Characterizations of Voluntary and Involuntary Imagery in Aphantasia

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Abstract

Aphantasia refers to the condition one is unable to summon visual mental images in minds. However, whether aphantasia loses such ability completely or only the consciousness for image generation is a debated and unsolved issue. To address this question, the present study aimed to characterize aphantasia in voluntary (II) and involuntary imagery (VI). W.S., a woman aphantasia, and her age-, IQ-, attention ability-matched control groups (gender-mixed or gender-matched) were recruited and assessed with four differential threshold tasks (DT). In three DTs, visual mental images were instructed to create voluntarily or involuntarily preceded the DT task varying with imagery duration time (II-0.5s, VI-0.5s and VI-6s). The other is the pure perceptual task (baseline). Systematical impairments were detected in W.S. in VI-6s: in congruent trials, W.S. exhibited extremely lower accuracy rates than controls; in incongruent trials, the deficit was evident in the difference of DT between baseline and imagery condition (DDT). However, no deficit was observed in comparison between W.S. and controls in VI-0.5s and II-0.5s tasks. All these results suggested that aphantasia was entangled in creating mental images voluntarily. As such, more mental resources would be required for image generation in aphantasia and showed difficulty in switching attention from distractor (mental images) to the following perceptual processing. On the other hand, aphantasia may still preserve the II abilities to summon images in minds unconsciously. The present results contribute to our understanding of aphantasia, suggesting that individuals with aphantasia are not completely losing imagery ability, but experience a reduction or absence of spontaneous mental imagery.

Keywords: aphantasia; visual mental imagery; voluntary imagery; involuntary imagery; differential threshold tasks

Introduction

In our daily lives, some individuals lack the ability to voluntarily form visual mental images, a condition known as "aphantasia" (Zeman, Dewar, & Della Sala, 2015), affecting approximately 2-3% of the population (Faw, 2009; Zeman et al., 2020). The term "aphantasia" is a combination of Aristotle's "phantasia" meaning the mind's eye, and "a" meaning absence, to describe people who self-report an inability to produce voluntary visual images while their visual perception remains intact (Keogh & Pearson, 2018; Zeman et al., 2015). They had less vivid and rich autobiographical memories (Monzel et al., 2023), imagined future scenarios (Dawes, Keogh, Andrillon, & Pearson, 2020) and fewer and poorer quality dreams (Dawes et al., 2020; Zeman et al., 2020), while spatial capabilities still intact (Dawes et al., 2020). However, confusion remains about whether aphantasia's ability to imagine voluntarily or involuntarily (Nanay, 2021; Siena & Simons, 2024). In other words, are aphantasia individuals deficient in visual imagery completely, or showing partial deficit in voluntary or involuntary visual imagery only?

There are at least two types of VMI: voluntary imagery (VI) and involuntary imagery (II), depending on whether it is spontaneous or not (Pearson, 2019). VI refers to the process of imagination under the influence of stimuli or according to a certain purpose (Pearson, 2019). II refers to the process of imagery without prior purpose, often triggered by associations or sensory experiences, without direct sensory stimulation (Pearson, 2019; Pearson & Westbrook, 2015). Both VI and II were found to affect the subsequential perceptual processing in healthy individuals (Koenig-Robert & Pearson, 2019; Kok, Jehee, & De Lange, 2012; Kwok, Leys, Koenig-Robert, & Pearson, 2019; Pearson, Clifford, & Tong, 2008). Binocular rivalry paradigm was commonly used to measure VI (Keogh & Pearson, 2011; Pearson et al., 2008; Pearson, Rademaker, & Tong, 2011; Rademaker & Pearson, 2012). In a typical binocular rivalry task, participants were asked to identify which of two rival patterns of red and green grating was dominant (Tong, Meng, & Blake, 2006). Interestingly, when participants were asked either to see or to imagine a stimulus preceded, such a process was found to strongly influence which of the two competing stimuli was perceived during binocular rivalry (Keogh & Pearson, 2018; Pearson et al., 2008). Notably, the duration of VI was crucial in studies involving VI (Pearson et al., 2008). According to Person et al. (2008), at least five seconds were required for one to generate mental images voluntarily in minds' eyes.

On the other hand, VMI has been proven can be generated involuntarily (Kwok et al., 2019). For example, Kwok and colleagues found the priming effect on the subsequent perceptual tasks when participants were either instructed to "imagine" or "avoid imagining" the object stimulus (2019). Such effect observed in "avoid imagining" condition was interpreted as suppressed thoughts creating a sensory bias or VMI involuntarily (Kwok et al., 2019). An alternative way to induce visual mental images in minds involuntarily was based on associative learning (Pearson, 2019). For example, in Kok and colleagues' study (2012), participants were asked to detect the orientation of rotation (clockwise *vs.* counterclockwise) of the two consecutive gratings presented on the screen which were slightly different in direction. In each trial, an auditory cue was presented before the perceptual task with 75% effectiveness on the overall orientation of the grating (45° or 135°). VMI was assumed to be generated and maintained involuntarily according to such auditory cues. The differential threshold (DT) of the two subsequent gratings was found significantly smaller when the orientation of imagined and perceived gratings was congruent as compared to incongruent condition. These results suggested that II can be generated and affect the following perceptual processing process.

Recently, researchers have shed light on aphantasia (Zeman, 2024; Zeman et al., 2015) and embarked on M.X., the first person subjectively reported losing VMI abilities. Normally, aphantasia are screened according to their subjective report as well as the score of vividness of visual imagery questionnaire (VVIQ) (Marks, 1973; Zeman et al., 2015; Zeman et al., 2020; Zhang et al., 2024). In VVIQ, participants generate mental images of four scenarios—a familiar person, a sunrise, a frequently visited store, and a nature scene with trees, hills, and a lake. In each scenario, four items were listed and participants were asked to rate the vividness of the mental images generated in their minds' eyes on a Likert-5 scale (1: no image to 5: very vivid). Therefore, there are 16 items in VVIQ with total a score range from 16 to 80. Individuals who scored 16 points on VVIQ referring to the absence of VMI were screened as aphantasia (Knight et al., 2022; Blomkvist & Marks, 2023), as well as those scored from 17 to 32 points according to the existing literature (Dance, Ipser, & Simner, 2022; Dance, Ward, & Simner, 2021; Keogh & Pearson, 2018, 2024; Wicken, Keogh, & Pearson, 2021; Zeman et al., 2015).

