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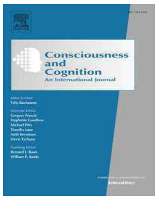

Congenital lack and extraordinary ability in object and spatial imagery: An investigation on sub-types of aphantasia and hyperphantasia

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ABSTRACT

Studies that have shown a distinction between object and spatial imagery suggest more than one type of aphantasia and hyperphantasia, yet this has not been systematically investigated in studies on imagery ability extremes. Also, if the involuntary imagery is preserved in aphantasia and how this condition affects other skills is not fully clear.

We collected data on spatial and object imagery, retrospective, and prospective memory, face recognition, and sense of direction (SOD), suggesting a distinction between two subtypes of aphantasia/hyperphantasia. *Spatial aphantasia* is associated with difficulties in visuo-spatial mental imagery and SOD. Instead, in *object aphantasia* there are difficulties in imaging single items and events — with no mental visualization of objects, out-of-focus, and black-and-white mental images more frequent than expected — in SOD and face recognition. Furthermore, associative involuntary imagery can be spared in aphantasia. The opposite pattern of performance was found in spatial and object hyperphantasia.

1. Introduction

How many doors are there in your house? Which is bigger, a cherry or a golf ball? In answering such questions probably, you have visualized the environments/objects with your "mind's eye" and "looked" at them. In other words, you have used visual mental imagery, that is, the experience of seeing in the absence of the appropriate sensory input (Kosslyn, 1987).

Mental imagery research has long been dominated by a vigorous debate over the nature of mental representations (Kosslyn, 2005; Pearson & Kosslyn, 2015; Pearson, 2019). On the one hand, researchers suggested that the information about visual objects was stored in a symbolic format (e.g., Pylyshyn, 1973, 1981), whereas on the other, researchers suggested that this information can be stored in a depictive (pictorial) format (e.g., Kosslyn, 1980, 1994). This debate evolved over the years, and when neuroimaging began to be used, it focused on showing brain activity at the level of the primary visual cortex during mental imagery tasks, following the assumption that this brain area represents visual information in a depictive format (Kosslyn, 2005; Pearson, 2019). In 2015, Pearson and Kosslyn claimed that this debate was over since a copious quantity of studies prove that imagery can be depictive.

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In people with normal mental imagery functioning, visual mental imagery is crucial in learning, storing, and retrieving information previously encountered and in experiencing objects, places, or events that do not exist in the world through imagination. Also, visual mental imagery is pivotal for a number of cognitive skills, such as episodic memory and visual working memory, reading comprehension, spatial orientation, prospective memory, creativity, and face processing (Brunsdon et al., 2007; Kosslyn, 2005; Kosslyn et al., 1995; Palermo et al., 2008; Pearson, 2019), and is widely used in rehabilitation training (e.g., Boccia et al., 2019; Piras et al., 2011; Potvin et al., 2011). The crucial role of imagery in cognition was already discussed in the De Anima by Aristotele, who claimed that "the soul never thinks without a phantasma" (Οὐδέποτε νοεῖ ἄνευ φαντάσματος ἡ ψυχή; Aristotle, ca. 350B. C. E. /2015; III 7, 431a 16–17). This claim seems to subtend the idea that everyone can create mental images and that mental imagery is a universal ability (Faw, 2009).

However, several studies (e.g., Cui et al., 2007; D'Angiulli et al., 2013; Marks, 1973; McKelvie & Demers, 1979; Palermo et al., 2013) suggest that there is high interindividual variability in the quality and vividness of mental imagery, in terms of luminosity and clarity of a mental image and of how much it approximates to an actual percept, and that, in turn, this variability affect the performance in different cognitive tasks. Also, people affected by congenital aphantasia (φαντάσία, phantasia is the classical Greek term for imagination), that is a lifelong condition of reduced or absent voluntary imagery (Zeman et al., 2015), have a "blind mind's eye" and, although they show normal intelligence and typical vision, can struggle to answer the questions reported above. Mental imagery can be affected in psychiatric conditions (for an overview, see for example Ji et al., 2019; Pearson et al., 2015) and after brain damage (for group studies see for example: Guariglia et al., 2013; Palermo et al., 2010; Stangalino et al., 1995; for a review see: Trojano & Grossi, 1994); however, in congenital aphantasia, the lack of mental imagery is not due to any manifest brain injury or mental disorder. This last evidence could suggest a similarity between congenital aphantasia and congenital deficits for specific cognitive skills such as developmental prosopagnosia (Barton & Corrow, 2016; Behrmann & Avidan, 2005; Duchaine & Nakayama, 2005), agnosia for objects (Germine et al., 2011), amusia (Stewart, 2006), or developmental topographical disorientation (Bianchini et al., 2010; Conson et al., 2018; Iaria & Barton, 2010; Iaria et al., 2009; Palermo et al., 2014; Piccardi et al., 2019). However, while these congenital conditions all result in clear and specific impairments that impact daily life activities, there is currently no indication that individuals with aphantasia present any clinically significant cognitive impairment except for self-reported difficulties in autobiographical memory and face recognition (Zeman et al., 2020). Accordingly, at the moment, aphantasia is not considered a medical disorder, but "an intriguing variation in human experience" (Zeman et al., 2020, p. 438).

The lifelong lack of mental images was first described by Francis Galton that, in the 19th century, carried out an empirical study on mental imagery vividness using a self-report questionnaire. Referring to the findings from his study, Galton stated: "To my astonishment, I found that the great majority of the men of science to whom I first applied protested that mental imagery was unknown to them" (Galton, 1880, p. 55).

However, since then, there has been very little formal investigation on the topic, until Faw (2009) suggested that "2–5% of people are very poor- or non-visual- imagers" and Zeman et al. (2015) coined the term, describing 21 cases of individuals with no imagery or minimal imagery. Thus, research on aphantasia is still in its infancy, and there are several open questions on the topic.

The *first question* is related to understanding which mental imagery component (i.e., the visual or the spatial one) is affected in these individuals and if different kinds of aphantasia can be identified. Indeed, the distinction between object and spatial processing first proposed for the visual system (Ungerleider & Mishkin, 1982; see also Haxby et al., 1991) has been suggested for the working memory (e.g., Courtney et al., 1996; Della Sala et al., 1999; Logie, 1995) and the mental imagery domain too. In particular, higher-level visual brain areas are divided into two functionally and anatomically distinct pathways: the *ventral pathway*, which runs from the occipital lobe to the inferior temporal lobe and processes the properties of objects (e.g., color and shape), and the *dorsal pathway,* which runs from the occipital lobe to the posterior parietal lobe and processes object localization and spatial attributes. Converging evidence from behavioral and neuroimaging studies on healthy individuals (Blajenkova et al., 2006; Boccia et al., 2015; Boccia, Sulpizio, Palermo et al., 2017; Kozhevnikov et al., 2002, 2005; Mazard et al., 2004; Sack et al., 2005), as well as neuropsychological studies on individuals with brain damage (Levine et al., 1985; Morton & Morris, 1995; Palermo et al., 2010), suggest a similar distinction between visual-object imagery (i.e., the mental representation of the visual features of an object such as shape, brightness, or color) and visual-spatial imagery (i.e., the mental representation of the spatial locations and relations between parts of an object). For such reason, a dissociation between spatial and object processing can be hypothesized also for the congenital lack of mental imagery (for such an argument, see also Blazhenkova & Pechenkova, 2019).

