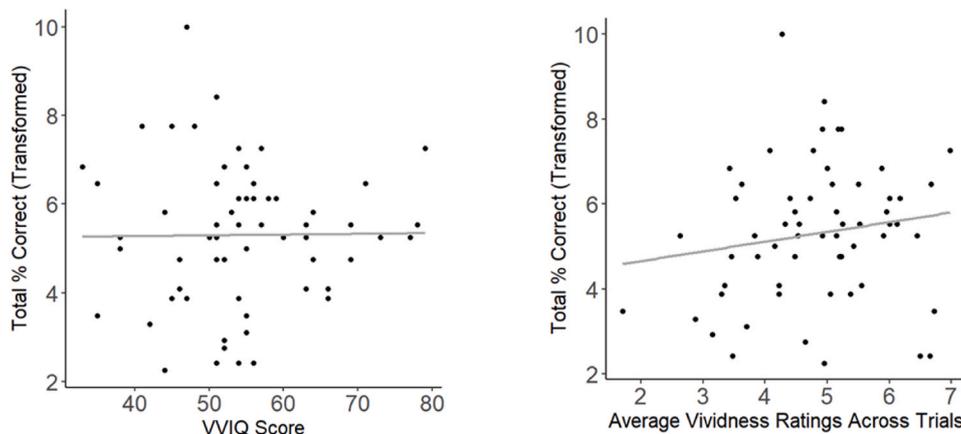

Fig. 3. Scatterplots of the relationships between memory scores and VVIQ (left) and average vividness ratings (right).

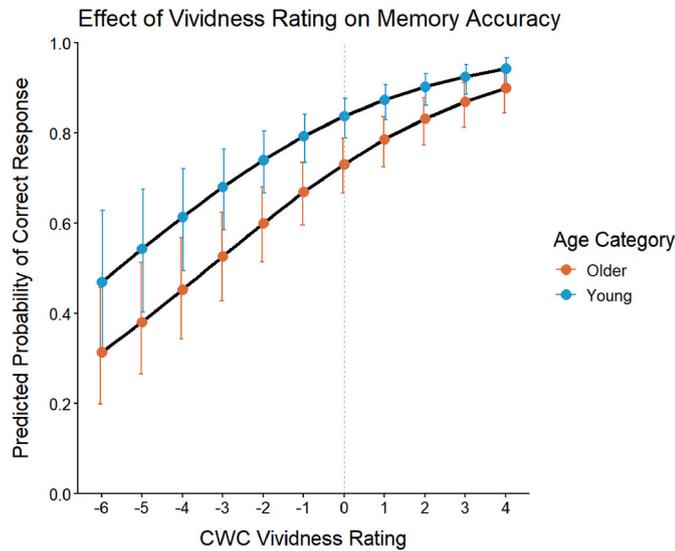## Effect of Vividness Rating on Memory Accuracy

Fig. 5. Plot of predicted probabilities of a correct response by CWC vividness rating, error bars represent 95% confidence intervals. Error bars are offset from means to prevent overlap.

3.4. Modality effects

To investigate whether mental imagery influences memory accuracy to different extents depending on modality (H_2), several analyses were conducted. Simple linear regression was used to investigate whether average vividness ratings significantly predicted memory performance in each of the modalities independently. Fitted regression models were:

[Modality]CorrectPercentageTr ~ [Modality]MeanVividnessRating

The overall regression model was only significant for Visual modality changes ($F(1, 58) = 7.51$, $p = .008$, $R^2 = 0.11$, adjusted $R^2 = 0.10$) but was found to be non-significant for Spatial ($F(1, 58) = 0.70$, $p = .486$, $R^2 = 0.01$, adjusted $R^2 = -0.01$) and No-changes (F(1, 58) = 0.06 $p = .808$, $R^2 = <0.01$, adjusted $R^2 = -0.02$), see Fig. 6 for visualisations of these relationships. Participants' average subjective vividness appears to be significantly related to subsequent performance when identifying visual changes, but not spatial or no-changes.

As each regression model above used averaged ratings and total percentage correct, effects may have been smoothed over in a similar manner to prior initial vividness analyses. To appropriately investigate the CWC trial-by-trial contribution of vividness in each modality, Binomial GLMMs with logit link were run for trials in each modality independently, results of which can be found in Table 2, with the following formula:

Table 2
Statistical outputs following the GLMMs for each modality.

