Individuals with congenital aphantasia show no significant neuropsychological deficits on imagery-related memory tasks

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Abstract

Aphantasia describes the experience of individuals who self-report a lack of voluntary visual imagery. It is not yet known whether individuals with aphantasia show deficits in cognitive and neuropsychological tasks thought to relate to aspects of visual imagery, including Spatial Span, One Touch Stocking of Cambridge, Pattern Recognition Memory, Verbal Recognition Memory and Mental Rotation. Twenty individuals with congenital aphantasia (VVIQ < 25) were identified and matched on measures of age and IQ to twenty individuals with typical imagery (VVIQ > 35). The only group differences found within the neuropsychological and visuo-spatial working memory tests were slower performance in the One Touch Stocking of Cambridge task during trials that had greater working memory load. These results suggest that the cognitive profile of people without imagery does not greatly differ from those with typical imagery when examined by group. However, observed group differences were apparent with increased working memory load. This raises questions about whether or not aphantasia represents a differences cognitive function or in conscious experience.

Keywords: Aphantasia, visual imagery, spatial imagery, neuropsychology

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1. Introduction

Most people self-report that they experience visual mental imagery, in other words, they have the ability to create an image in their mind's eye in the absence of direct perceptual information (Galton, 1880; McKelvie & Demers, 1979). However, a subset of the population self-report an absence of visual imagery, despite having no obvious neurological impairment and having intact visual perception (Faw, 2009; Keogh & Pearson, 2018; Zeman, Dewar, & Della-Sala, 2015). This experience, termed *congenital aphantasia* (often shortened to aphantasia), was first named in 2015 (Zeman et al., 2015). Up to now, much exploration of aphantasia has been based on subjective report, although there is some evidence that individuals with aphantasia and typical imagers differ on objective measures such as binocular rivalry (Keogh & Pearson, 2018), visual memory performance assessed through drawing (Bainbridge, Pounder, Eardley & Baker, 2020) and physiological responses (Wicken, Keogh & Pearson, 2021). What is not yet clear is what underpins the apparent differences in imagery experience.

A straight-forward question is whether aphantasia may reflect other underlying cognitive deficits that manifest as differences in performance within neuropsychological tasks. Potential deficits in aphantasic individuals have already been noted in relation to working memory and/or executive function; Jacobs, Schwarzkopf & Silvanto (2017) noted in the case study of *AI*, that she performed less accurately within a visuo-spatial working memory task at the highest level of difficulty relative to sighted controls, compared to her performance in a matched imagery version of the task. Although they were discussing acquired aphantasia, it is worth noting that Zeman et al. (2010) reported in their case study that Patient *MX* displayed longer reaction times in a Mental Rotation Task (MRT), which is a classic visuo-spatial imagery task thought to involve working memory function, although with comparable accuracy to neurotypical controls. The authors explained this in terms of *MX* adopting a different strategy in the task (Zeman et al., 2010). *MX's* performance was nevertheless normal on a range of executive function tasks (Zeman et al., 2010).

Potential deficits have also been noted in relation to episodic memory, such that individuals with aphantasia reported lower levels of episodic memory compared to typical imagers (Dawes, Keogh, Andrillion, & Pearson, 2020). Recent work from Milton et al. (*unpublished findings*) has also reported subjective impairments in autobiographical memory in aphantasic individuals relative to typical imagery controls. Although both working memory and episodic memory have been previously reported as being potential areas of weakness or impairment in aphantasia (Dawes et al., 2020; Milton et al., *unpublished findings*; Jacobs et al., 2017), results are limited. What is lacking in the literature is an objective neuropsychological assessment of memory performance in a larger sample of congenital aphantasic individuals.

To address the gap in knowledge around core cognitive deficits, we selected four tests from the Cambridge Neuropsychological Test Automated Battery (CANTAB). The tasks were: Verbal Recognition Memory (VRM), Pattern Recognition Memory (PRM), Spatial Span (SSP) and One Touch Stocking of Cambridge (OTS). The MRT, a classic visuo-spatial imagery task and measure of spatial ability involving object rotation (Shepard & Metzler, 1971; Xue et al., 2017), was also included in the battery. These tasks tap into two domains thought to be essential to the imagery process: episodic memory (VRM and PRM) and visuo-spatial working memory (SSP, OTS and MRT). These broadly map on to hippocampal and prefrontal brain regions respectively (Burgess, Maguire, O'Keefe, 2002; Eichenbaum, 2017; Zacharopoulos, Klingberg, Kadosh, 2020), although these regions are relevant to a range of other non-imagery tasks (e.g. Eichenbaum, 2017; Grossmann, 2013).

Pattern recognition (PRM) was selected in order to examine visual memory performance, with verbal memory (VRM) as a comparison. If impaired on both then a general episodic memory impairment may be assumed. If impaired only on visual memory then the indication is that the impairment is specific to visual episodic memory. If performance is within the normal range for both of these tasks then this provides initial evidence that they are not clinically impaired on episodic memory.