Some recent studies suggest that aphantasia could reflect a selective reduction in 'object imagery' as opposed to 'spatial imagery' (Bainbridge et al., 2021; Dawes et al., 2020; Keogh & Pearson, 2018; Zeman et al., 2020). For example, Keogh and Pearson (2018), using the Object and Spatial Imagery Questionnaire (OSIQ; Blajenkova et al., 2006), which is a self-report questionnaire that requires participants to indicate how well each statement on object imagery ability and spatial imagery ability describe them, found that participants with aphantasia subjectively report weaker object imagery compared to spatial imagery. In line with this finding, Bainbridge et al. (2021) found that aphantasic participants in a performance task, in which they were required to draw from memory previously seen real-world scene images, recalled significantly fewer objects than controls but showed normal spatial accuracy since they positioned objects at accurate locations with the correct sizes. However, as suggested by Blazhenkova and Pechenkova (2019), current findings could be biased by how individuals with aphantasia have been identified. Indeed, the instrument that has been mainly used to identify individuals with aphantasia, the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), only measures the object component of visual mental imagery, as suggested by previous studies (e.g., Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2010; Chabris et al., 2006; Vannucci et al., 2006; for such an argument see also Blazhenkova, 2016) in which the VVIQ score was selectively associated with that of the OSIQ object scale (see the method section for details on the OSIQ) but not with the OSIQ spatial scale and spatial imagery tasks (e.g., mental rotation and paper folding tasks). Consequently, current studies could have analyzed only one type of aphantasia, neglecting the possible distinction between object and spatial aphantasia (Blazhenkova & Pechenkova, 2019). Specifically, the VVIQ is a self-report instrument that requires respondents to form a visual image based on a verbal description (e.g., Think of the front of a shop which you often go to. Consider the picture that comes before your mind's eye), and to rate its vividness. Therefore, it is non-surprising that, so far, aphantasic individuals have been described as individuals with very low or absent object imagery but intact spatial imagery.

A *second open question* is related to understanding if a dissociation between affected voluntary imagery and spared involuntary imagery is present in individuals with aphantasia. Indeed, the voluntary experience of creating a conscious mental image has been differentiated from types of imagery that are considered involuntary, such as those triggered by associative learning. For example, after several co-occurrences of seeing bananas as yellow, a black and white image of a banana is seen as yellow due to involuntary imagery; in other words, the brain fills in the color (Pearson, 2019). Many individuals with aphantasia report visual imagery in dreams (Zeman et al., 2015, 2020), a piece of evidence that, according to Pearson (2019), suggests that involuntary forms of imagery could be intact. However, aphantasic participants reported fewer and qualitatively impoverished dreams than control participants in a study by Dawes et al. (2020). Also, there is evidence that individuals with aphantasia have fewer involuntary memory intrusions (Dawes et al., 2020) and are less susceptible to involuntary hallucinations (Königsmark et al., 2021). Thus, if involuntary imagery is spared in aphantasia is still a matter of debate.

A *third open question* is related to if and to what extent the lack of object and spatial imagery can affect other aspects of cognition since visual mental imagery is involved in several cognitive skills, spanning from retrospective and prospective memory (Pearson, 2019) to spatial orientation (Palermo et al., 2008). However, the potential impact of aphantasia on cognition has been scarcely investigated in a systematic way and using standardized instruments. In a questionnaire-based study, Zeman et al. (2020) found that aphantasia is associated with reported difficulty in autobiographical memory and face recognition. Difficulties in these two skills have been further underlined in other studies. Dawes et al. (2020) have evaluated the impact of aphantasia on episodic memory with specific questionnaires (i.e., the Episodic Memory Imagery Questionnaire and The Survey of Autobiographical Memory), showing that individuals with aphantasia have a lower ability to remember past life events. Milton et al. (2021) have evaluated with standardized instruments the impact of aphantasia on anterograde memory, autobiographical memory, face and landmark recognition, showing that individuals with aphantasia have more difficulties than controls in autobiographical memory and face recognition. In the same study, these authors also found differences in the neural activations between controls, hyperphantasic and aphantasic, when comparing visualization of famous faces with perception. In keeping with these findings, it is also interesting to note that a reduction in mental imagery vividness has been described in individuals with congenital prosopagnosia (Grüter et al., 2009), further suggesting a possible link between congenital aphantasia and difficulties in face processing. However, considering that the processing of the shape and configuration of facial features are mainly mediated by neural substrates within the ventral visual pathway (Liu et al., 2010; Maurer et al., 2007; Yovel & Kanwisher, 2004), individuals with spatial aphantasia, differently from individuals with object aphantasia, could report no difficulties in their face recognition experience.

Previous studies also suggest some alterations in the ability to imagine experiencing future situations (i.e., *episodic future thinking*) in individuals with aphantasia (e.g., Dawes et al., 2020; Milton et al., 2021). Episodic future thinking and *prospective memory* (i.e., the ability to remember to carry out a planned activity such as buying milk after work) are two core components of future-oriented cognition (Szpunar et al., 2014; Terrett et al., 2016, 2019) in which mental imagery plays an important role (Brewer et al., 2011; D'Argembeau & Van der Linden, 2006). Recent findings also suggest that episodic future thinking might crucially contribute to the prospective memory performance (Schacter et al., 2017; Terrett et al., 2016, 2019). In particular, generating a mental image of when and where an intention will be carried out enhances prospective memory performance. Hence, imagery encoding may be used to facilitate several important aspects of intention fulfillment (Brewer et al., 2011; McFarland & Glisky, 2012). Also, imagining the future visuospatial context in which the prospective memory task is to be performed can result in a stronger association between the context of the ongoing task and the cue to perform the prospective memory task (Terrett et al., 2019). However, despite this evidence, less attention has been paid to the impact of aphantasia on the ability to perform an intended action in daily life (i.e., prospective memory).

Mental imagery is also a crucial aspect of cognition in topographical orientation. For example, a relevant model of spatial memory and mental imagery, the BBB model (Burgess et al., 2001; Byrne et al., 2007; for an overview, see also Bird & Burgess, 2008), suggests that, in planning a route through a familiar environment, "parietally generated egocentric mental imagery can be manipulated via real or mentally generated idiothetic information in order to accomplish spatial updating or mental exploration in familiar environments" (Byrne et al., 2007, p. 351). Accordingly, deficits in mental imagery (e.g., imagery or representational neglect) result in difficulties in environmental navigation (Guariglia et al., 2005; Palermo et al., 2012). Also, patients with acquired and developmental topographical disorientation have been described who report difficulty with revisualisation of spatial environments (Brunsdon et al., 2007), and, more generally, individuals with developmental topographical disorientation have been described who report difficulty in mental imagery measures (Bianchini et al., 2010; Burles & Iaria, 2020). Interestingly, there is evidence that imagery-based training can improve the ability to navigate the environment in patients with acquired topographical disorientation (Boccia et al., 2019). However, despite these findings, little is currently known about the impact of aphantasia on the ability to learn and navigate through environments.