Some studies have also reported experiences of aphantasia individuals involuntarily "flashing" visual images while awake, sleeping, or dreaming (Zeman et al., 2015). The ability to dream (one type of involuntary imagery) and recall dream content was also present in aphantasia individuals (Dawes et al., 2020; Zeman et al., 2020). While little systematical work has been done in aphantasia in VI and II performances. In Keogh and Pearson's study (2018), fifteen aphantasia individuals were assessed with binocular rivalry, the typical measurement for VI (Pearson et al., 2008). A significant deficit was revealed in such inabilities as compared to the control individuals. Interestingly, when more aphantasia individuals were recruited and exhibited an inconsistent result (Keogh & Pearson, 2024). A subset of (6 out of 51) aphantasia participants scored over 60%, showing the priming effect on the binocular rivalry paradigm. These results were interpreted as at least some aphantasia may still show intact II to form "unconscious VMI". Similarly, Jacobs and her colleagues (2018) found AI, an aphantasia woman showed comparable performance as her control groups in VI tasks, while her metacognitive accuracy was impaired. In this case, it is possible unconscious mental imagery was used in AI to cope with the imagery tasks while she lost the ability to insight into their imagery content (Jacobs, Schwarzkopf, & Silvanto, 2018). In other words, the individual with aphantasia may still have VMI ability to generate mental images involuntarily (Nanay, 2021). However, to our best knowledge, there has been no study yet to access II abilities in aphantasia directly.

Therefore, the present study aimed to further clarify whether aphantasia was characterized by a complete absence of imagery. Specifically, whether aphantasia still have the ability to generate mental images voluntarily or involuntarily. To address this question, a single aphantasia individual was assessed the differential threshold (DT) task, a typical II task (II-0.5s task) identical to Kok et al. (2012) in which 0.5 seconds was given to generate and maintain the involuntary VMI contents. According to Krempel's theory (2024), the difference between VI and II is whether a specific instruction was given to induce one's mental image voluntarily. We assessed the individual aphantasia and the control groups with the DT tasks in which imagery instruction was given to enforce participants to summon VI in each trial. To be identical with II-0.5s task, 0.5 seconds was also given for VI generation (VI-0.5s task). In addition, 6s imagery duration time was considered (VI-6s task) as at least five seconds were suggested for VI generation and maintenance according to Pearson et al.'s report (2008). The age-, IQ-, attention- and spatial working memory ability-matched control participants were randomly assigned to one of three task groups, II-0.5s task, VI-0.5s task and VI-6s task. To specifically figure out how voluntary or involuntary imagery works for perceptual processing, the pure perceptual task was given to the aphantasia individual and each control participant as their baseline performance. Response time, accuracy rates and difference of differential threshold between baseline and each imagery task (DDT) were calculated and compared between the aphantasia individual and her gender-matched and gender-mixed controls. If aphantasia is impaired in one type of VMI abilities, there would be presences of deficit performance in W.S. as compared to her control groups as indexed by RTs, ACC or DDT. According to Pearson et al.'s observation on VI duration (2008), we predicted that comparable performances would be observed in VI-0.5s task. Both aphantasia and controls would not be able to summon VI in such a short time. Aphantasia deficit performance would probably show in at least one of the imagery tasks, VI-6s or II-0.5s tasks.

Method

Participants

Aphantasia individual. W.S., a 21-year-old university female student majoring in Japanese from Shanghai Jiao Tong University, was recruited in the present experiment. She contacted us on purpose as she realized she was suffering from aphantasia in borne by accident when chatting with her roommates. W.S. subjectively reported having difficulty in generating objects or scenes in her minds even during dreams. Interestingly, she debriefed having trouble remembering faces but no difficulty in spatial navigation.

Control group. Sixty-six participants (age= 22.45 ± 2.19 years old, 33 female; age range from 17-27) from Shanghai Jiao Tong University and East China Normal University were recruited and randomly assigned to one of the three imagery type groups. Data from nine participants were excluded from analysis (two participants in II-0.5s; four participants in VI-0.5s; three participants in VI-6s) because of their low accuracy on the imagery task (<75%). Therefore, there were 57 participants (age = 22.23 ± 2.21 years old, 26 female) for data analyses.

W.S. and control groups of individuals were right-handed, had no history of physical or mental illness, had normal or corrected-to-normal vision, and had normal hearing. They were rewarded with ¥175 for their participation. The current study was approved by Shanghai Jiao Tong University (SJTU) in line with guidelines on ethical human research (No.: B20222261I). All participants were informed of the contents before the study. None of the participants had ever participated in a similar experiment before.

Psychometrics tests and Questionnaires

W.S. and control groups of individuals participated in the following standard and bespoke tests: (i) intelligence quotient (IQ): Wechsler's Adult Intelligence Scale, Revised by China (WAIS-RC) (Gong, 1983; Wechsler, 1981); (ii) attention: Stroop test (Stroop, 1935); (iii) visuospatial working memory capacity: Corsi block tapping task (CBT) (Berch, Krikorian, & Huha, 1998; Richardson, 2007); (iv) vividness of visual imagery: the Chinese version of Vividness of Visual Imagery Questionnaire (VVIQ-C) (Marks, 1973; Zhang et al., 2024).

Behavioral paradigm

W.S. completed the behavioral paradigm in the order of pure differential threshold (DT) tasks (without imagery), involuntary imagery task (II-0.5s task), voluntary imagery 0.5s task (VI-0.5s task), and voluntary imagery 6s task (VI-6s task). Participants in the control groups were randomly assigned to one of three imagery types groups, and each group was asked to complete a pure DT task and a DT task with imagery (II-0.5s task; VI-0.5s task; VI-6s task).