Both SSP and OTS are considered an assessment of visual working memory. The SSP is a visual sequencing working memory task, often used as a measure of visuo-spatial working memory capacity. Patt et al. (2014) states that a key strategy for performance on the SSP is the generation of visual imagery by 'making shapes' from imaginary lines. The SSP has also been shown to correlate with the strength of visual imagery (Keogh & Pearson, 2014), suggesting the stronger one's visual imagery, the greater the visual working memory capacity. In contrast, the OTS requires the maintenance and manipulation of increasing amounts of visuo-spatial information in working memory, a process suggested to engage visual imagery (Hodgson, Bajwa, Owen, & Kennard, 2000). If impairments are evident on the SSP then this suggests a fundamental impairment in holding a visual sequence in mind, which might also be expected to correspond to impairments in the OTS task given that both tasks require the maintenance of visuo-spatial information. However, if there is normal performance on the SSP but not on the OTS, then it follows that the impairment may be due to difficulties with manipulating the information rather than just maintaining the information in mind, which becomes more difficult with increasing number of items to manipulate. It is important to note that the OTS also has a planning and strategy element, which more directly reflects executive function and does not necessarily implicate the visuo-spatial system. The MRT was chosen to supplement these visuo-spatial tasks as, like the OTS, it requires manipulation but unlike the OTS it does not require any additional planning. As such, if a difference was found in the MRT and the OTS, this would suggest an impairment in the manipulation element, but if impairment was only found in the OTS, then it might suggest an impairment in planning and strategy.

Nevertheless, it is important to note that whilst the SSP, the MRT, and the OTS are defined as visual working memory tasks, they have strong spatial components (Foster, Bsales, Jaffe, & Awh, 2017; McCants, Katus, & Eimer, 2019). Furthermore, evidence from congenitally totally blind individuals suggests that working memory tasks traditionally considered to rely on visual processes, including the MRT, can be carried out without visual experience (e.g. Carpenter & Eisenberg, 1978; Kerr, 1983; Marmor & Zaback, 1976; Zimler & Keenan, 1983).

In summary, this study uses clinical tests to explore episodic memory and visuo-spatial working memory in a group of individuals with aphantasia and typical imagery. Firstly, it examines episodic memory performance in people who self-report a lack of visual imagery, specifically assessing whether there are deficits that are specific to the visual domain. Secondly, this research draws on three tasks to examine whether or not individuals with aphantasia show deficits for tasks requiring different levels of holding and manipulating visuo-spatial information.

2. Materials and Methods

The data reported here was part of a larger battery of tasks, that were carried out over two separate testing sessions of 2 hours each, one week apart. Within each session, the order of the tasks was randomised.

2.1. Participants

Twenty (7 males, 13 females) individuals with congenital aphantasia were recruited from aphantasia-specific online forums, including “Aphantasia (Non-Imager/Mental Blindness) Awareness Group”, “Aphantasia!” and Aphantasia discussion pages on Reddit. Control participants (those with typical visual imagery) were recruited from students and staff at the University of Westminster as well as recruited through social media. At present, there is no agreed cut-off score for defining groups based on typical and atypical self-reports of imagery (Zeman et al., 2015). In line with other studies that adopt a conservative cut-off of self-reported imagery vividness (e.g. Zeman et al., 2020; Bainbridge et al., 2020): congenital aphantasic participants (n = 20: 7 males, 13 females) were identified through the Vividness of Visual Imagery Questionnaire (VVIQ), defined by scores ≤ 25 (M = 16.65, SD = 1.95). Typical imagery control participants (n = 20: 8 males, 12 females) were identified by VVIQ scores ≥ 35 (M = 63.8, SD = 12.34). These mean VVIQ scores for typical imagers are in line with the normative VVIQ scores of ‘normal’ imagery experience as identified in a meta-analysis (McKelvie, 1995). Individuals with congenital aphantasia did not differ from controls on age (aphantasic age: M = 40y0m, SD = 8.92; control age: M = 39y6m, SD = 11.61; $t(38) = -0.28$, $p = .78$, $d = .04$). They also did not differ on Weschler Adult Reading Test (WTAR; Wechsler, 2001), which can be used as a proxy measure for intelligence (Mathias, Bowden, & Barrett-Woodbridge, 2007) (aphantasic WTAR score: M = 43.35, SD = 3.01 or predicted Full-Scale IQ (FSIQ) equivalence: M = 108, SD = 3.21; control WTAR score: M = 42.30, SD = 4.12 or predicted FSIQ equivalence: M = 106.6, SD = 4.42, WTAR: $t(38) = -0.92$, $p = .36$, $d = .29$). All participants had normal or corrected-to-normal vision and no history of mental health illness.