The recent findings on congenital aphantasia have also focused attention on the opposite extreme of the imagery capability spectrum, which Zeman et al. (2020) defined hyperphantasia, that is "imagery as vivid as real seeing". Individuals with hyperphantasia outperform controls in future and atemporal imagination and in other cognitive skills such as autobiographical memory and face recognition (Milton et al., 2021). Also, stronger connectivity between prefrontal cortices and the visual network in individuals with hyperphantasia than in individuals with aphantasia has been reported using resting-state fMRI (Milton et al., 2021). However, as for aphantasia, the instrument that has been mainly used to identify hyperphantasic individuals is the VVIQ (Marks, 1973). Thus, current studies could have analyzed only object hyperphantasia, neglecting the possible distinction between object and spatial types of hyperphantasia (Blazhenkova & Pechenkova, 2019).

Considering these open questions, we developed an online protocol, including anamnestic information, mental imagery questionnaires, a color imagery task, and questionnaires probing different cognitive skills, aiming to explore (i) whether two different types of aphantasia/hyperphantasia could exist, (ii) whether involuntary visual imagery can be spared in aphantasia, and (iii) if and to what extent the lack of object and spatial imagery can affect retrospective and prospective memory, face recognition, and navigational skills.

We also aimed to provide some preliminary indication about the prevalence of congenital aphantasia in the Italian context. Indeed, the studies on the topic have mainly been carried out in UK, USA, and Australia.

2. Materials and methods

2.1. Participants

Data from 553 individuals were collected; however, 16 participants were excluded due to the incompletion of the *Object and Spatial Imagery Questionnaire* (OSIQ). Similarly, since we were interested in studying congenital aphantasia, 47 participants with a neurological or psychiatric disease history were excluded from the final analysis. Thus, the final sample consisted of 490 participants (27% males; mean age = 28.67 years, SD = 11.67, range = 18–78 years; mean education = 14.83 years, SD = 2.96, range = 5–21 years). The respondents were mainly from the Center (43.06%) and South and Insular Italy (50.61%).

Considering the scores at the object and spatial subscales of the OSIQ (see para. *Imagery assessment* for details) we identified:

434 individuals with average mental imagery skills on both object and spatial domains (Controls; 117 males; mean age = 28.61 years, SD = 14.81; mean education = 11.87 years, SD = 2.89);

15 participants (3.1% of the sample) with object aphantasia (OAph; 4 males; mean age = 32.80 years, SD = 11.71; mean education = 15.07 years, SD = 4.13);

17 participants (3.5% of the sample) with spatial aphantasia (SAph; 1 male; mean age = 27.12 years, SD = 10.86; mean education = 14.47 years, SD = 2.94);

8 participants (1.6% of the sample) with object hyperphantasia (OHyper; 1 male; mean age = 25.50 years, SD = 7.50; mean education = 13.0 years, SD = 3.78);

14 participants (2.9% of the sample) with spatial hyperphantasia (SHyper; 11 males; mean age = 28.07 years, SD = 6.91; mean education = 16.79 years, SD = 2.61);

1 female participant with spatial aphantasia and object hyperphantasia (SAph + OHyper; age = 32 years; education = 18 years);

1 female participant with both object and spatial hyperphantasia (OHyper + SHyper; age = 49 years; education = 13 years).

Additional information on the score distribution of the OSIQ object and spatial scales for all the groups is reported in Supplementary material (see Figure S1).

The study was approved by the Ethics Committee of the Department of Psychology of Bologna University (Prot. n. 172660, 2020) in line with the guidelines on human research of the Declaration of Helsinki (1964). All participants gave informed consent before completing the study. Participation was voluntary and without compensation.

2.2. Procedure and measures

The protocol was performed online on the Qualtrics platform, and it included three sections: demographic and general health information, imagery assessment, and other cognitive skills assessment. Since we were interested in providing some preliminary information on the prevalence of aphantasia in the Italian context, we did not approach online groups of people with aphantasia as in some previous studies (e.g., Dawes et al., 2020), but we recruited participants from the general community through advertisements on social media and university web pages. Data were collected from April 2020 to May 2021.

2.2.1. Imagery assessment

The *Object and Spatial Imagery Questionnaire* (OSIQ; Blajenkova et al., 2006; Vannucci et al., 2006) requires participants to rate 30 items on a 5-point scale ranging from 1 (*totally disagree*) to 5 (*totally agree*). Specifically, the OSIQ includes 15 object items intermixed with 15 spatial items that are averaged to form, respectively, the score of the OSIQ object scale and of the OSIQ spatial scale.

The OSIQ was used to subdivide participants into individuals with average mental imagery skills on both object and spatial domain (Controls); participants with object aphantasia (OAph; i.e., individuals with a score under two standard deviations in the OSIQ object scale, as calculated referring to the sample of Blajenkova et al., 2006; OSIQ object total score $\leq$ 36); participants with spatial aphantasia (SAph; i.e., individuals with a score under two standard deviations in the OSIQ spatial scale, as calculated referring to the sample of Blajenkova et al., 2006; OSIQ spatial total score $\leq$ 25); participants with object hyperphantasia (OHyper; i.e., individuals with a score above two standard deviations in the OSIQ object scale, as calculated referring to the sample of Blajenkova et al., 2006; OSIQ object total score $\geq$ 71); participants with spatial hyperphantasia (SHyper; i.e., individuals with a score above two standard deviations in the OSIQ spatial scale, as calculated referring to the sample of Blajenkova et al., 2006; OSIQ spatial total score $\geq$ 62).

The *Mental Imagery Questions* (MIQ; see Appendix) is an ad-hoc created self-report questionnaire including six questions on the ability to imagine single items (i.e., faces, environmental landmarks, objects; MIQ-single items), past and future events (MIQ-events) and to solve visuo-spatial problems (i.e., mental rotation of abstract item; MIQ-spatial), and one question on the presence of mental images in dreams.

The *Short Vividness Task* (SVT; a modified short version from Palermo et al., 2013) was used to evaluate the self-rated degree of richness, detail, and clarity of mental images of common objects. It includes five items in which the participants were required to image a bottle, a knife, a boot, a tie, and a glass. Specifically, the participant is required to close his/her eyes and to imagine an object (e.g., Close your eyes and image a bottle. Can you imagine it?) and, if so, to judge the vividness of his/her mental image on a Likert scale ranging from 1 (*low vividness*) to 7 (*good vividness*) (SVT-Likert scale). Then, the participant is required to choose among four pictures which one is more similar to his/her mental image (SVT-Choice). The four pictures showed the same object depicted with different

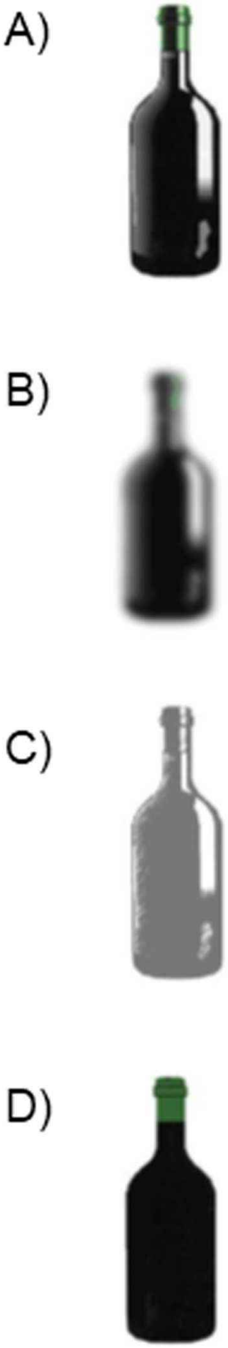

Fig. 1. Example of Short Vividness Task (SVT-Choice) item. In the SVT, if participants can image an item, they are asked to judge the vividness of their mental image on a Likert scale and then to choose among four pictures the one that is more similar to their mental image (SVT-Choice). For example, in the figure, there are four options for the item "bottle": a perfect 3D figure (A), an out-of-focus figure (B), a black-and-white figure (C), and a 2D figure (D).

degrees of vividness (see Fig. 1 for an example): a perfect 3D figure (A), an out-of-focus figure (B), a black-and-white figure (C), a 2D figure (D). B, C, and D options do not represent a continuum from a perfect image (option A) to the complete absence of an image (answering “No” to the preliminary question “Can you imagine it?”), since each of them shows the loss of a specific feature, namely, the lack of focus (option B), color (option C), and depth (option D).