Apparatus and Stimuli. Circular gratings were selected as visual stimuli in the present experiment which were generated using MATLAB 8.0.0 (R2021b; MathWorks, Natick, MA) and the Psychtoolbox (Watson & Pelli, 1983). The circular grating stimuli were sinusoidal grayscale luminance-defined with a 15° viewing angle outer diameter and a 3° inner diameter. The fixation point was a square with 64-pixel sides presented in the center of the screen. The auditory cue was produced by using the MATLAB function "sound" to play a basic tone (450 or 1,000Hz).

Pure DT task (without imagery; baseline). Two consecutive grating stimuli were displayed for 500ms each in each trial, separated by a blank screen (100ms). The first grating had a 50% chance of being 45° or 135°, and the second grating deviated slightly in orientation from the first. The Angle deviation between the two gratings was adjusted by the Quest toolbox in MATLAB (Watson & Pelli, 1983). Participants had to determine whether the second grating was rotated clockwise or counter-clockwise in relation to the first. The Quest function in Psychtoolbox (Watson & Pelli, 1983) was used to calculate the orientation differences between the two gratings (tGuess=3.5399; tGuessSd=3; pThreshold=0.75). When all of the 64 trials of 7 minutes were completed, the Quest function calculated the least angle difference threshold that participants could identify, which reflected the participant's pure perceptual ability.

Three DT tasks (with imagery). As shown in Figure 1, three types of DT tasks in which visual imagery was required to generate precede DT task.

II-0.5s task. The experiment paradigm was similar to Kok (Kok et al., 2012). In this II-0.5s task, each trial began with an auditory cue and was followed by two consecutive grating stimuli. The auditory cue was either a low-frequency (450Hz) or high-frequency (1000Hz) tone that predicted the orientation of the subsequent grating stimulus (45° or 135°) with 75% validity. Participants were not told how the auditory cue corresponded to the subsequent grating. The order of correspondence between sound stimulus and grating was counterbalanced among participants. Then two consecutive grating stimuli were displayed for 500ms each in each trial, separated by a blank screen (100ms). The first grating, which had an orientation of either 45° or 135°, resulted in either congruent or incongruent condition depending on whether the direction of it matches the direction suggested by the cue. The orientation of the second grating was marginally different from the first. The participants had to complete an orientation discrimination test in which they had to determine whether the second grating was spun clockwise or counter-clockwise with regard to the first grating using a response box marked as "clockwise", "counter-clockwise" and "unable-to-judge".

---insert Figure 1 about here---

VI-0.5s task. The procedure was similar to II-0.5s task. But the auditory cue was either a low-frequency (450Hz) or high-frequency (1000Hz) tone that indicated the orientation of the subsequent grating stimulus (45° or 135°) with 50% validity[1]. Participants were told the relationship between tone and grating (i.e., which orientation the tone indicated) and instructed to visualize the corresponding grating for 0.5s in their mind's eye during the blank screen. Then the grating rotation direction is determined. Finally, participants were asked to rate the vividness of the grating imagery they had created in their minds' eyes after hearing the auditory cue (1: no imagery; 2: fuzzy and dim; 3: relatively clear; 4: very clear and vivid).

[1] In the II-0.5s task, the auditory cue predicted the orientation of the subsequent grating stimulus with 75% validity. However, in the VI-0.5s and VI-6s, the validity of auditory cues was 50%. The 75% validity may lead to an expectation by participants. A recent study indicated that the imagery effect on perceptual threshold was independent of expectation (Dijkstra, Mazor, Kok, & Fleming, 2021). The influence of imagery on the subsequent perceptual differential threshold might be not interfered with expectation.

VI-6s task. The procedure was the same as VI-0.5s task except that the visualization continues for 6s instead of 0.5s after hearing the auditory cue. The Quest function in Psychtoolbox (Watson & Pelli, 1983), an adaptive staircase algorithm, was used to calculate the orientation differences between the two gratings individually for trials with congruent and incongruent orientations (tGuess=3.5399; tGuessSd=3; p Threshold=0.75). The smallest angle difference threshold that participants could detect independently in congruent and incongruent trials were measured using this method.

Experimental procedure

Wechsler's Adult Intelligence Scale, Revised by China (WAIS-RC) (Gong, 1983; Wechsler, 1981) and Stroop test (Stroop, 1935) were administered using paper-based questionnaires. Vividness of visual imagery: the Chinese version of Vividness of Visual Imagery Questionnaire (VVIQ-C) (Marks, 1973; Zhang et al., 2024) was administered online using WJX platform. Corsi block tapping task (CBT) and DT tasks were run on a Dell D2421H 23.8 inch viewing screen with 1920 × 1080 resolution and a 60-Hz refresh rate. The experiment was carried out in a special laboratory. During the DT tasks, participants sat in the laboratory with dim light, 57 cm away from a computer screen.

W.S. completed all of psychometrics tests, questionnaires and DT tasks. All of psychometrics tests and questionnaires were first completed by W.S. for about 60 minutes. Then W.S. completed pure DT task and three DT tasks with imagery (II-0.5s, VI-0.5s and VI-6s task). The order of DT tasks was pure DT task, II-0.5s, VI-0.5s and VI-6s task. The pure DT task lasted for about 6 minutes. For II-0.5s, VI-0.5s and VI-6s task, all individuals completed one task (128 trials for 13, 16, and 20 minutes, respectively). In all the tasks, W.S. responded by pressing response box marked as “clockwise”, “counter-clockwise” and “unable-to-judge”.

Participants in control groups were instructed to complete psychometric tests, questionnaires and DT tasks. Half of the participants were firstly instructed to complete psychometric tests and questionnaires, followed by behavioral paradigm, and the other half completed in reverse order. During the behavioral experiments, the pure DT task was firstly instructed to complete, which lasted for about 6 minutes. For II-0.5s, VI-0.5s and VI-6s task, all individuals completed one task (128 trials for 13, 16, and 20 minutes, respectively). Then participants completed one of three DT tasks with imagery (II-0.5s, VI-0.5s and VI-6s task). In all the tasks, the participants responded by pressing response box marked as "clockwise", "counter-clockwise" and "unable-to-judge".

Data analysis

The procedure (SINGLIMS.EXE) developed by Crawford and Garthwaite (2002) was implemented to compare age, VVI scores (VVIQ-C score and online VVI score) and cognitive tests performances (WAIS-RC, corsi block and STROOP test) of W.S. as well as her gender-matched and gender-mixed controls in each group respectively.