2.2. Behavioural tasks

2.2.1. Cambridge Neuropsychological Test Automated Battery (CANTAB)

Four tasks were selected from the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Cambridge Cognition, Cambridge UK version 5.0.0): '*Verbal Recognition Memory* (VRM),' '*Pattern Recognition Memory* (PRM),' '*Spatial Spa*n (SSP),' '*One Touch Stocking of Cambridge* (OTS).' All CANTAB tests were administered on a Windows operating system on a 15.6-inch touch-screen tablet computer. All participants first undertook a motor screen test to ensure participants were familiar with the concept of the touch-screen interface. A brief outline of each task is provided below:

1. Verbal Recognition Memory (VRM) comprises of two phases. In the first phase, participants were shown a series of 12 words which appeared on a screen one-by-one. Following the sequence, participants were asked to verbally recall as many words as possible from the list they had seen and correct and incorrect responses were noted. In the second phase of the task, participants were shown another sequence of words and for each word, had to decide whether they recognised it from the original list in a two-alternative forced-choice paradigm. Outcome measures in the first phase were the number of correctly recalled words and in the second phase, the number of correct responses.

2. Pattern Recognition Memory (PRM, see Figure 1A) participants were shown two different series of 12 visual patterns which appeared in the centre of the screen in a continuous sequence one after the other. These patterns were novel and unfamiliar comprising of lines which are designed so that they cannot be given verbal labels, nor did they look similar to common objects. In the first phase, participants were shown one series of 12 visual patterns, following which participants were presented with two options: one novel pattern and one pattern that had been presented during the continuous sequence. Participants had to indicate the previously presented pattern. This was repeated in the second phase of the task with a new set of patterns. Outcome measures were the number of correct trials.

3. Spatial Span (SSP, see Figure 1B) participants were shown a number of white squares on a black screen which changed colour one-by-one. The aim of the task was to

remember and select the order in which various boxes changed colour in a sequence. The task increased in difficulty, with an increasing number of boxes in the sequence, from two boxes at the start to a maximum of nine. The task terminated when a participant failed to answer three consecutive trials correctly. Outcome measures were the span length (the longest sequence correctly recalled), number of errors and usage errors. The number of errors denotes the total number of times a participant pressed an incorrect box. The usage error is the number of times an incorrect box is pressed per sequence.

4. One Touch Stocking of Cambridge (OTS, see Figure 1C), based on the Tower of Hanoi, participants were shown two arrangements of three coloured balls, one set positioned at the top, the other at the lower half of the screen. Each stocking had the capacity to hold three balls. The aim of the task was to rearrange the balls at the bottom of the screen in order to match the arrangement and the top of the screen. However, there were certain rules with regard to the way the balls could be moved. Participants had to calculate the minimum number of moves '*within their head*' and indicate their response. Participants were informed not to physically use any part of their bodies, for instance, their hands, fingers or head to aid the calculation of the minimum number of moves. In the most difficult trials, the maximum number of moves to solve the task was always 6. The results for move 1 were discounted in any analysis owing to the fact the test administrator was explaining instructions during this trial; thus, it increased the time taken to complete the trial. Outcome measures were the mean number of 'moves' (or attempts) to select a correct response (accuracy) and latency to correct (time taken to successfully complete the trial).