For the SVT-Likert scale, the maximum score is 35. The frequency with which each participant reports no mental visualization of the item (i.e., answering “No” to the preliminary question “Can you imagine it?”) and selects the A, B, C, or D option is recorded.

In the *Color imagery task* (CIT; adapted for online assessment from Color 3 of the Complete Visual Mental Imagery Battery – CVMIB, Palermo et al., 2016), participants are shown two black-and-white drawings depicting two very common and well-known fruits or vegetables (e.g., a tomato and an aubergine) and they have to indicate which of them had the darker color (see Fig. 2). The CIT includes ten items. Accuracy of answer (maximum score = 10) and response time were recorded for each participant.

This task can elicit the use of involuntary imagery and thus can be solved without voluntarily creating the mental image of the element. Indeed, as suggested by Pearson (2019), after thousand co-occurrences of seeing a particular element (e.g., a tomato) in a specific color (e.g., red), a black and white image of the element is seen in that color due to involuntary imagery (for such account see also Pearson & Westbrook, 2015; for neuroimaging data supporting this hypothesis see also Bannert & Bartels, 2013).

2.2.2. Other cognitive skills questionnaires

The *Prospective and Retrospective Memory Questionnaire* (PRMQ; Smith et al., 2000) includes 16 items in which the respondents have to evaluate the frequency of prospective memory (e.g., "Do you forget appointments if you are not prompted by someone else or by a reminder such as a calendar or a diary?") and retrospective memory (e.g., "Do you fail to recall things that have happened to you in the last few days?") failures on a five-point scale ranging from 5 (*very often*) to 1 (*never*). We reversed the scores so that the lower the score, the worse the memory self-evaluation (score range 8–40 for both kinds of memory).

The 20-item prosopagnosia index (PI20; Shah et al., 2015) is a self-report instrument including 20 items in which the respondents indicate on a five-point scale (from strongly agree to strongly disagree) the extent to which each of them describes their face recognition experience. The scores are comprised between 20 and 100, where higher scores indicate worse face recognition. Specifically, PI20 scores in the ranges 65–74, 75–84, 85–100 broadly indicate mild, moderate, and severe developmental prosopagnosia.

The *Sense of Direction and Environment Familiarity Questionnaire* (Nori & Piccardi, 2012; Piccardi et al., 2011) includes 22 questions evaluating different aspects of navigation abilities that is spatial cognitive style, right/left discrimination, sense of direction, and familiarity and knowledge of the city of residence. Since respondents were from different Italian cities in this study, we considered only the sense of direction (SOD; items 1, 2, 3, 4, 6, 7, 9, 10, 11, and 22; e.g., Item 1: “How is your ability to read a map?”; Item 2: “How is your sense of direction?”) score that is the ability to find shortcuts or the ability to read a map.

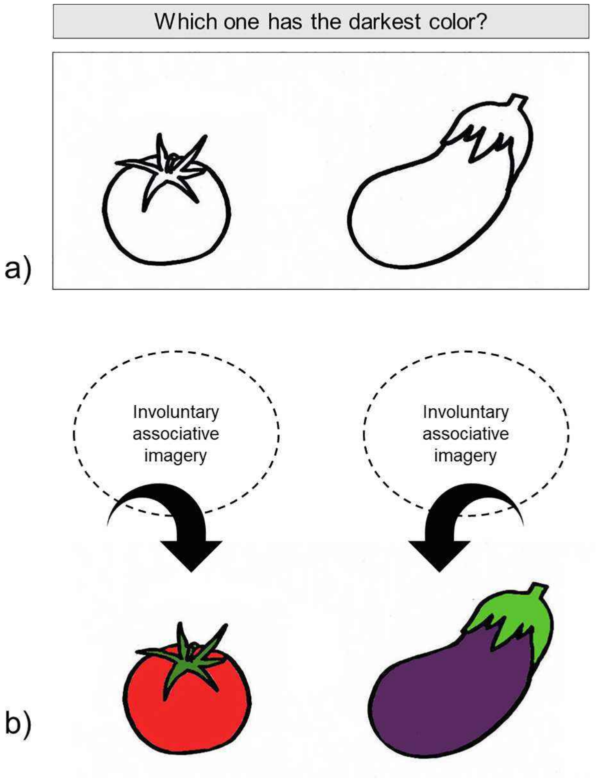

Fig. 2. Color imagery task (CIT). Example of CIT item (a) and image induced by the associative involuntary imagery (b).

2.3. Statistical analyses

Due to the non-normal distribution of the demographic, mental imagery, and other skills measures, as verified with the Shapiro-Wilk test (see Table S1 in Supplementary material), non-parametric analyses (i.e., Kruskal–Wallis tests) were performed to evaluate possible differences among the groups.

Since we only identified one SAph + OHyper participant and one OHyper + SHyper participant, we performed group comparisons only on five groups: Controls, OAph, SAph, OHyper, and SHyper; thus, these two participants were not included in the group analyses.

A Bonferroni adjusted alpha level of 0.005 was applied (0.05/11). Significant group effects were further analyzed with planned post hoc comparisons using Mann–Whitney U tests and applying a Bonferroni correction for multiple comparisons (0.05/6 = 0.008). In particular, the following planned post-hoc comparisons were performed: OAph vs. SAph, OAph vs. Controls, SAph vs. Controls, OHyper vs. SHyper, OHyper vs. Controls, SHyper vs. Controls.

Similarly, Chi-square tests were performed for the discrete variables (i.e., SVT-Choice).

All group comparisons were performed using SPSS version 23.0 (SPSS, Inc. Chicago, IL, USA).

Crawford’s analyses were performed by using the computer program SINGLIMS_ES.exe (Crawford & Garthwaite, 2002; Crawford & Howell, 1998) to determine whether the scores of one participant with SAph + OHyper and one participant with OHyper + SHyper were significantly lower/higher than those of controls. This analysis uses the t-distribution, and each individual is treated as a sample of N = 1. It is a very robust method even when data exhibit severe departures from normality.

2.4. Hypotheses

We expect to find different self-reported difficulties between individuals with object/spatial aphantasia and different self-reported abilities between individuals with object/spatial hyperphantasia in specific metal imagery questionnaires as follows.

Concerning the self-reported efficacy in the generation and transformation of mental images (MIQ), we expect (i) that the mental image generation of single items (i.e., faces, environmental landmarks, objects) and events will be selectively altered/enhanced in object aphantasia/hyperphantasia but not in spatial aphantasia/hyperphantasia and (ii) that the mental rotation of an abstract item will be selectively altered/enhanced in spatial aphantasia/hyperphantasia but not in object aphantasia/hyperphantasia.