As our main concern about aphantasia performance in four DT tasks, accuracy rates (ACC), response times (RTs) and difference of differential threshold (DDT) were calculated. For each participant, the ACC and RTs in correct trials were calculated for congruent and incongruent trials respectively in all three imagery DT tasks. DT was calculated using Quest function in MATLAB (Watson & Pelli, 1983) for each DT task and for congruent and incongruent trials respectively. DDT was calculated for each participant by subtracting the differential threshold in the pure DT task from that in congruent and incongruent condition respectively in each imagery DT task. To explicitly explore the possible deficit in W.S., the procedure (SINGLIMS.EXE) was again applied on RTs, ACC and DDT separately to compare W.S. and her gender-matched or gender-mixed controls performance in each imagery task for congruent and incongruent trials respectively.

Results

Demographic information of aphantasia

Demographic information and psychometric results of W.S., the female aphantasia were summarized in Table 1 as well as her gender-matched and gender-mixed controls. W.S. subjectively reported her lost ability to generate mental images and scored 20 in VVIQ-C (Marks, 1973) which met the criteria for aphantasia (VVIQ score < 32) (Zeman et al., 2015). As shown in Table 1, the VVIQ-C score was significantly lower in W.S., the female aphantasia, as compared to her gender-matched and gender-mixed controls in all three imagery type groups (both ps$\leqq$0.001). Estimated percentage of female and mixed-gender normal population falling below W.S.'s VVIQ-C score was lower than 0.08% and 0.02% respectively. Based on online vividness rating, W.S. impaired VI ability was further confirmed with significantly lower online VVI scores in W.S. when voluntary mental image was asked to generate in mind for 0.5 (VVI = 1.00) and 6 seconds (VVI = 1.79) than her gender-matched (VI-0.5s: VVI = 3.15 $\pm$ 0.58; VI-6s: VVI = 3.11 $\pm$ 0.45, both ts$\leqq$-2.78, ps$\leqq$0.012) and mixed controls (VI-0.5s: VVI = 3.05 $\pm$ 0.62; VI-0.5s: VVI = 3.14 $\pm$ 0.59, both ts$\leqq$-2.23, ps$\leqq$0.019). Estimated percentage of female and gender-mixed normal population falling below W.S. online VVI score was lower 1.94%.

----insert Table 1 about here----

Other than imagery ability, W.S. (aphantasia) performed as well as her age and gender-matched and gender-mixed controls in a series of cognitive tests, suggesting an intact memory and attention ability in W.S. as well as general intelligence as indexed by corsi block (Corsi, 1972), Stroop test (Stroop, 1935) and WASI-RC (Gong, 1983; Wechsler, 1981) respectively.

The performance of behavioral paradigm

II-0.5s task.

Difference of differential thresholds

As shown in the left-most column, top panel in Figure 2, there was no difference in DDT of congruent trials between W.S. (M = -1.06°) and her gender-matched (M = -0.94°; SD = 0.85°) or gender-mixed control group (M = -1.07°;

SD = 1.10°) recruited in II-0.5s task, all ts≦0.13, ps≧0.90. Estimated percentage of the control groups in congruent trials exhibiting a higher differential threshold than W.S. was below 49.62%. A similar observation was obtained in incongruent trials, W.S. detected -0.56 angle on the DDT indicator, showing comparable performance as compared to her gender-matched (M = -0.54°; SD = 0.98°; $t(8) = 0.02$, $p = 0.99$) or gender-mixed control group (M = -0.99°; SD = 1.34°; $t(19) = 0.31$, $p = 0.76$). Estimated percentage of the control groups in incongruent trials exhibiting a higher differential threshold than W.S. was below 37.89%.

Accuracy rates

W.S. also exhibited intact performance indexed by ACC in generating involuntary imagery (Fig.2). She performed the II-0.5s task accurately (congruent: M = 0.76; incongruent: M = 0.78), slightly lower than her gender-matched (congruent: M = 0.82; SD = 0.08; incongruent: M = 0.89; SD = 0.05) and gender-mixed control groups (congruent: M = 0.83; SD = 0.07; incongruent: M = 0.87; SD = 0.06) but without statistically significant difference, all ts ≤ 2.23 ps ≥ 0.06). Estimated percentage of the control groups in congruent trials and incongruent trials exhibiting a lower ACC than W.S. was below 2.82%.

Response times

As shown in Fig.2, similar performance was also detected in response time between W.S. and her different gender-matched or gender-mixed control group in both congruent (ts≤ 0.98, ps≥ 0.34) and incongruent conditions (ts≤ 1.39, ps≥ 0.20) in II-0.5s task. W.S. (congruent: M = 995.40ms; incongruent: M= 1037.77) responded numerically slower than her different gender-matched (congruent: M = 833.61ms; SD = 193.12; incongruent: M = 795.11ms; SD = 165.99) or gender-mixed control group (congruent: M = 961.78ms; SD = 275.69; incongruent: M = 925.69ms; SD = 295.21). Estimated percentage of the control groups in both congruent and incongruent trials exhibiting a longer RT than W.S. was below 10.15%.

---insert Figure 2 about here---

VI-0.5s task.

Difference of differential thresholds

As depicted in the top section of the middle column in Figure 2, there was no discernible difference in DDT between W.S. (M = 1.13°) and her gender-matched (M = -0.25°; SD = 2.06°) or gender-mixed (M = 0.68°; SD = 1.50°) control group in the congruent imagery condition, all .ts≤ 1.17, ps≥ 0.26. Estimated percentage of the control groups in congruent trials exhibiting a higher differential threshold than W.S. was below 12.9%. Additionally, there was no difference in the DDT of incongruent trials between W.S. (M = 2.66°) and her gender-matched (M = -0.57°; SD = 1.64°) or gender-mixed control groups (M = -0.29°; SD = 2.35°), all ts≤ 1.98, ps≥ 0.08. Estimated percentage of the control groups in incongruent trials exhibiting a higher differential threshold than W.S. was 3.61%.