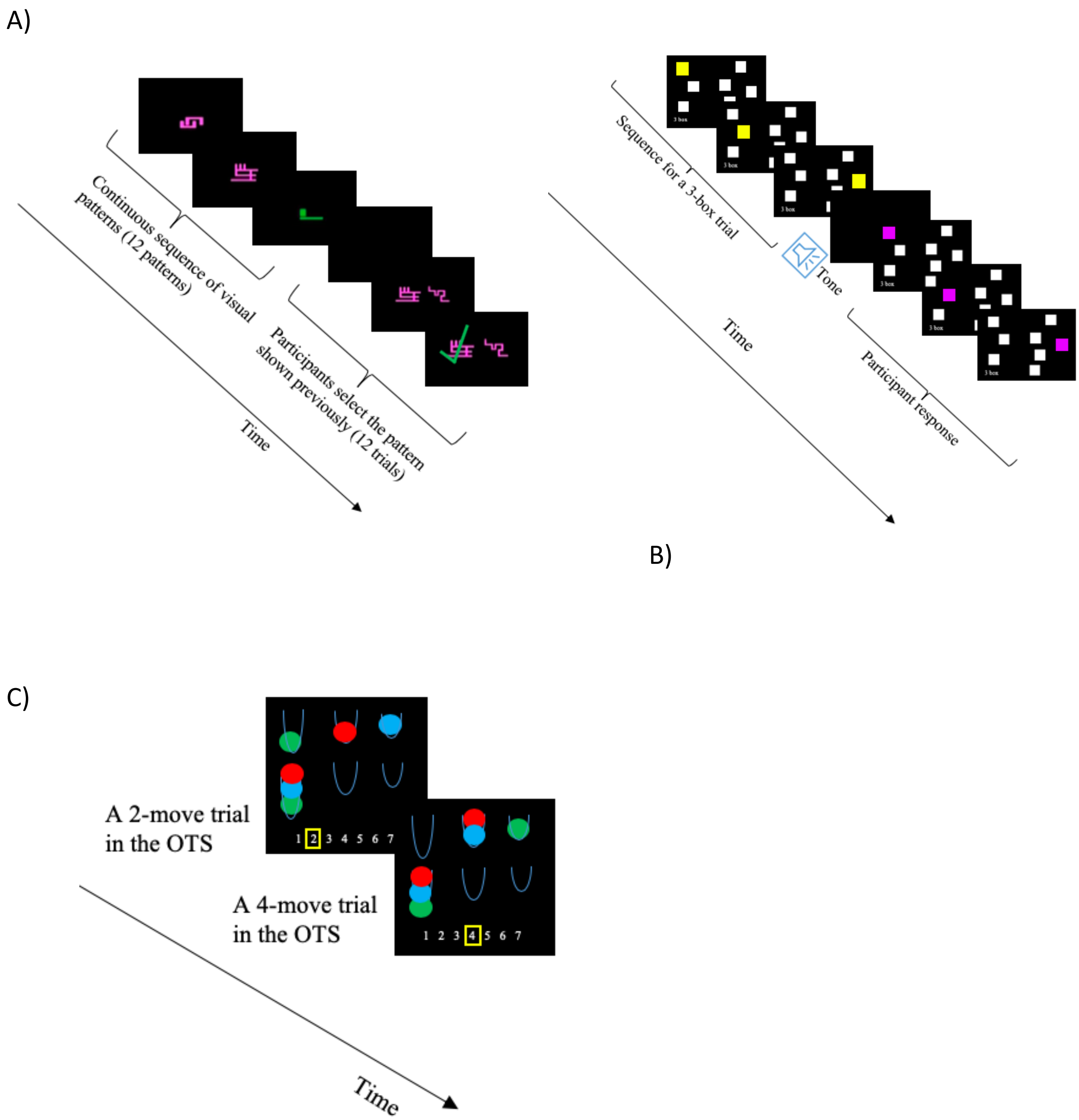

Figure 1: A) Diagram to show an example of the Pattern Recognition Memory (PRM). A continuous stream of visual patterns were presented, following which, participants selected the pattern they recognised. B) Diagram to show an example of a three-box trial in the Spatial Span (SSP). Participants were presented with a sequence of coloured boxes, and following the sound of a tone, selected the boxes as shown in the sequence. C) Diagram to show an example of a 2-move and 4-move trial in the One Touch Stocking of Cambridge (OTS). Participants needed to rearrange the bottom configuration of balls 'in their head' to match the top configuration and select the number referring to the minimum number of moves required.

2.2.2. Mental Rotation Task (MRT)

Adapted from the classic Shepard and Metzler mental rotation experiment, stimuli were acquired from the Mental Rotation Stimulus library (Peters & Battista, 2008). All stimuli comprised of 10 cubes glued together in different orientations to form 'arms.' 138 white-cubed stimuli were selected, rotating around the x-axis with a full view (parts not occluded by parts of arms) were chosen from the Mental Rotation Stimulus library. Each stimulus was super-imposed on a black background for the task.

Based on the remaining angles, 6 levels of difficulty were chosen relative to 0°: 40°, 85°, 130°, 175°, 220°, 265°). Following an informal pilot of 12 participants, angle rotations of 130°, 220° and 265° were excluded as these angles had a higher accuracy relative to the 'easier' angles of rotation. As a result, three angles of rotation were selected; these were angles: 40°, 85°, and 220°. The task comprised of two blocks of 48 trials, forming 96 trials in total. One block (i.e. 48 trials) was included in each testing session of the study. The blocks were matched in terms of difficulty, with 16 trials per angle of rotation in each block and in terms of the number of same and different responses. In each block of 48 trials, 24 stimuli were the same (i.e. the stimuli were of the shape, but displayed at a different orientation) and 24 were different. Of the 'different' trials, 23 were mirror images, while 25 trials were comprised of different images. The task was programmed on E-prime version 2, and outcome measures of performance were reaction time and accuracy.

2.3. Statistical analysis

Participant characteristics, imagery questionnaires and neuropsychological tasks, data were analysed with two-way mixed ANOVAs and independent t-tests or the non-parametric equivalent, the Mann Whitney test when normality assumptions were violated. All data transformations were undertaken on MATLAB. Data visualisations represent the raw data. All statistics analysed were performed with a significance level of $p \leq .05$, and all p values are two-tailed.