Variable	B	SE	p
Visual			
(Intercept)	−0.47	0.81	0.563
CWC Trial-by-trial Vividness Rating	0.38	0.08	<0.001***
Age Category (Young)	0.58	0.27	0.033*
Average Trial-by-trial Vividness	0.38	0.14	0.007**
VVIQ Score	−0.01	0.02	0.505
CWC Vividness Rating x Age Category (Young)	−0.18	0.11	0.110
Spatial			
(Intercept)	−0.07	1.17	0.955
CWC Trial-by-trial Vividness Rating	0.29	0.09	0.001**
Age Category (Young)	0.76	0.40	0.056
Average Trial-by-trial Vividness	0.16	0.20	0.423
VVIQ Score	0.00	0.02	0.842
CWC Vividness Rating x Age Category (Young)	0.09	0.13	0.474
No Change			
(Intercept)	1.18	1.33	0.375
CWC Trial-by-trial Vividness Rating	0.27	0.11	0.013*
Age Category (Young)	0.57	0.45	0.213
Average Trial-by-trial Vividness	0.05	0.23	0.811
VVIQ Score	0.01	0.03	0.806
CWC Vividness Rating x Age Category (Young)	−0.07	0.15	0.636

Correct ~ CWCVividness * AgeCategory + AvgTBTVividness + vviq_score + (1 | Anon_ID)

Additionally, analyses were run including item (labelled "Object" in the data) as a random effect (1| Object). The inclusion of item did not alter previously reported significances, see Appendix E.

As can be seen in Table 2, higher CWC trial-by-trial vividness ratings were significantly related to correctly identifying changes across all modalities. However, only in the visual modality did young participants demonstrate significantly higher baseline performance compared to older adults. Average vividness ratings were also significant predictors of performance in the visual modality only.

For further modality-related analyses, including the proportion of responses from participants, see Supplementary Materials.

3.5. Age effects

To investigate age-related effects of memory and vividness (H_3, H_4), the data were separated out into young and older age groups. To test for any differences in memory scores, VVIQ scores, and vividness between young and older individuals, a series of Welch Two Sample T-tests were run as variance was unequal between groups for all measures. Mean memory score for young participants was 5.79 ($SD = 1.86$) whereas the mean for older participants was 4.81 ($SD = 1.18$). Analyses revealed this difference was statistically significant, $t(58) = −2.43$, $p = .018$, indicating that younger participants scored higher on average than older participants. Mean VVIQ score for young individuals was 51.60 ($SD = $
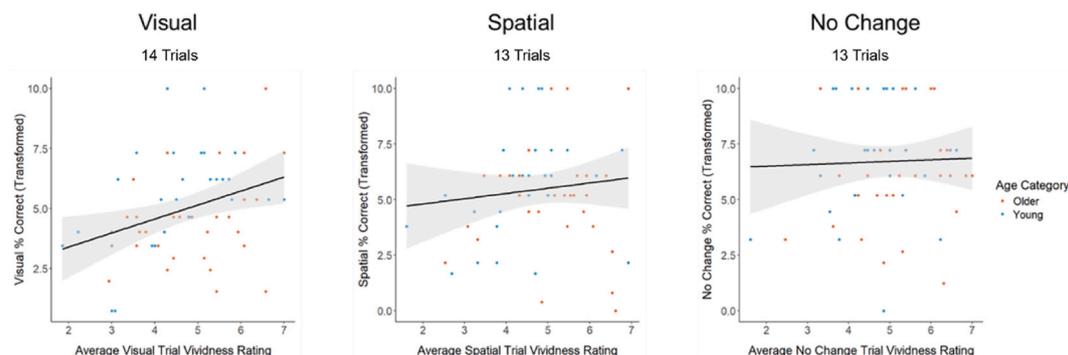

Fig. 6. Scatterplots of average vividness ratings and memory performance across modalities.

8.44) whereas the mean for older individuals was 57.07 ($SD = 11.53$). Analyses revealed this difference was statistically significant, $t(58) = 2.10$, $p = .040$, where on average, older participants scored higher on the VVIQ than younger individuals. Mean vividness ratings across trials for young participants was 4.54 ($SD = 1.12$), whereas the mean for older participants was 5.07 ($SD = 1.08$). Analyses revealed that this difference trended towards statistical significance, $t(58) = 1.87$, $p = .067$, indicating that across trials, young and older individuals differed to some degree in how they rated their vividness on average. Overall, it appears that younger individuals performed better on the memory task than older individuals on average, even though their VVIQ scores (and, to an extent, their average vividness ratings) were lower than older individuals'. Results can be seen in Fig. 7.