Accuracy rates

Similar accuracy rates were found in congruent trials by comparing W.S. (M = 0.84) and her gender-matched (M = 0.84; SD = 0.06) or gender-mixed control group (M = 0.85; SD = 0.07) recruited in VI-0.5s task, all ts≤ 0.14, ps≥ 0.90 (as seen in Figure 2, center panel and middle column). The percentage of control groups with ACC higher than W.S. did not exceed 44.83%. Similarly, W.S. (M = 0.91) did not significantly vary from her gender-matched (M = 0.86; SD = 0.07; $t(7) = 0.67$, p = 0.52) and gender-mixed control group (M = 0.85; SD = 0.05; $t(17) = 1.05$, p = 0.31) in incongruent trials. Estimated percentage of the control groups in congruent trials and incongruent trials exhibiting a lower ACC than W.S. was below 44.83%.

Response times

As shown in Fig.2, response times in W.S. in congruent (M = 1122.30ms) and incongruent (M = 1068.72ms) trials were not significantly different from her gender-matched (congruent: M = 1111.05ms, SD = 417.18ms; incongruent: M = 1122.27ms, SD = 454.66ms) or gender-mixed control groups (congruent: M = 1084.19ms, SD = 359.78ms; incongruent: M = 1092.20ms, SD = 388.58ms), all ts≤ 0.10, ps≥ 0.92. Estimated percentage of the gender-matched and gender-mixed control groups exhibiting longer RT in congruent and incongruent trials than W.S. were all below 45.95%.

VI-6s task.

Difference of differential thresholds

As shown in the right-most column, top panel in Figure 2, when W.S. was asked to generate VI and maintain for 6s (VI-6s task), she showed a significant difference in DDT as compared to her control groups in incongruent trials (*t*s ≧ 2.67, *p*s ≦ 0.016). As compared to the DT in the pure perceptual condition, W.S. showed around 2.70° angel difference in incongruent trials, which was significantly larger than her gender-matched control group (M = -0.34°; SD = 0.92°), $t(8) = 3.13$, $p = 0.014$. Estimated percentage of the gender-matched control groups exhibiting a higher differential threshold than W.S. was below 0.71%. Similar results were also obtained in the comparison between W.S. and her gender-mixed control group (M = -0.99°; SD = 1.34°), $t(18) = 2.67$, $p = 0.016$. The Estimated percentage of gender-mixed control group obtaining a higher DDT than W.S. was below 0.78%.

Notably, there was no significant difference in DDT between W.S. (M = 1.16°) and her gender-matched control group (M = -0.73°; SD = 0.99°), $t(8) = 1.81$, $p = 0.108$. But compared to the health control group (Maximum = 1.01°), DDT of W.S. in congruent trials was still in reaching the edge of the range of control individuals. The DDT of W.S. was higher in both congruent and incongruent trials, which lower differential threshold was not identified by W.S.. These results were also found in the comparison between W.S. and her gender-mixed control group (M = -1.07°; SD = 1.10°) in congruent trials, $t(18) = 1.98$, $p = 0.064$. Estimated percentage of both control groups obtaining a higher DDT than W.S. was below 5.42%. The results indicated that control group detected lower DT in congruent and incongruent trials of VI-6s task than the pure DT task compared W.S..

Accuracy rates

As shown in Figure 2, in the congruent trials, lower accuracy was observed in W.S. (M = 0.69) than in gender-matched (M = 0.84, SD = 0.06), $t(8) = 2.37$, $p = 0.045$, and gender-mixed control groups M = (0.85, SD = 0.05), $t(18) = 3.20$, $p = 0.005$. Both estimated percentages of control groups in VI-6s falling below W.S. were lower 2.26%. The above statistical differences between W.S. (M = 0.73) and her gender-matched (M = 0.86, SD = 0.06) or gender-mixed control group (M = 0.85, SD = 0.06) were not found in the incongruent conditions, all ts≦2.06, ps≧0.074.

Response times

There were no differences in response time between W.S. (congruent: M = 1432.54ms; incongruent: M = 1278.70ms) and her different gender-matched (congruent: M = 1095.50ms; SD = 533.02ms; $t(8) = 0.60$, $p = 0.57$; incongruent: M = 1083.35ms; SD = 522.84ms; $t(8) = 0.35$, $p = 0.73$) or gender-mixed control group (congruent: M = 1167.96ms; SD = 707.74ms; $t(18) = 0.36$, $p = 0.72$; incongruent: M = 997.08ms; SD = 373.93ms; $t(18) = 0.73$, $p = 0.47$) recruited in congruent and incongruent trials, as seen in the right-most column on the bottom panel. All estimated percentages of control groups in VI-6s falling below W.S. were lower 63.39%.

Discussion

The present study aimed to characterize the VI and II abilities in aphantasia, closely associated with the unsolved question on whether VMI ability was completely absent in aphantasia. To this aim, W.S., a woman aphantasia individual was assessed with one II task in which 0.5s imagery duration was given (II-0.5s task), as well as two VI in which 0.5s (VI-0.5s task) and 6s were given (VI-6s task) mental images generation and maintenance. Her age-, IQ-, attention and spatial working memory ability-matched control individuals (gender-mixed or gender-matched) were recruited and randomly assigned to one of the three imagery tasks (II-0.5s, VI-0.5s, and VI-6s). To specifically explore how VI and II affect the following perceptual processes, each individual (W.S. or controls) was assessed with a pure perceptual task as baseline performance. Response times (RTs), accuracy rates (ACC) and the difference of differential threshold between the pure perceptual and each imagery condition (DDT) were calculated and compared between W.S. and her control groups.