Concerning the vividness of mental imagery (i.e., the Short Vividness Task), we expect that only individuals with object aphantasia/hyperphantasia will report a low/high vividness of mental imagery (SVT-Likert) as compared to controls and individuals with spatial aphantasia/hyperphantasia. Accordingly, we expect that the individuals with object aphantasia will report a complete lack of mental images or mental images with the loss of a specific feature (i.e., lack of focus, color, and depth; SVT-Choice) more often than controls and individuals with spatial aphantasia.

Concerning the involuntary imagery, in light of the mixed results of previous studies, we have no strong prediction regarding group differences between object/spatial aphantasic and controls, as evaluated considering the dream experience and the performance in an involuntary associative imagery task (i.e., Color Imagery Task).

We also expect to find different self-reported difficulties/abilities between individuals with object/spatial aphantasia and between individuals with object/spatial hyperphantasia in questionnaires probing retrospective and prospective memory, face recognition, and sense of direction.

Based on previous studies that suggest difficulties in individuals with (object) aphantasia (e.g., Dawes et al., 2020; Milton et al., 2021; Zeman et al., 2020) in remembering past life events and in imaging future events and on the role of mental imagery vividness in memory (e.g., D’Angiulli et al., 2013; Marks, 1973; McKelvie & Demers, 1979), we predict that individuals with object aphantasia will report more retrospective and prospective memory slips in everyday life than controls and individuals with spatial aphantasia.

Based on previous studies that suggest difficulties in face recognition in individuals with (object) aphantasia (e.g., Milton et al., 2021; Zeman et al., 2020) and on the evidence that the processing of the shape and configuration of facial features is mainly mediated by neural substrates within the ventral visual pathway (Liu et al., 2010; Maurer et al., 2007; Yovel & Kanwisher, 2004), we predict that individuals with *object* aphantasia will report more difficulties than controls and individuals with spatial aphantasia in a self-report questionnaire probing the face recognition experience.

Finally, we predict that individuals with spatial aphantasia will report a poor sense of direction compared to controls and individuals with object aphantasia, since SOD is an important dimension of spatial cognition.

3. Results

3.1. Sample characteristics

Kruskal–Wallis tests were performed to evaluate possible age and education differences among the groups. There was no clear indication of a difference between groups for age (H(4) = 6.16; p =.187) or education (H(4) = 8.94; p =.063).

3.2. Mental imagery assessment

Performance on mental imagery tests and self-report questionnaires across the groups is reported in Table 1.

3.2.1 Mental Imagery Questions (MIQ). Concerning the voluntary imagery skills as evaluated with the MIQ, we found a significant effect of the group for all subscores (MIQ-single items: H(4) = 32.95, p <.001; MIQ-events: H(4) = 34.85, p <.001; MIQ-spatial: H(4) =

22.26, p <.001). The effect of the group was also confirmed when the role of the sex was taken into account (see Supplementary results in Supplementary material for details).

As regards the aphantasic groups, post hoc comparisons showed that the OAph group reported a significantly lower ability in imagining single items ($p_s < 0.001$) and events ($p_s < 0.001$) than the SAph and Control groups. The SAph group reported a lower ability in spatial imagery than Controls (p <.001) and OAph (p =.05), but this last difference did not survive after Bonferroni correction for multiple comparisons. The SAph group reported better imagining of events than Controls (p =.02), but this difference did not survive after Bonferroni correction for multiple comparisons. No other significant differences were found between OAph, SAph, and Controls.

As regards the hyperphantasic groups, post hoc comparisons showed no statistically significant differences between them in imagining events (p =.21) and in spatial imagery (p =.48). The OHyper reported better single items imagining than SHyper (p =.04) and Controls (p =.01) and better events imagining than Controls (p =.02). The SHyper group reported better spatial imagery than Controls (p =.04). However, all these differences did not survive after Bonferroni correction for multiple comparisons. No other significant differences were found between OHyper, SHyper, and Controls.

3.2.2 Short Vividness Task (SVT). Concerning the vividness of mental images as self-evaluated with the SVT-Likert scale scores, a significant effect of the group was found (H(4) = 37.86, p <.001). The effect of the group was also confirmed when the role of the sex was taken into account (see Supplementary results in Supplementary material for details).

Post hoc comparisons showed no statistically significant differences between SAph and Control (p =.31) or between SHyper and Controls (p =.99). OAph reported less vivid mental images than Controls (p <.001) and SAph (p <.001) while OHyper reported more vivid mental images than Controls (p =.005) and SHyper (p =.04). However, this last difference did not survive after Bonferroni correction for multiple comparisons.

Concerning the vividness of mental imagery as evaluated with the SVT, we also performed a Chi-square analysis to evaluate differences between groups in the frequency with which they reported no mental visualization of the item, a perfect 3D mental image (option A), an out-of-focus image (option B), a black-and-white image (option C), or 2D image (option D).

Chi-square analysis on frequencies showed a significant difference between the five groups (Chi-Square(16) = 342.83; p <.001). Analysis of the standardized residual showed that compared with the critical value (±1.96), the no mental visualization of the item, out-of-focus images (option B), and black-and-white images (option C) were significantly more frequent than expected in the OAph group (no visualization = 16.30; option B = 2.31; option C = 4.77). Perfect 3D mental images (option A) were significantly less frequent than expected in the OAph group (-4.03) and more frequent than expected in the OHyper group (1.99). Finally, 2D images were significantly less frequent than expected in the OAph group (-2.63).

3.2.3 Involuntary imagery: Color imagery task (CIT). Concerning the involuntary imagery, the Kruskal–Wallis analyses showed a non-significant effect of the group on the CIT accuracy scores (H(4) = 4.22; p =.377) and response times (H(4) = 4.96; p =.291), suggesting that this kind of involuntary object imagery is intact in all groups. The lack of a significant group effect was also confirmed when the role of the sex was considered (see Supplementary results in Supplementary material for details).

Similarly, concerning the MIQ question about the presence of mental images in dreams, only one SAph participant reported no mental images, while all OAph participants reported the presence of mental images.

3.3. *Other cognitive skills*

Performance on memory, face recognition, and sense of direction self-report questionnaires across the groups is shown in Fig. 3.

Concerning the memory skills, the Kruskal–Wallis analyses showed a non-significant effect of the group on the retrospective (H(4) = 5.27; p =.260) and prospective (H(4) = 5.59; p =.232) scores of the PRMQ. The lack of a significant group effect was also confirmed when the role of the sex was considered (see Supplementary results in Supplementary material for details).

Concerning the face recognition ability, we found a significant group effect on the PI20 scores (H(4) = 16.03, p =.003). The effect of the group was also confirmed when the role of the sex was taken into account (see Supplementary results in Supplementary material for details).

Post hoc comparisons showed that the OHyper group reported significantly better face recognition skills than Controls (p =.006), while the OAph group reported significantly lower face recognition skills than the SAph (p =.02), although this last difference did not

Table 1
Mean performance (SD) on mental imagery questionnaires and tasks across groups.