3. Results

3.1. Episodic Memory Tasks

3.1.1. Pattern Recognition Memory

In the PRM, a Mann-Whitney test was conducted as the data were not normally distributed, this showed that there was no evidence of a difference in performance (U = 179.5, p = .57, *r* = .09) between aphantasic (median of 22, range: 19 – 24) and control (median = 22, range: 19 – 24) participants.

3.1.2. Verbal Recognition Memory

There was a ceiling effect in the recognition phase of the VRM (98-99% correct). As a result, only the free recall phase was analysed. An independent t-test showed that there was no difference in performance on the free recall phase of the task ($t(38) = 0.11$, p = .92, *d* = .02) between aphantasic (M = 7.4, SD = 1.7) and control (M = 7.5, SD = 1.82) participants.

3.2. Visuo-spatial Working Memory

3.2.1 Spatial Span

In the SSP, a Mann-Whitney test was conducted as the data were not normally distributed, this showed no evidence of a difference in memory spatial span (U = 170.5, p = .39, *r* = .14) between aphantasic (median = 7, range: 5 – 8) and control participants (median = 7, range: 6 – 8). Moreover, an independent t-test showed no significant difference in the total number of errors (the number of times an incorrect box was pressed across all trials) ($t(38) = 0.47$, p = .63, *d* = .16) between aphantasic (M = 14.1, SD = 4.61) and controls (M = 13.2, SD = 6.62) participants. For total usage error, an independent t-test showed no significant difference in the number of times a box was selected that was not in the span sequence for the trial ($t(38) = 0.46$, p = .65, *d* = .15) between aphantasic (M = 2.1, SD = 1.41) and control (M = 1.9, SD = 1.2) participants. These results show that the performance of individuals with aphantasia was comparable to individuals with typical imagery.

3.2.2. Mental Rotation (MRT)

The proportion correct MRT data was transformed using an arcsin transformation (Studebaker, 1985). The accuracy of mental rotation performance was first examined by angle of rotation between aphantasic and control participants using a two-way mixed measures ANOVA with Greenhouse-Geisser correction with a between-subject factor of group (aphantasic/ control) and within-subject factor of the angle of rotation (40°, 85°, and 220°). There was a significant main effect of angle of rotation ($F(1.70, 64.7) = 29.92$, $p < .001$, $\eta p^2 = .44$), with higher accuracy at the smallest angle of rotation compared to the largest angle of rotation. There was no main effect of group ($F(1, 38) = 0.76$, $p = .39$, $\eta p^2 = .02$) and no significant interaction between the angle of rotation and group ($F(1.70, 64.7) = 0.29$, $p = .72$, $\eta p^2 = .008$). These results show that despite self-reporting a lack of visual imagery, participants with aphantasia do not significantly differ from participants with typical imagery on this task.

Reaction time data for the MRT was transformed using the Box-Cox transformation to meet normality assumptions (Box & Cox, 1964). Reaction time data was analysed by angles of rotation (40°, 85°, and 220°) and compared between groups. The data was analysed using a two-way mixed ANOVA with Greenhouse-Geisser corrections. The results of the two-way mixed measures ANOVA with between-subject factor group (aphantasic/control) and within-subject factor angle of rotation (40°, 85°, and 220°), showed a significant main effect of angle of rotation on reaction time ($F(1.65, 62.86) = 66.22$, $p < .001$, $\eta p^2 = .64$), with quicker response times at the smallest angle of rotation compared to slower response times at the largest angle of rotation. There was no significant main effect of group ($F(1, 38) = 3.62$, $p = .07$, $\eta p^2 = .087$) and no significant interaction between angle of rotation and group ($F(1.65, 62.86) = 0.45$, $p = .60$, $\eta p^2 = .012$).

3.2.3. One Touch Stocking of Cambridge

In the OTS, data were transformed using the BoxCox transformation (Box & Cox, 1964) to address a violation of normality. Mean moves to correct is defined by the number of attempts a participant takes to opt for the correct response. Accuracy in the OTS was analysed for each number of moves, from 2 moves to 6 moves using a two-way mixed measures ANOVA with factors participant group (aphantasic/control) and the number of moves (2-6). There was no significant main effect of participant group ($F(1, 38) = 0.09$, $p = .76$, $\eta p^2 = .002$), however, there was a significant main effect of number of moves ($F(4, 152) = 36.63$, $p < .001$, $\eta p^2 = .49$). Post hoc tests using the Bonferroni correction for multiple comparisons revealed a significant pairwise difference in accuracy between all moves ($p < .01$) except (moves 1-2, 2-3, and 4-5, $p > .09$). There was no significant interaction between participant group and number of moves ($F(4, 152) = 0.82$, $p = .52$, $\eta p^2 = .02$).