Significant deficits in the VI-6s task were found in W.S., the aphantasia individual as indexed by the impaired DDT and ACC performance in incongruent and congruent trials respectively. A higher differential angle was detected in W.S. when she was asked to generate mental images in the incongruent orientation with the following perceived grating than in the pure perceptual condition (baseline). Such difference in differential threshold (DDT) in W.S. was significantly higher than that in control groups in the incongruent trials (rightmost column, top panel in Fig.2), while showing intact performance in ACC and RTs. In congruent trials, though comparable performance was observed in DDT and RTs in W.S. and her control groups, she showed extremely lower ACC than her gender-mixed and gender-matched controls (rightmost column, middle panel in Fig.2). These results indicated that the aphantasia participant did not perform as well as her controls when were asked to generate mental images voluntarily in minds and maintain for 6s. This deficit is consistent with existing observations (Keogh & Pearson, 2018, 2024) in which impaired performance was also detected in (at least a subset of aphantasia) aphantasia participants in binocular rivalry paradigm. Such observed deficits of individuals of aphantasia may be due to the absence or decreased VI abilities in aphantasia (Blomkvist & Marks, 2023; Zeman et al., 2015; Zeman et al., 2020).

Moreover, the present study provided a deeper understanding of how perceptual processing would be affected by the decline or deficit VI abilities in aphantasia. It is noticeable that the aphantasia individual, W.S. scored 20 on VVIQ-C (Marks, 1973, 1995; Zhang et al., 2024) referring to that she did not lose VMI ability completely but has difficulty representing mental images. She might indeed follow the instructions trying to generate and maintain the mental images in her mind's eyes, though not able to complete eventually. According to the neural efficiency hypothesis (Neubauer & Fink, 2009), individuals with decreased ability might consume more cognitive resources than healthy controls to cope with the same task. W.S. might occupied more mental resources than controls in generating mental images and therefore induced different performances according to task complexity. In a relatively simple task (congruent trials), control individuals performed well (the averaged ACC> 85%) (rightmost column, middle panel in Fig.2), while W.S., though occupied more resource, might still not complete the task accurately as her controls and showed a deficit in ACC. Notably, in this condition, W.S.'s DDT performance reaches the boundary value of her control group range (rightmost column, top panel in Fig.2), suggesting that she was at high risk to fall out of the normal range as indexed by DDT performance as compared to the control group.

On the other hand, to cope with incongruent trials, no statistical difference was observed between W.S. and controls. This is probably due to more variance observed in control individuals (as can be seen clearly in rightmost column, middle panel in Fig.2) in this more complex situation. On the other side, W.S. showed her deficit than controls in detecting differential threshold in two consecutive perceived gratings. VMI is closely associated with attention (Cabbai et al., 2023). Moreover, it has been pointed out that attention control is needed to switch from one's current thought or working memory (Kiyonaga, et al., 2014; Soto et al., 2012). When VI is required, W.S. probably consumes more mental resources (i.e., attention) to generate the grating with a specific orientation (i.e., 45°) and has more difficulty in inhibiting her attention to the distractor (the imagined content) and switching to the other orientation (i.e., 135°) in incongruent trials.

In the VI-0.5s task, W.S. showed comparable performance with her healthy controls as indexed by DDT, ACC and RT. It is possible that W.S. and controls cannot generate VI in such a short period. An alternative possibility is that both W.S. and the control groups generate VI successfully in VI-0.5s task. However, some studies demonstrated that VI led to the formation of a short-term sensory trace that increased in strength with prolonged exposure, requiring 5 seconds or more to impact subsequent perception (Koenig-Robert & Pearson, 2019; Pearson et al., 2008; Pearson et al., 2011). In such cases, 0.5s duration time is even too short for health control groups to generate VI (Koenig-Robert & Pearson, 2019; Pearson et al., 2008; Pearson et al., 2011). Therefore, the present results in VI-0.5s task might probably be due to the inability to generate complete VI within 0.5s such a short time in both aphantasia and control individuals.

As one of our main concerns in the present study, interestingly, no deficit performance was observed in W.S., the aphantasia in II-0.5s task as indexed by DDT, ACC and RTs. There were three possible explanations. Firstly, neither W.S. nor control groups generated II during the phase of instructing participants to generate II. Notably, the paradigm we used was identical to Kok et al.'s study (2012; 2017) in which II was successfully induced in healthy participants, based on associative learning (Pearson, 2019). According to the definition, II refers to the process of imagery without prior purpose, including expectation, associative learning and so on (Krempel & Monzel, 2024; Pearson, 2019; Pearson & Westbrook, 2015). Control participants were, therefore, assumed to generate images involuntarily according to the auditory cue with 75% effectiveness after several trials.

Secondly, the control group may generate II, while W.S. generates other forms of representation. It is possible different formats of mental representation exists (Zhao, Della Sala, Zeman, & Gherri, 2022). For example, in our previous observation (Zhao et al., 2022), M.X., the aphantasia showed intact performance as well as comparable mental rotation ability (as indexed by electrophysiological results) in the typical mental rotation task with canonical letters. It is possible M.X. generate other formats of mental representation (i.e., language-like) for everyday encountered canonical letters for mental transformation. However, to deal with the unfamiliar mirror-reversed characters, it would be difficult for M.X. to generate either depictive or language-like mental representation and therefore fail to complete the task. Similar to the mirror-reversed letters, it would be difficult to generate language-like format for the static grating stimuli in the present study.

Most likely, both W.S. and her control groups can generate II successfully to cope with the II-0.5s task. This possibility aligns with previous observations demonstrating that aphantasia was able to experience II (i.e., dreams or involuntarily "flashing") (Jacobs et al., 2018; Kwok et al., 2019; Siena & Simons, 2024). Moreover, at least some aphantasia individuals were reported can perform II tasks as well as the control group (i.e., Jacobs et al., 2018; Kwok et al., 2019; Keogh & Pearson, 2024). A cognitive explanation has been proposed for aphantasia that individuals with aphantasia might lose VI ability only with an impaired neural network supporting conscious imagination and perception (Liu & Bartolomeo, 2023; Milton et al., 2021), while the ability to possess and utilize unconscious or below the level of awareness imagery remains (Zeman, 2024). Though the statistical power of a single case observing no deficit exists in aphantasia in II is limited, the present study looks insight into aphantasia's performance in II for the first time and provides preliminary evidence supporting for the hypothesis that the II ability is intact in aphantasia.