To investigate whether memory scores could be predicted by VVIQ scores, mean vividness ratings, and age, a multiple regression analysis was conducted. The overall model trended towards significance, $F(4, 55) = 2.53$, $p = .050$, $R^2 = 0.15$, adjusted $R^2 = 0.09$, with the only significant predictor of memory scores being age group when all other variables were held constant (See Table 3).

3.6. Confidence

To encourage participants to consider vividness and confidence independently, confidence ratings were given on a 1-5 scale, where vividness ratings were given on a 1-7 scale. To allow accurate comparisons between the two, each measure was normalised using the following formulae applied to each participant:

$$\text{Normalised Vividness} = \frac{(\text{Mean Vividness Rating} - 1)}{(7 - 1)}$$

$$\text{Normalised Confidence} = \frac{(\text{Mean Confidence Rating} - 1)}{(5 - 1)}$$

To test for potential relationships between confidence and vividness (H_5), a Spearman's rank correlation was run as confidence was not normally distributed ($W = 0.94$, $p = .008$). Analyses revealed a significant positive relationship between normalised average confidence and vividness ratings ($r(58) = 0.84$, $p = <0.001$), and normalised average confidence ratings and VVIQ scores ($r(58) = 0.34$, $p = <0.001$), which can be seen in Fig. 8.

To test for differences between average normalised confidence and vividness ratings, a Paired t-test was run. Analyses showed that there was a significant difference between average confidence scores (Mean = 0.77, $SD = 0.13$) and average vividness ratings (Mean = 0.63, $SD = 0.19$), $t(59) = 9.42$, $p = <0.001$, see Fig. 9.

3.7. Re-analysis of Siena and Simons (2024)

Siena and Simons (2024) used a task with some similarities to the present paradigm to investigate objective and subjective aspects of

Table 3
Details of the multiple regression model of memory performance based upon vividness measures and age.

Variable	B	SE	p
(Intercept)	5.57	4.00	0.170
VVIQ Score	−0.05	0.08	0.509
Mean Vividness Rating	−0.09	0.79	0.909
Age Category (Young)	1.18	0.42	0.007**
VVIQ Score * Mean Vividness Rating	0.01	0.01	0.537

memory in people with aphantasia, people with reduced imagery, and controls. Participants were required to memorise and recall learned object locations and colours within a 3D environment, switching between first and third-person perspectives to investigate how visual mental imagery ability related to episodic memory accuracy. Like in the present analysis, Siena and Simons observed a distinction between memory accuracy and rated vividness across trials. However, they did not examine trial-by-trial vividness in their analyses. The first author provided access to the data for re-analysis. Data were first converted to long format using the packages *'jsonlite'* (v2.0.0; Ooms, 2014) and *'tidyverse'* (v2.0.0; Wickham et al., 2019) in R. Data were processed following the same criteria and mathematical formulae as the original authors to generate scores. Those in the 'Reduced' mental imagery category were participants who reached aphantasic thresholds (VVIQ <32) but did not report total lack of mental imagery (VVIQ = 16). While some consider a VVIQ of <32 as aphantasic (Cabbai et al., 2023; Dance et al., 2022; Dawes et al., 2022; Wicken et al., 2021), for the purpose of subsequent analyses and to match Siena and Simons (2024), those in the 'Reduced' category are considered separately to aphantasics, as others suggest they represent distinct groups (Pounder et al., 2022).

The resulting data were analysed using a GLMM with a Gamma distribution and log link function due to the positively skewed performance errors. To investigate whether vividness ratings related to error rate across both the object and spatial measures, and between aphantasics and controls, the following formulae were used for object and spatial performance respectively:

Object Angular Difference ~ Vividness Rating * Type + (1 | ID)

Spatial Euclidian Distance ~ Vividness Rating * Type + (1 | ID)

where fixed effects were performance error, vividness ratings, and mental imagery category. Participant IDs were entered as a random effect. See Table 4 for statistical outputs:

Results indicate that for both object and spatial memory, greater trial-by-trial vividness was significantly associated with reduced error, and therefore greater memory. Aphantasics significantly out-performed controls across both modalities, having lower error than controls. There was no significant difference between the performance of Aphantasics and people with reduced imagery. There was no significant interaction
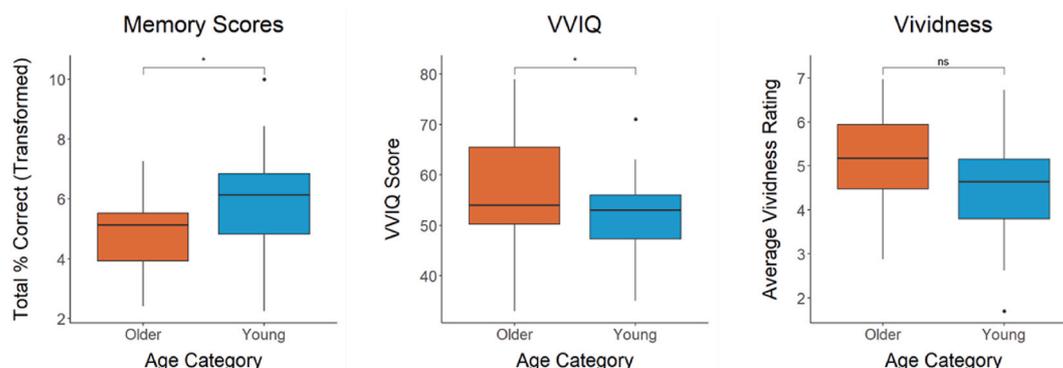

Fig. 7. Boxplots of memory, VVIQ, and vividness scores across age groups.
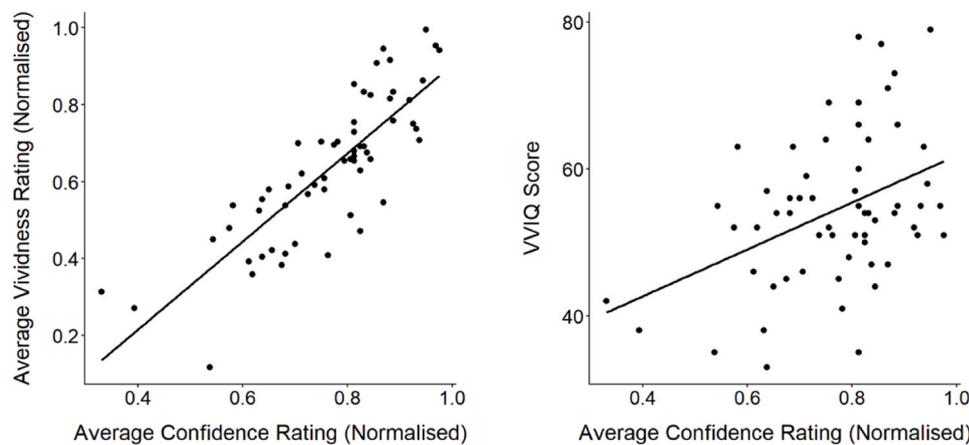
Fig. 8. Scatterplots of the relationships between normalised average confidence and vividness ratings (left) and normalised average confidence and VVIQ scores (right).
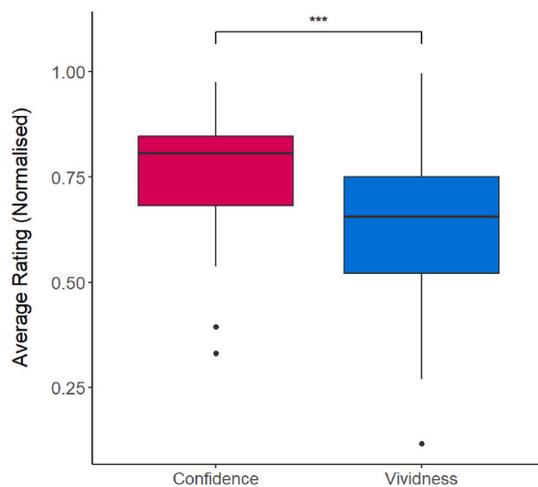

Fig. 9. Boxplot of normalised average confidence and vividness ratings.

Table 4
Statistical outputs following the GLMM on the Siena and Simons (2024) dataset.

Variable	B	SE	p
Object			
(Intercept)	3.61	0.11	<0.001***
Trial-by-trial Vividness Rating	−0.01	0.002	<0.001***
Type (Control)	0.65	0.14	<0.001***
Type (Reduced)	0.17	0.19	0.371
Vividness Rating* Type (Control)	−0.003	0.002	0.068
Vividness Rating* Type (Reduced)	−0.002	0.002	0.368
Spatial			
(Intercept)	2.55	0.09	<0.001***
Trial-by-trial Vividness Rating	−0.01	0.001	<0.001***
Type (Control)	0.30	0.12	0.012*
Type (Reduced)	−0.002	0.16	0.989
Vividness Rating * Type (Control)	−0.001	0.001	0.489
Vividness Rating* Type (Reduced)	−0.0002	0.002	0.904

between vividness and Type (Control, Reduced, or Aphantasic) across modalities, suggesting the effect of vividness on error rate did not differ between each category, with participants utilising vividness to the same extent across subjective experiences.