Mean latency of correct responses is defined as the amount of time taken for participants to respond correctly within each trial-type. This was analysed using a two-way mixed ANOVA with Greenhouse-Geisser correction. The results of the two-way mixed ANOVA with factors participant group (aphantasic /control) and number of moves (2-6), showed that there no significant main effect of participant group ($F(1, 38) = 1.90$, $p = .18$, $\eta p^2 = .05$) but a significant main effect of number of moves ($F(2.80, 106.43) = 287.17$, $p < .001$, $\eta p^2 = .88$). Post hoc tests using the Bonferroni correction for multiple comparisons revealed a significant pairwise difference in latency to correct for all moves 2-6 ($p < .001$). There was a significant interaction between participant group and the time taken across moves 2-6 ($F(2.80, 106.43) = 3.40$, $p = .023$, $\eta p^2 = .08$). Subsequent independent t-tests showed a significant difference in latency at moves 5 ($t(38) = 2.65$, $p = .012$, $d = .78$) and move 6 ($t(38) = 2.62$, $p = .013$, $d = .76$). All other moves (2-4) were not significant ($p > .61$). These results indicate that time to correct response different only at levels of greater difficulty in which executive function demands could be expected to be highest (see Figure 2).

It should be noted, that within the sample of aphantasic participants there was great variation in terms of reaction time for moves 5 and moves 6 in the OTS. For comparison, the mean reaction time for control participants at move 6 was 58.70 seconds (SD = 24.44 seconds), and within the aphantasic sample, 8 aphantasic participants were quicker than control participants (min = 40.55, M = 51.38 seconds, SD = 6.41 seconds). However, the other 12 aphantasic participants displayed longer reaction times than the mean of the control participants (min = 59.83 seconds, max = 226.97 seconds, M = 122.6 seconds, SD = 50.33 seconds). Clinically, 8 of these aphantasic participants would be categorised as severely impaired for reaction times at move 6 in the OTS (M = 149.16 seconds, SD = 37 seconds). This shows that some aphantasic participants were more impaired on the task than others participants, suggesting that some aphantasic participants were more efficient during these trials involving high manipulation and working memory load.

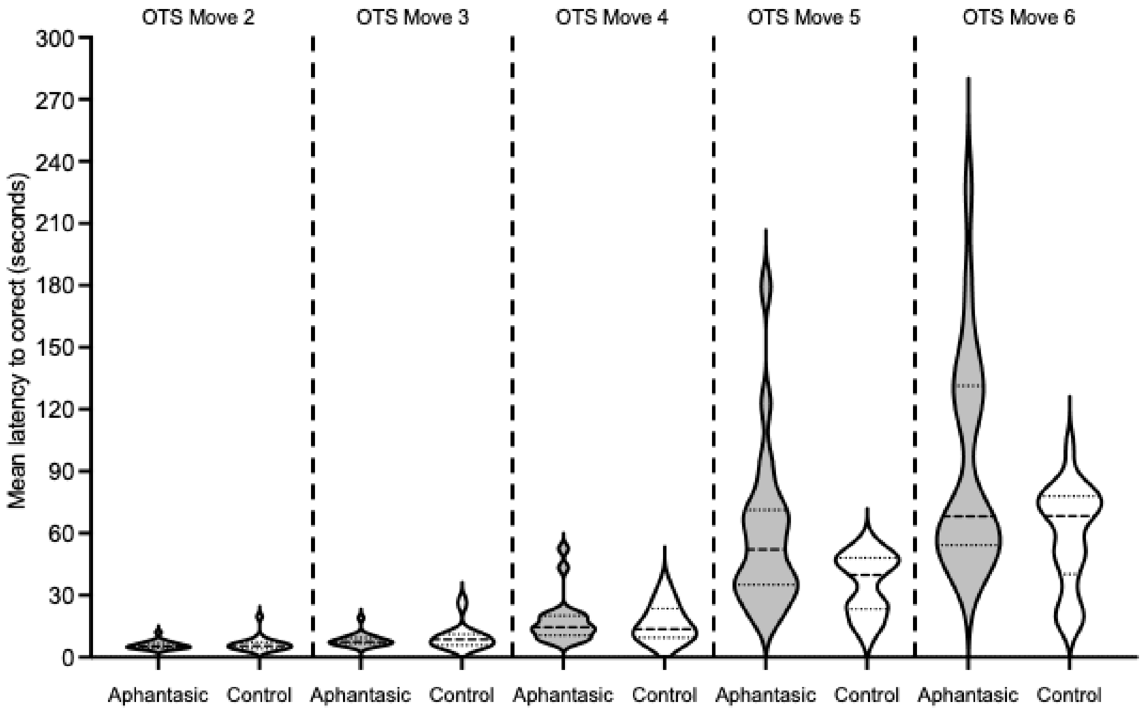

Figure 2 – Raw data showing latency to correct (response time in seconds) for each move in the OTS between control and aphantasic participants.