	OAph		SAph		Controls		OHyper		SHyper	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Voluntary imagery										
MIQ										
MIQ-Single items	3.04	0.90	4.43	0.60	4.43	0.61	4.92	0.15	4.36	0.78
MIQ-Events	2.63	0.69	4.26	0.83	3.86	0.79	4.50	0.60	3.89	1.02
MIQ-Spatial	4.07	1.10	3.24	1.20	4.35	0.82	4.50	0.76	4.79	0.43
SVT										
SVT-Likert scale	12.71	9.67	26.29	5.65	28.53	5.74	31.88	5.08	29.64	4.73
Involuntary imagery										
CIT	8.60	1.68	8.29	1.21	8.71	1.30	8.50	1.20	8.50	1.22

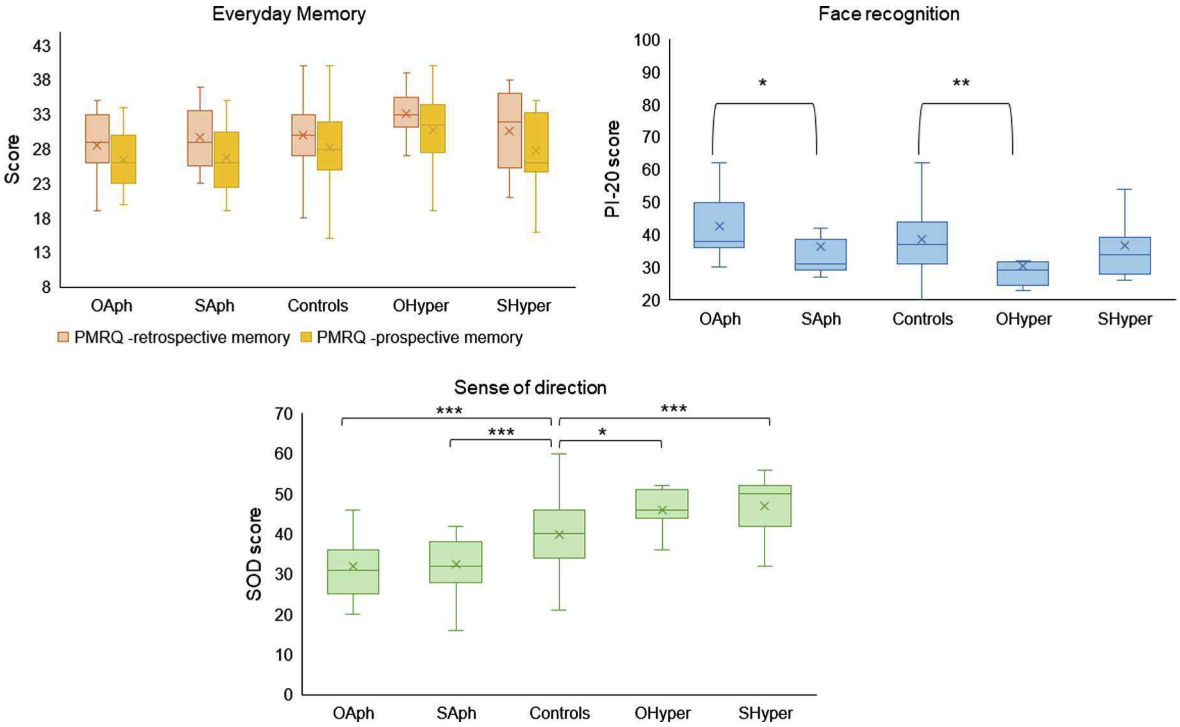

Fig. 3. Performance on memory, face recognition, and sense of direction self-report questionnaires across the groups. Note: In the PI-20 a higher score reflects worse performance. * $p < .05$; ** $p < .01$; $p < .001$. Only the following planned comparisons were performed: OAph vs. SAph, OAph vs. Controls, SAph vs. Controls, OHyper vs. SHyper, OHyper vs. Controls, SHyper vs. Controls.

survive after Bonferroni correction for multiple comparisons. No other statistically significant differences were found among groups.

For each group, the percentage of individuals with developmental prosopagnosia was also calculated (i.e., individuals with scores above 65 at the PI20; see Shah et al., 2015).

We found that 12 out of 484 respondents who filled in the PI20 showed developmental prosopagnosia (i.e., 2.5% of the sample): 10 out of 428 individuals in the control group (2.3%), one out of 17 in the SAph group (5.9%) and one out of 14 in the SHyper group (7.1%).

Concerning the navigational skills, we found a significant effect of the group on the SOD scale ($H(4) = 41.42$, $p < .001$). The effect of the group was also confirmed when the role of the sex was taken into account (see Supplementary results in Supplementary material for details).

Post hoc comparisons showed that both the OAph ($p < .001$) and SAph ($p < .001$) groups reported significantly lower navigational skills than Controls, while both the SHyper ($p = .001$) and OHyper ($p = .016$) groups reported better navigational skills than Controls, although this last difference did not survive after Bonferroni correction for multiple comparisons. No other statistically significant differences were found among groups.

For each group, the percentage of individuals with developmental topographical disorientation (i.e., individuals with a score under two standard deviations in the SOD scale) was calculated referring to the normative sample of Nori and Piccardi (2012), as suggested by Piccardi et al. (unpublished results).

We found that 16 out of 487 respondents who filled in the SOD scale showed developmental topographical disorientation (i.e., 3.3% of the sample): 9 out of 431 individuals in the control group (2.1%), 5 out of 15 in the OAph group (33.3%) and 2 out of 17 in the SAph group (11.8%).

3.4. Single-case analyses

Crawford's analyses performed by using the computer program SINGLIMS_ES.exe (Crawford & Garthwaite, 2002; Crawford & Howell, 1998) showed that the scores of one participant with SAph + OHyper (two-tailed probability: all $p_s > 0.18$) and one participant with OHyper + SHyper (one-tailed probability: all $p_s > 0.075$) were not significantly different from that of controls both on mental imagery and other cognitive skills measures.

4. Discussion

This study primarily sought to investigate a possible distinction between object and spatial imagery skills in aphantasia and hyperphantasia. We also explored whether involuntary visual imagery is spared in aphantasia, and to what extent the lack of object and spatial imagery can affect retrospective and prospective memory, face recognition, and navigational skills.

Considering the scores reported on the OSIQ (Blajenkova et al., 2006), we found that 3.1% of the respondents showed very poor scores on the OSIQ object scale (i.e., OAph participants), and 3.5% of the respondents showed very poor scores on the OSIQ spatial scale (i.e., SAph participants), suggesting a possible distinction between two different subtypes of aphantasia that is object and spatial aphantasia. This distinction was further proven by the different performances of OAph and SAph groups on mental imagery measures. Indeed, individuals with SAph did not have difficulties in imagining single items (e.g., objects, landmarks, and faces) and events and rated their mental images as vivid as control. SAph individuals may even have object hyperphantasia. Indeed, we identified a participant with spatial aphantasia and object hyperphantasia. Conversely, they reported difficulties in performing tasks involving visuo-spatial mental imagery (i.e., mental rotation).

On the other hand, individuals with OAph did not report difficulties in performing tasks involving visuo-spatial mental imagery. At the same time, they found it challenging to image single items (e.g., an object, a landmark, or a face) and events. Furthermore, using a specific task designed to evaluate the vividness and quality of object mental images (i.e., the SVT), they show a low vividness rating and reported no mental visualization of the objects, out-of-focus mental images, or black-and-white mental images more frequently than expected.