Following this, predicted probabilities were calculated to determine the predicted memory error based upon vividness ratings for each category. Analyses were run using the '*ggeffects*' (v2.2.1; Lüdecke, 2018)

package in R. As demonstrated by Fig. 10, higher vividness ratings are associated with lower error probability.

4. Discussion

4.1. Vividness

This study sought to investigate the relationship between mental imagery and memory. Using a novel experimental procedure, several key findings were supported. Firstly, while the VVIQ and mean vividness ratings (a trait measure and a state measure averaged across trials, respectively) were found not to significantly relate to memory abilities, trial-by-trial ratings of vividness within individuals (very much a state-dependent measure) were significant predictors of performance. H_1 is therefore supported for trial-level state analyses, whereas trait and mean vividness measures did not relate significantly to memory accuracy.

Although the current literature frequently finds no relationship between mental imagery and memory (Keogh et al., 2021; Siena and Simons, 2024), many studies often use either the VVIQ or mean vividness ratings as measurements of vividness to compare to overall performance. While the VVIQ is a reliable measure of trait mental imagery vividness (Campos and Pérez-Fabello, 2009; Jankowska and Karwowski, 2023), using VVIQ or mean vividness scores to predict performance appears to smooth over effects that may be present, such as how an individual's state vividness relates to memory performance on a fluctuating basis over the course of an experiment. Moreover, meta-analyses by Runge et al. (2015, 2017) and several behavioural studies (D'Angiulli et al., 2013; Dijkstra et al., 2017; Pearson et al., 2011) found that trial-by-trial vividness reports demonstrate significantly larger effect sizes than the VVIQ, reaching the similar conclusion that trial-by-trial self-reports have higher predictive value than the VVIQ. The present study identifies and supports the need to incorporate and analyse task-relevant measures, such as trial-by-trial responses, in future research, as utilising mean ratings or trait VVIQ scores may obscure within-participant vividness effects. Through re-analysis of the Siena and Simons (2024) dataset, previously missed findings were identified, evidencing the importance of state measurements and analyses, even in existing data.

4.2. Modality

Modality specific results would suggest differing contributions of memory vividness on identifying visual and spatial changes between study and test. Average vividness rating regression analyses significantly predicted overall visual performance, but not spatial or no-change performance (Fig. 6). However, when running GLMMs on each modality
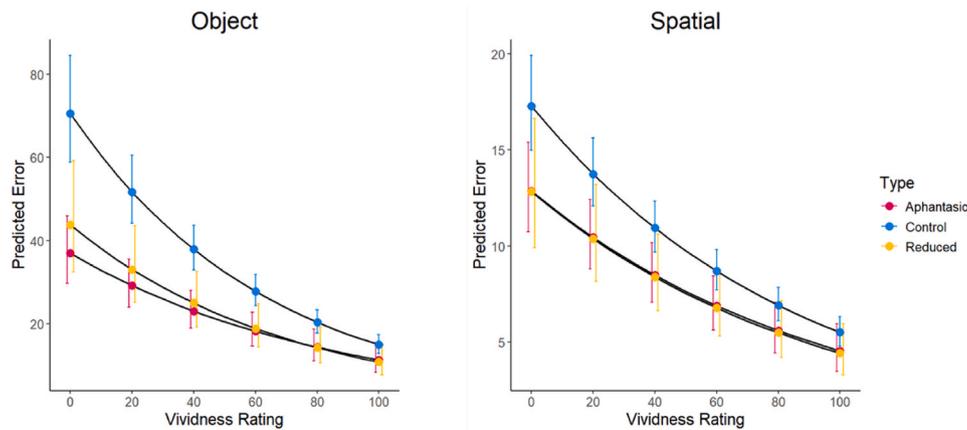
Fig. 10. Predicted probabilities of memory error by vividness from the Siena and Simons (2024) dataset. Error bars are offset from means to prevent overlap.

independently, it was revealed that trial-by-trial vividness was significantly related to correctly identifying changes across all modalities, further highlighting the need for trial-by-trial level analyses. This included spatial modalities, where greater trial-by-trial vividness was related to greater accuracy, failing to support H_2. When considering average vividness ratings, regression analyses found significant differences between young and older adults in visual modalities, indicating mental imagery may be utilised differently across the lifespan when identifying visual changes. As visual performance could be predicted by average-level data (Fig. 6), it appears the effect of vividness in visual modalities is particularly salient as effects persist even when averaging. Future research should continue to investigate the effect of modality, perhaps with more sensitive visual and spatial aspects, to further our understanding of the contribution of mental imagery in different modalities.