4. Discussion

This study examined the performance of individuals with congenital aphantasia within a battery of neuropsychological episodic memory and visual working memory tasks. On episodic memory tasks, the results showed no differences between aphantasic individuals and typical imagers. In other words, aphantasic individuals do not appear to have either a general episodic memory impairment nor an impairment specific to visual episodic memory problem. On visuo-spatial working memory tasks, no differences were found between participants in the SST or in the MRT, suggesting no deficits in capacity, or in the holding and manipulating of visuo-spatial information. Within the OTS, although there were no differences in accuracy, differences in reaction time were evident between aphantasic and typical imager participants during the most cognitively demanding trials (5/6 balls). In other words, although differences in the OTS, but not the MRT may suggest a difficulty in the planning components of the OTS task, these difficulties were not consistent across all levels of difficulties. Rather, there appears to be slower performance at the stages that involve the most complex manipulations and/or high working memory load.

Although this is the first study to explore differences in behavioural episodic memory, the results show no differences in performance between aphantasic and typical imager participants, which is in contrast to the self-reported deficits in both episodic memory (Dawes et al., 2020) and autobiographical memory (Milton et al, unpublished). However, while both the episodic memory task (used here) and the self-reports (e.g. Dawes et al., 2020) concern memory for an episode, the self-reports more specifically probe the retrieval of experience or specific aspects of previous events or scenes from one's life. In comparison, the episodic memory tasks probe the retrieval of learned experimental material. While both are considered episodic memory, they are shown to engage different brain regions (Chen, Gilmore, Nelson, & McDermott, 2017; Roediger & McDermott, 2013). Autobiographical retrieval of life events is shown to activate the default mode network, whereas the retrieval of recently encountered experimental material within behavioural episodic memory tasks is shown to activate frontal parietal regions (Chen et al., 2017; McDermott, Szpunar, & Christ, 2009). This suggests that there are differing forms of episodic memory (i.e. memory of retrieval of life events and memory of recently learned material), which are underpinned by differing neural networks and processes (Chen et al., 2017; Roediger & McDermott, 2013). This distinction within episodic memory may be further explored within aphantasia, whereby preliminary evidence through self-reports suggest impairment in episodic autobiographical memory retrieval, but not episodic retrieval of experimental materials. At the same time, it should be noted that not all aphantasic individuals report difficulties with autobiographical memory (Zeman et al., 2020). Further research is required to examine differences in episodic memory experience in aphantasia.

The lack of differences in performance in the SSP between aphantasic and typical imager participants is perhaps surprising, given the previously reported relationship between self-reports of imagery vividness and SSP performance (Keogh & Pearson, 2014). Similarly, for the MRT, although the lack of significant difference in accuracy mirrored performance by patient *MX,* who had acquired aphantasia (Zeman et al., 2010), the lack of group difference in reaction time differed from *MX,* who showed longer reaction times in the task (Zeman et al., 2010). It was suggested, that if visual imagery was crucial to the undertaking of tasks requiring spatial transformations such as object rotation, then differences in performance would have been expected between aphantasic and typical imagery control participants. A possible reason for the lack of differences in performance on the SSP and MRT could be that these tasks load more heavily on spatial imagery, with studies documenting that aphantasic participants self-report intact spatial imagery abilities (Bainbridge at al., 2020; Dawes et al., 2020; Keogh & Pearson, 2018). Tasks such as mental rotation are reported not rely on visual, but spatial representations (Liesefeld & Zimmer, 2013). Further, evidence from the congenitally blind literature, suggests that some imagery tasks can be undertaken as accurately in the absence of a 'visual' component (e.g. Carpenter & Eisenberg, 1978; Marmor & Zaback, 1976; Eardley & Pring, 2007). This suggests that aphantasic participants may be using spatial imagery in these tasks similar to congenitally blind individuals. Despite this, differences have been documented on objective tasks such as differences in imagery priming in binocular rivalry and fewer object details draw in a visual memory paradigm (Bainbridge et al., 2020; Keogh & Pearson, 2018). This suggests these tasks load more on the requirement and experience of visual representations, however, it should be noted that no drawing differences in spatial details were apparent between aphantasic and typical imager participants (Bainbridge et al., 2020). Neuroimaging, neuropsychological case studies and individual differences research have demonstrated the dissociation between visual-object and visual-spatial imagery, and these imagery subtypes are underpinned by functionally and anatomically separate processing pathways - the ventral and dorsal pathways, respectively (e.g. Blajenkova, Kozhevnikov & Motes, 2006; Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001; Farah, 1984; Farah, Levine, & Calvanio, 1988; Kozhevnikov, Hegarty, & Mayer, 2002; Kozhevnikov, Kosslyn, & Shephard, 2005).