Regarding the other extremity of the mental imagery ability spectrum, eight participants (1.6% of the sample) showed very high scores on the OSIQ object scale, and 14 participants (2.9% of the sample) showed very high scores on the OSIQ spatial scale, suggesting a possible distinction between object and spatial hyperphantasia. This difference was consistent with the different performances of OHyper and SHyper groups on mental imagery measures. Indeed, in crude measures of mental imagery skills, the OHyper reported better imaging of single items than SHyper and Controls, and of events, as compared to Controls. In contrast, the SHyper group reported better spatial imagery than Controls. Object hyperphantasia, but not spatial hyperphantasia, was also associated with more vivid mental images that were judged as perfect as 3D pictures.

Concerning the involuntary imagery, we found no difference between groups when required to indicate which one of two black-and-white drawings of common fruits or vegetables had the darker color. This kind of task (i.e., CIT) can elicit the use of involuntary imagery since, after thousand co-occurrences of seeing a particular element in a specific color, a black and white image of that element is seen, involuntarily, in that color as a product of the associative learning (Pearson, 2019; Pearson & Westbrook, 2015). Also, the fact that we did not observe differences between groups in response times suggests that all participants used the same cognitive processes to solve the CIT, although we cannot completely exclude that they used a semantic strategy. In keeping with this finding, all OAph participants reported the presence of mental images in dreams, and only one SAph participant reported no mental images. This result is consistent with previous studies that have described the presence of mental images in the dreams of individuals with aphantasia (Milton et al., 2021; Zeman et al., 2015, 2020). If our findings are indicative of absent/reduced voluntary imagery and preserved involuntary imagery, what neural mechanism might underpin such behavioral results? A specific alteration in the backward connectivity between prefrontal executive areas and visual cortices, but not in the forward connectivity, can be a possible candidate. Indeed, although our knowledge of the neural networks involved in the involuntary visual imagery is very limited, the reference to an analogous dichotomy that has been extensively explored, that is the differences between endogenous attention (i.e., a goal-driven and voluntary type of attention) and exogenous attention (i.e., a stimulus-driven and involuntary type of attention), can be particularly relevant (for an overview, see Pearson, 2019; Pearson & Westbrook, 2015). In particular, as for the endogenous and exogenous attention (Dugué et al., 2020), we can hypothesize that, due to their differential engagement of top-down and bottom-up processes, involuntary and voluntary visual imagery distinctly modulate activity in fronto-occipital networks. The reduced connectivity between prefrontal executive areas and visual cortices recently detected in individuals with aphantasia (Milton et al., 2021) is in line with this hypothesis. Further work is, however, necessary to better define the possible difference in the brain network dynamics of voluntary and voluntary imagery, and the study of aphantasia can be particularly relevant to shed further light on this topic.

Our study also provided an insight into the impact of very poor/lack of object and spatial imagery on retrospective and prospective memory, navigational skills, and face recognition.

Individuals with object and spatial aphantasia did not report more prospective or retrospective memory slips in everyday life than controls. Similarly, we found that individuals with hyperphantasia did not report better retrospective or prospective memory than controls. Considering the link between mental imagery and memory this result can seem surprising. However, in everyday life the individuals with aphantasia can recall previously encountered information and implement intentions, using, for example, verbal strategies or memory aids, bypassing their mental imagery difficulties. To the best of our knowledge, no previous studies have evaluated prospective memory in everyday life in individuals with aphantasia/hyperphantasia; thus, future studies should better investigate this ability using objective measures probing both event and time-based prospective memory. Instead, current results on retrospective memory are consistent with a recent study by Milton et al. (2021) in which individuals with (*probably object*) aphantasia did not show difficulties in verbal and visuo-spatial well-known long-term memory tests (i.e., the delayed recall of the Logical Memory Test and of the Rey–Osterrieth Complex Figure Test), performing as well as controls and individuals with (object) hyperphantasia.

However, there is evidence of long-term memory difficulties in (object) aphantasia and of stronger memory skills in (object) hyperphantasia, using questionnaires that involve the ability to remember past life events (Dawes et al., 2020) and in autobiographical memory interviews (Milton et al., 2021). It is possible that autobiographical memory questionnaires and interviews tap more into mental imagery skills, requiring participants to use scene visual imagery (Hassabis & Maguire, 2007; Milton et al., 2021). A scene is a "naturalistic three-dimensional spatially coherent representation of the world typically populated by objects and viewed from an egocentric perspective" (Clark et al., 2019, p. 1862), and scene visual imagery is a crucial process that autobiographical memory and spatial navigation have in common (Maguire & Mullally, 2013; Teghil et al., 2021). Indeed, the ability in scene visual imagery explains performance in a range of tasks probing autobiographical memory recall and navigation (Clark et al., 2019). Also, scene visual imagery is the dominant strategy individuals use in performing autobiographical memory and navigational tasks (Clark et al., 2020). Different levels of ability in scene visual imagery could explain why individuals with *object* aphantasia and hyperphantasia showed, respectively, a low and strong sense of direction to the same extent as individuals at the extremes of the *spatial* imagery spectrum. Navigational tasks are associated with both scene visual imagery (Clark et al., 2019) and spatial imagery (Clark et al., 2019; Palermo et al., 2008) that may be respectively affected in object and spatial aphantasia, and, on the contrary, respectively enhanced in object and spatial hyperphantasia. Also, since visual scene imagery requires both object mental imagery to represent the visual features of the navigational objects and spatial mental imagery to set spatial parameters (e.g., location of the landmarks), poor scene visual imagery can result in a poor sense of direction both in object and spatial aphantasia (while the opposite pattern would be observed for both kinds of hyperphantasia). The unique link between imagery and navigation was also evident when we considered the percentage of participants that showed a SOD score compatible with a diagnosis of developmental topographical disorientation. Notably, 16 participants (3.3% of the sample) had scores indicative of developmental topographical disorientation. Seven of these individuals also showed aphantasia (5 in the OAph group and 2 in the SAhp group). This finding ties in well with previous studies on developmental topographical disorientation that have described navigational deficits associated with mental imagery difficulties in self-report (Burles & Iaria, 2020) and objective (Bianchini et al., 2010, 2014) mental imagery measures. However, cases of developmental topographical disorientation with object and spatial mental imagery skills in the normal range have also been described (e.g., Conson et al., 2018; Palermo et al., 2014), suggesting that topographical disorientation is not a secondary deficit due to aphantasia.

Considering that the self-reported sense of direction is not a key marker of spatial aphantasia and hyperphantasia, what could the best cognitive marker be? Visuo-spatial working memory in the reaching space can probably be a better candidate, and we suggest that future studies should include spatial working memory tests in the assessment. Indeed, although the distinction between dorsal and ventral streams is a key framework that has guided several works in visual neuroscience and mental imagery, including the present one, we should consider that while the characterization of the ventral stream as a 'what' pathway is relatively uncontroversial, the nature of dorsal stream is less clear (Kravitz et al., 2011). In fact, Kravitz et al. (2011) have identified three pathways emerging from the dorsal stream that consist of projections from the posterior parietal cortex to prefrontal areas, premotor areas, and medial temporal lobe. These three pathways support three different kinds of visuospatial processing: spatial working memory, visually guided action, and navigation.

Thus, developmental topographical disorientation could be linked to an alteration in the functional connectivity of the spatial navigation network (i.e., the parieto–medial temporal pathway; for the characterization of this pathway in humans, see Boccia, Sulpizio, Nemmi et al., 2017), as suggested by connectivity studies (Iaria et al., 2014; Kim et al., 2015), while spatial aphantasia could be linked to an alteration in the functional functioning of the dorsal stream projecting to the frontal lobe. However, this is tentative, and future behavioral and neuroimaging studies should explore this hypothesis better.