4.3. Age

Regarding age-related effects, results supported previous findings (Folville et al., 2020, 2021). On average, older individuals scored significantly higher on the VVIQ than younger individuals yet performed significantly worse on the memory task (see Fig. 7). Therefore, H_3 and H_4 are supported. However, no significant age differences were observed in average within-trial vividness ratings, and GLMM analyses showed the interaction between vividness and memory did not differ between age groups. While older individuals score higher on trait VVIQ, this did not translate to state vividness during the task, as both average vividness ratings (Fig. 7) and trial-by-trial vividness ratings (Table 1) did not significantly differ between young and older participants.

Furthermore, a linear regression revealed a significant difference in memory performance between age groups, with young individuals outperforming older individuals (see Table 3), further supporting H_4. The lack of age-related differences for within-trial vividness (Fig. 7), despite strong relationships between VVIQ and state average vividness (Fig. 3) suggests that the two are measuring similar subjective experiences but are rated differently on a trait vs state basis.

These findings suggest that while trait vividness ratings, such as VVIQ, may vary across age, state measures of vividness do not, with young and older participants appearing to have similar subjective experiences when rating memory vividness on a trial-by-trial basis. As there was no significant difference between trial-level vividness between young and older participants, but a significant difference in memory performance, the results further highlight a disconnect between vividness and memory performance. Vividness appears to influence memory but is not sufficient alone to explain episodic memory performance. Memories rely upon visual representations that underly them (Brady et al., 2011; Keogh et al., 2021; Kosslyn, 1975; Palombo et al., 2015), but

several other processes, such as executive control functions (Dobbins et al., 2002; Rajah et al., 2008; Tomita et al., 1999), may also contribute to retrieval, which are often reduced in older adults (Best and Miller, 2010; Buckner, 2004; Craik, 2005; De Luca et al., 2003; Fjell et al., 2017; Hedden and Gabrieli, 2004). Therefore, older adults may subjectively experience a memory as vivid as those younger than themselves, but other cognitive processes may explain the reduced accuracy of older adults during retrieval. Measuring trial-by-trial state vividness is therefore important to establish accurate relationships between mental imagery and memory across the lifespan.

4.4. Confidence

Confidence analyses revealed a strong significant relationship between vividness and confidence (Fig. 8), with confident memories tending to be rated as more vivid supporting H_5. While it could be argued participants conflated the two, the use of a standard, as used by previous studies (Folville et al., 2021), explained the concept of mental imagery, resulting in participants rating each measure accordingly. Moreover, as a Paired *t*-test revealed a significant difference between average vividness and confidence ratings (Fig. 9), it would suggest that the two measures, although correlated, reflect distinct aspects of subjective experience. These findings are reflected in neuroimaging research, with vividness and confidence being functionally and anatomically distinct (Zou and Kwok, 2022). It may be the case that the subjective experience of a vivid mental image coincides closely with the subjective feeling of confidence, as when one creates a clear, vivid image in one's mind, it may feel accurate, correct, and confident. The data suggest that a subjectively vivid memory is a confident memory, but the two experiences are subtly distinct from one another. Future research may wish to separate the two subjective experiences, perhaps by manipulating stimuli to create a subjectively vivid, but unconfident memory, or vice versa, to pinpoint what it is that we mean by 'vivid' and 'confident' in isolation.

4.5. Re-analysis of Siena and Simons (2024)

Siena and Simons (2024) found significant correlations between average vividness ratings and performance on their object and spatial tasks in controls, but not in aphantasics. Given that the present study found no correlations between VVIQ and memory, or between average vividness ratings and memory performance (Fig. 3), but GLMM analyses identified significant relationships on a trial-by-trial basis within participants, the same analyses were applied to the Siena and Simons (2024) dataset. Analyses revealed significant effects of trial-specific vividness on memory performance, for both aphantasics and controls, as well as those with reduced mental imagery experience. Moreover,

aphantasics appeared to have less error than controls. While the interaction between controls and vividness ratings was non-significant, it does appear that in object/visual modalities, people with mental imagery may rely on their vividness to a somewhat greater extent than aphantasics/reduced imagers. Combined with vividness being a significant predictor of only visual performance (Fig. 6), the relationship between vividness and modalities should be investigated further.