Taken together, we exhibited a single case study and showed that individuals with aphantasia are not completely devoid of VMI capabilities. First, systematic deficit performance was detected in aphantasia in generating mental images voluntarily: in congruent trials, a deficit was obtained in aphantasia in ACC than controls; in incongruent trials, a deficit was observed in DDT in aphantasia than controls. The aphantasia individual might occupy more mental resources in generating mental images and therefore induce impaired performance in the following perceptual processing. Notably, such deficits in VI performance were only detected in VI-6s but not in VI-0.5s tasks. Future studies can be conducted to further explore our speculation to dig out the imagination duration in both VI and II in aphantasia and healthy individuals by utilizing EEG techniques. More interestingly, no impaired performance was observed in the present study in generating involuntary imagery. This at least provided preliminary evidence that involuntary imagery abilities might still be intact in aphantasia, associating with a datable issue on aphantasia.

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Figure 1

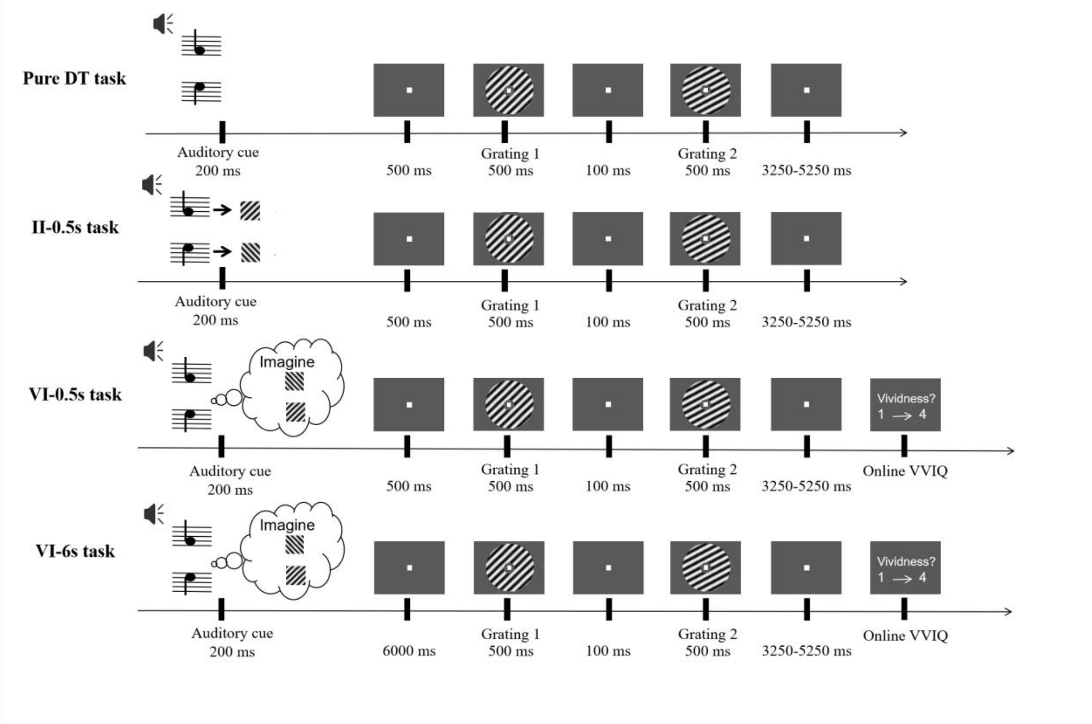

Figure 1 Experimental Paradigm. Pure DT Task (baseline): Participants discerned the rotation direction of two sequentially presented gratings with varying orientations, establishing a measure of pure perceptual ability without imagery. II-0.5s Task: The II-0.5s task involved an auditory cue predicting the orientation of subsequent gratings, where participants determined the rotation direction, introducing an element of imagery without explicit visualization instructions. VI-0.5s Task: Participants were instructed to visualize a grating after hearing an auditory cue with 50% validity and then judge the rotation direction, integrating imagery with the perceptual task. VI-6s Task: The VI-6s task extended the visualization period to 6s after the auditory cue, asking participants to maintain the imagined grating before making a rotation judgment, thus examining the effect of prolonged imagery on perceptual thresholds.