Although these results did not suggest a blanket deficit with the planning components of the OTS task, significantly slower performance in the more complex levels of the task suggests that the self-reported lack of visual imagery may be impacting performance. These trials where performance was slower than typical imagers were associated with instances of high working memory load and manipulation of visuo-spatial information (i.e. at move 5 and move 6). In terms of the multicomponent working memory, it has been suggested that in scenarios where highly detailed visual details are required to be maintained, it may involve the repeat generation of the image within the visual buffer, rather than maintenance of visual information in the visual cache (Darling, Della Sala & Logie, 2009; Kosslyn & Thompson, 2003). In contrast, during low load working memory trials, which are suggested to comprise of the maintenance and manipulation of no more than four balls (Fukuda, Awh, & Vogel, 2010), there were no differences in performance between aphantasic and control participants with typical imagery. This suggests that the processes that the aphantasic participants adopted were conducive only up to a certain level, with increasing manipulation and working memory load resulting in significant group differences in reaction time. This pattern of performance is similar to that exhibited by congenitally blind individuals who show longer reaction times in imagery tasks (e.g. Carpenter & Eisenberg, 1978; Kerr, 1983; Zimler & Keenan, 1983) as they are suggested to have a lower visuo-spatial processing capacity compared to sighted individuals (Vecchi, 1998; Vecchi, Monticellai, & Cornoldi, 1995).

It is also worth noting that although this research uses a larger sample than previous experimental research (Keogh & Pearson, 2017), the effect size is small. Consequently, it is possible that performance differences may have been found in the tasks if a larger sample had been used. One-way larger samples could be recruited is by converting the tasks to an online format and recruiting participants through aphantasic communities on the internet. Nevertheless, this research highlights a notable contrast between the impaired experience of imagery and the largely unimpaired performance on objective measures looking at aspects of cognition thought to be involved in the imagery process. A potential explanation for difference in the magnitude of effect may lie in recent research that has identified variation in the experience of aphantasia (Dawes et al., 2020; Zeman et al., 2020), raising the possibility that there may be subtypes of aphantasia. Within the current study, variations of performance in aphantasic individuals were identified in the most challenging trials within the OTS task (at move 5 and 6). At the hardest level, 8 aphantasic participants met the criteria for classification as 'severely impaired'. At the same time, 8 participants responded faster than typical imagers. While this may be anomalous performance or 'noise' within the data, this also might suggest that aphantasic participants are using different processes or strategies to complete the task processes. Arguably, it raises the possibility that at least some aphantasic individuals, may retain the ability to generate visual imagery, but lack conscious access to this imagery. These aphantasic participants may be able to use the visual buffer to regenerate the complex configurations (Darling et al., 2009) required with the OTS task (similar to individuals with typical imagery), despite this re-generation process occurring outside of conscious awareness. Future studies should explore individual differences to further identify variations in behavioural performance.

5. Conclusion

Despite their difference in self-reported conscious experience of visual imagery, individuals with aphantasia performed as well as individuals with typical imagery on neuropsychological tasks exploring episodic and visuo-spatial working memory. The only exception was evidence of a difference in reaction time for aphantasic individuals relative to typical imagers, on the most cognitively demanding levels of the OTS task. Potentially, individuals with aphantasia are using different mechanisms, which are functionally equivalent for all but the most cognitively demanding tasks, when the lack of visual imagery experience begins to impact on performance. Related to this, and based on the evidence of slower performance on only the more complex tasks, is the possibility that aphantasic individuals are completing these tasks without access to visual imagery, but rather by using spatial imagery (similar to congenitally blind individuals). Alternatively, the similar levels of performance could be explained by the fact that aphantasics individuals lack conscious awareness of their visual imagery experience, although this does not explain the differences observed in the OTS task. The sample size did not permit exploration of individual differences, however, there may have been a subset of aphantasic participants who were not impaired on any of the tasks, and a subset who were impaired. Ultimately, the results suggest that despite the differences in the subjective experience of visual imagery, aphantasic individuals do not show impairments in visual working memory or episodic memory, with no major impairments that would hamper everyday life.

Funding

Participant payment was funded by The European Research Council awarded to JS, grant number: 336152.

Acknowledgements

We would like to greatly thank all of our aphantasic and typical imager participants who took the time to undertake this study.

CRediT authorship contribution statement

Z. Pounder: Study Conceptualization, Methodology, Investigation, Project administration, Software, Data curation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization; **J. Jacob**: Conceptualization, Methodology, Software, Writing - review & editing; **S. Evans:** Resources, Software, Writing - review & editing; **C. Loveday**: Conceptualization, Methodology, Writing - review & editing; **A. Eardley:** Writing - review & editing; **J. Silvanto:** – Conceptualization, Methodology, Funding acquisition, Writing - review & editing

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