Re-analysis of the Siena and Simons (2024) dataset provided further evidence that using averaged data smooths over effects and can lead to the conclusion that there is no relationship between subjective mental imagery and objective memory performance. Further research using appropriate statistical analyses and state measures is required to confirm the findings of vividness relating to memory performance, and how aphantasics' imagery appears to both improve performance, and lead to greater baseline performance. Future research may also wish to investigate what constitutes a 'vivid' mental image in aphantasics, as it may differ qualitatively from controls.

5. Conclusion

The present experiment sought to investigate the relationship between mental imagery and memory via a novel experimental procedure. Results indicated that while some measures of vividness, such as the VVIQ and average vividness ratings, are not significantly related to memory performance, utilising statistical techniques such as GLMMs account for within-participant variability, and are able to reveal effects based upon state trial-by-trial measurements. To avoid potential Type II errors, it is recommended that future studies avoid averaging data and instead use st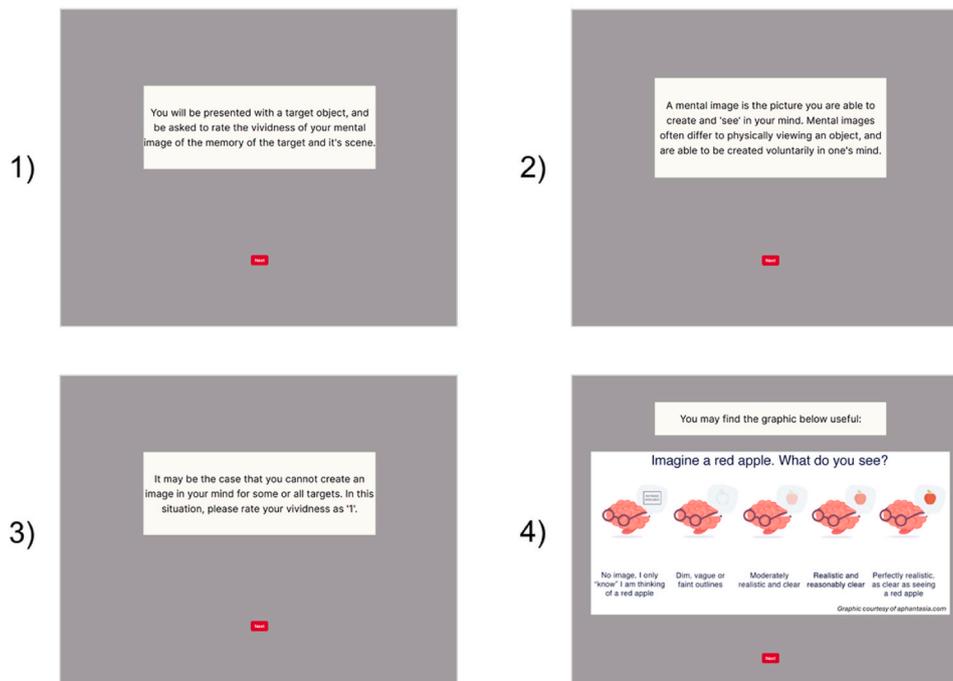ate measures to establish relationships between mental imagery and memory. Although the VVIQ is a well-established trait measure of mental imagery (Campos and Pérez-Fabello, 2009; Jankowska and Karwowski, 2023), it may suit only to categorise aphantasics and controls, and instead trial-by-trial state measures may be a more accurate reflection of the moment-by-moment fluctuations in mental imagery for subsequent analyses. There appears to be a state-level relationship between mental imagery and memory, with a more vivid memory tending to be more accurate.

CRediT authorship contribution statement

William Duckett: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jon S. Simons:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare no competing interests.

Acknowledgements

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2026.109399.