Figure 2

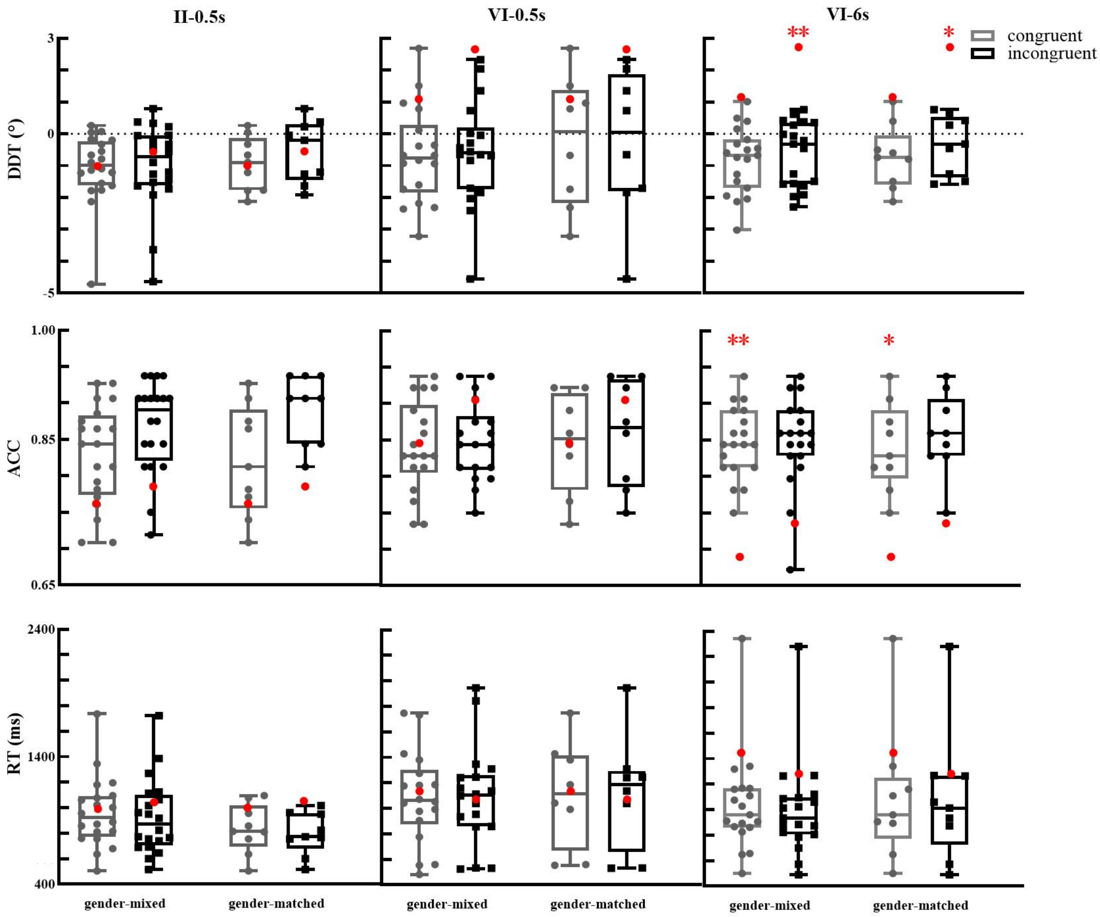

Figure 2 Behavioral performance in the aphantasia individual, W.S., and her gender-mixed, gender-matched control groups. Difference of differential threshold (DDT; top panel), accuracy rates (ACC; middle panel) and response time (RTs; bottom panel) in W.S., the woman aphantasia (red dots), as well as her gender-mixed (grey dots and bar) and gender-matched controls (black dots and bar).

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 1

Table 1 Neuropsychological results of W.S. and her gender-mixed and gender-match controls.

	W.S.	Gender-matched controls			Gender-mixed controls		
		II 0.5s (N=9) M (SD)	VI 0.5s (N=8) M (SD)	VI 6s (N=9) M (SD)	II 0.5s (N=20) M (SD)	VI 0.5s (N=18) M (SD)	VI 6s (N=19) M (SD)
Age (years)	21	23.67 (1.87)	22.38 (2.13)	22.33 (2.45)	22.10 (2.51)	22.44 (2.31)	22.16 (1.86)
Sex ratio (M/F)	0/1	0/9	0/8	0/9	11/9	10/8	10/9
VVIQ-C score	20	66.11 (6.90)***	67.63 (7.87)***	67.67 (9.79)**	66.95 (8.57)***	66.22 (10.20)***	64.05 (9.94)***
online VVI score	1/1.79	/	3.15 (0.58)**	3.11 (0.45)*	/	3.05 (0.62)**	3.14 (0.59)*
WAIS-RC							
VIQ	119	121.78 (6.12)	123.88 (7.06)	124.00 (5.43)	125.55 (6.53)	125.39 (7.65)	123.79 (8.26)
PIQ	117	119.00 (11.70)	109.25 (12.40)	117.56 (6.19)	116.60 (12.05)	117.44 (12.21)	115.68 (8.91)
FSIQ	120	122.33 (8.02)	119.38 (8.90)	123.33 (5.43)	123.60 (7.66)	123.89 (8.57)	122.26 (7.79)
KI	13	13.67 (1.12)	13.38 (1.92)	14.11 (2.09)	14.55 (1.57)	14.28 (1.96)	13.89 (2.77)
POI	12	12.89 (2.20)	13.63 (2.13)	14.33 (2.40)	13.15 (1.66)	13.89 (1.97)	13.79 (1.96)
AI	12	12.89 (1.76)	13.75 (1.91)	14.00 (2.00)	13.25 (1.52)	13.89 (1.88)	13.84 (1.92)
SI	14	13.22 (1.79)	13.25 (1.04)	13.11 (1.45)	13.60 (1.43)	13.22 (1.31)	13.32 (1.42)
DSI	14	15.56 (2.60)	15.50 (2.45)	14.22 (2.05)	16.80 (2.24)	15.67 (2.40)	15.42 (2.61)
VCI	13	12.89 (1.36)	12.75 (1.04)	12.67 (1.12)	13.00 (1.49)	12.72 (1.02)	12.58 (1.22)
PSI	14	14.89 (2.47)	15.13 (2.17)	16.33 (1.41)	15.55 (2.37)	16.39 (2.48)	16.00 (2.24)
PFI	7	10.89 (1.54)*	9.38 (0.92)*	9.89 (1.83)	10.95 (1.79)*	9.94 (1.55)	9.63 (1.86)
BGI	15	14.67 (1.58)	14.50 (1.20)	14.78 (0.67)	14.85 (1.50)	14.89 (0.96)	14.68 (1.34)
IRI	14	12.44 (3.21)	9.50 (3.42)	10.56 (3.00)	10.85 (3.94)	10.67 (3.60)	10.68 (2.38)
PPI	14	12.56 (2.01)	10.50 (1.67)	12.78 (2.17)	12.00 (2.79)	12.22 (2.41)	12.16 (2.43)
corsi	77	61.44 (21.85)	69.38 (21.19)	77.56 (13.45)	65.50 (25.61)	74.72 (24.34)	75.32 (21.69)
Stroop-RT (s)	64	49.78 (7.77)	49.25 (8.80)	49.63 (7.25)	52.30 (7.90)	47.83 (10.37)	51.05 (9.76)
Stroop-N	50	49.89 (0.33)	49.88 (0.35)	50.00 (0)	49.55 (1.79)	49.83 (0.51)	49.89 (0.32)

Abbreviations: II = Involuntary imagery; VI = Voluntary imagery; VVI = Vividness of visual imagery; WAIS = Wechsler adult intelligence scale-revision of China; VIQ = Verbal IQ, PIQ = Performance IQ; FSIQ = Full scale IQ; KI = Knowledge index; POI = Perceptual organization index; AI = Arithmetic index; SI = Similarity index; DSI = Digital span index; VCI = Verbal comprehension index; PSI = Processing speed index; PFI = Picture filling index; BGI = Block graph index; IRI = Image ranking index; PPI = Pattern patchwork index

Note: Aphantasia VVI online score: 1/1.789; in the VI 0.5s, Aphantasia VVI online score=1; in the VI 6s, Aphantasia VVI online score=1.789

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

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