Appendix A

Explanations of mental imagery used during testing procedures.
Graphics were acquired and used with expressed permission from *aphantasia.com*:

Appendix B

Screenshot of a practice demonstration during testing procedures.
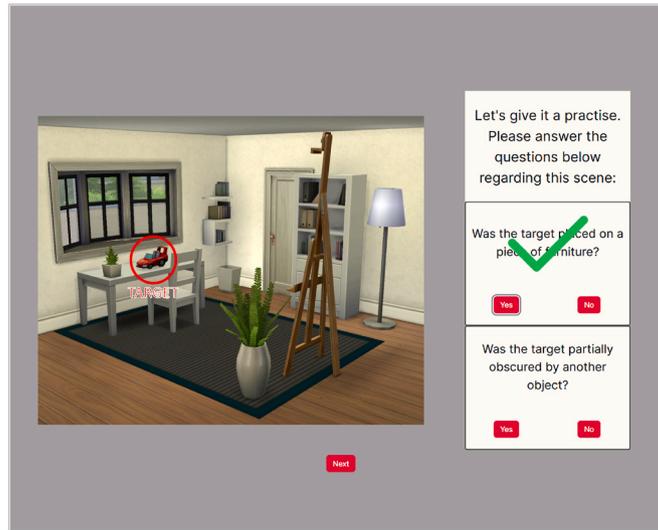
Appendix C

Visual and Spatial orientation questions from the Encoding section.
Visual:

- Was the target taller than it was wide?
- Does the target serve a purpose beyond decoration?
- Was the scene outdoors?
- Did the target match the overall style of the scene?

Spatial:

- Was the target placed on a piece of furniture?
- Was the target partially obscured by another object?
- Was the target placed on a wall?
- Would the target fit into a shoe box?

Appendix D

Predicted probability table of memory performance from vividness ratings, following a GLMM analysis.

CWC Vividness Rating	Memory Prediction	SE	Lower CI	Higher CI
Young				
−6	0.468886	0.330202	0.316089	0.627747
−5	0.54199	0.287074	0.402683	0.675027
−4	0.61333	0.24691	0.49435	0.720162
−3	0.680117	0.211407	0.58418	0.762902
−2	0.740253	0.183294	0.66553	0.803218
−1	0.792533	0.166359	0.733842	0.841084
0	0.836612	0.164102	0.787781	0.875977
1	0.872829	0.177084	0.829082	0.90664
2	0.901959	0.202393	0.860866	0.931876
3	0.92499	0.236099	0.885889	0.951428
4	0.942953	0.275132	0.906012	0.965921
Older				
−6	0.313144	0.311671	0.1984	0.456461
−5	0.380308	0.272311	0.264646	0.511367

(continued on next page)

(*continued*)

CWC Vividness Rating	Memory Prediction	SE	Lower CI	Higher CI
−4	0.452389	0.235673	0.342329	0.567311
−3	0.526525	0.203234	0.427482	0.623524
−2	0.599509	0.177316	0.513968	0.679386
−1	0.66833	0.161095	0.595054	0.734267
0	0.730638	0.157596	0.66574	0.786968
1	0.785006	0.167617	0.724433	0.835291
2	0.83094	0.18902	0.772385	0.876833
3	0.868701	0.218485	0.811731	0.910336
4	0.899053	0.253213	0.844284	0.936018

Appendix E

Statistical outputs following the GLMMs for each modality, including (1| Object) as a random effect. Note that Stimulus 1 is excluded for Spatial analyses due to below chance performance unduly influencing model estimates.

Variable	B	SE	p
Visual			
(Intercept)	−0.50	1.00	0.618
CWC Trial-by-trial Vividness Rating	0.32	0.08	<0.001***
Age Category (Young)	0.68	0.32	0.034*
Average Trial-by-trial Vividness	0.45	0.17	0.007**
VVIQ Score	−0.01	0.02	0.467
CWC Vividness Rating x Age Category (Young)	−0.12	0.12	0.331
Spatial			
(Intercept)	0.32	1.61	0.841
CWC Trial-by-trial Vividness Rating	0.33	0.11	0.004**
Age Category (Young)	1.03	0.56	0.064
Average Trial-by-trial Vividness	0.25	0.28	0.358
VVIQ Score	−0.00	0.03	0.990
CWC Vividness Rating x Age Category (Young)	0.21	0.16	0.185
No Change			
(Intercept)	1.20	1.35	0.374
CWC Trial-by-trial Vividness Rating	0.26	0.11	0.016*
Age Category (Young)	0.57	0.46	0.212
Average Trial-by-trial Vividness	0.06	0.23	0.808
VVIQ Score	0.01	0.03	0.810
CWC Vividness Rating x Age Category (Young)	−0.07	0.16	0.636

Data availability

Anonymised behavioural data are available at https://osf.io/eq4vb/files.

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