Concerning face recognition, we found that participants with object hyperphantasia, but not participants with spatial hyperphantasia outperformed controls. In contrast, the object aphantasic group, compared to the spatial aphantasic group, reported poor face recognition ability, consistently with a different cognitive profile for these two kinds of hyperphantasia/aphantasia. However, while we overall found that 2.5% of participants had congenital prosopagnosia, i.e., a percentage superimposable with that of previous prevalence studies (e.g., Bowles et al., 2009; Kennerknecht et al., 2008), none in the object aphantasic group reported a score at the PI20 compatible with a diagnosis of congenital prosopagnosia. Recently Milton et al. (2021) have found evidence of face recognition difficulty among participants with (object) aphantasia, as suggested by an elevation of PI-20 scores. However, they did not find any differences among participants with (object) aphantasia and controls using an objective measure probing famous face recognition. Overall, these findings suggest that individuals with object aphantasia can have difficulties in imaging people when they are not present (see our results on the MIQ single items); this, in turn, as suggested by Milton et al. (2021), can reduce their confidence in their ability to recognize faces, but they are not frankly prosopagnosic. However, future studies should further explore whether face recognition ability is reduced or aberrant in these individuals also using neuroimaging protocols.

Corollary, we were interested in providing preliminary information on the prevalence of aphantasia in the Italian context. Although this was not an epidemiological sample recruited with a probability sampling method (and therefore may not be representative of the prevalence of aphantasia in Italy), to the best of our knowledge, this is the largest Italian sample available to date (i.e., recruited in the Italian context and by using tools with instructions and questions written in Italian) that was not biased with respect to the imagery skills since we recruited participants from the general community and did not approach groups of individuals with aphantasia as in some previous studies (e.g., Dawes et al., 2020). However, it is still possible that individuals with mental imagery difficulties were more willing to participate in this research and that those who volunteer to take part may be different from those who choose not to (i.e., volunteer bias). We found that around 3% of the sample showed object aphantasia and 3.5% spatial aphantasia. This percentage is consistent with that reported by Faw (2009), that using a single question about visual imagery, stated that "2–5% of people are very poor- or non-visual- imagers", and with that reported by Dance et al. (2022) that, by using the VVIQ, suggested that the 3.9% of the population could be affected by aphantasia, while it is higher as compared to a recent study that suggests that aphantasia occurs in around 1% of the population (Zeman et al., 2020). Future work is needed to determine whether different kinds of aphantasia are equally prevalent in other individuals not represented in the current sample, such as in children, and using better gender balance samples (our sample included only 27% of men).

Also, in this study, we have attempted to tease apart two possible subtypes of aphantasia but it is likely that each kind of aphantasia is heterogeneous, with different degrees of difficulties. For example, individuals with a lack of mental images in dreaming can have a more severe profile of aphantasia that also affect the involuntary imagery capability.

4.1. Limits

The main limitation of the current study is that the classification as aphantasic, hyperphantasic or control participant was based on a self-report questionnaire. Unfortunately, so far, this is the main limitation of several studies in the field since only very recently a cut-off for an objective measure, that is binocular rivalry imagery paradigm (Keogh & Pearson, 2018; Pearson et al., 2008), to make a diagnosis of aphantasia has been suggested (Wicken et al., 2021). On a positive note, the OSIQ has been validated in two large scales studies (Blajenkova et al., 2006; Chabris et al., 2006), and it shows good convergent validity since scores on the spatial scale correlate with performance on objective spatial measures, such as mental rotation tasks, but not on object imagery tasks, while scores on the object scale show the reverse pattern (Blajenkova et al., 2006; Chabris et al., 2006).

We also acknowledge that the assessment of spatial mental imagery was limited since we used a crude measure (i.e., MIQ-Spatial) for a very complex construct. Also, considering that so far, the majority of studies on the topic have used the VVIQ, future studies should include this questionnaire in the test battery in order to demonstrate the selective association between object OSIQ and VVIQ scores, reported in several studies on healthy individuals, also in samples of object aphantasic individuals.

Finally, although we found specific differences between the different groups in the various self-report questionnaires (i.e., there was not a group that was systematically better or worse in all the questionnaires), we can not completely exclude a self-efficacy effect. On the other hand, a recent study also suggests that classic performance-based “visual imagery tasks” discriminate poorly between people with aphantasia and hyperphantasia (Milton et al., 2021). Thus, future studies in lab-based settings should confirm current findings using performance-based cognitive measures specifically designed to discriminate mental imagery extremes.

5. Conclusion

To conclude, the current study has expanded on previous findings on the topic and has offered converging evidence that visual-object and visual-spatial imagery can be selective impaired or enhanced. We have provided preliminary information on how low/high imagery abilities in one imagery domain can impact the other one and cognitive skills such as navigation, memory, and face recognition, inviting further behavioral and neuroimaging studies to shed more light on these two sub-types of aphantasia and hyperphantasia. Here, considering the lack of markers for these conditions, we have classified individuals adopting a “normative” view, that is, those who are at the low-end of the spectrum of object/spatial imagery abilities are those with object/spatial aphantasia. Still, as for the research on other developmental (congenital) disorders (for a similar argument on developmental prosopagnosia, see Barton & Corrow, 2016), future studies should better understand if these two sub-types of aphantasia are just the low-end of the spectrum of object/spatial imagery abilities (i.e., if they include individuals that are very weak in object/spatial imagery and are at the low end of the normal distribution) or if they reflect a pathologic failure to develop mental imagery skills (i.e., if they include people with aberrant development of imagery skills that are different from people with very weak object/spatial imagery) and, if so, which is the marker that differentiates people with weak object/spatial imagery skills from individuals with an aberrant development of object/spatial imagery skills. In the same vein, future studies should better understand if these two sub-types of hyperphantasia are just the high-end of the spectrum of object/spatial imagery abilities or if there are marker that differentiates people with good object/spatial imagery skills from individuals with an exceptional development of object/spatial imagery skills.

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CRediT authorship contribution statement

Liana Palermo: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Maddalena Boccia:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **Laura Piccardi:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Raffaella Nori:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

1. Can you see images of objects, places, and people in your dreams?
   ☐ Yes ☐ No

2. How do you judge your ability to imagine the faces of people you know (e.g., your best friend)?
1 (poor) 2 3 4 5 (excellent)

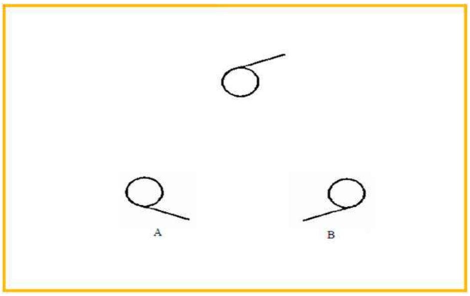
3. How do you rate your ability to imagine places, buildings, and monuments that you know (e.g., the school you attended)?
1 (poor) 2 3 4 5 (excellent)

4. How do you judge your ability to imagine objects (e.g., the wardrobe in your bedroom, the refrigerator in your kitchen)?
1 (poor) 2 3 4 5 (excellent)

5. How do you rate your ability to remember past events (e.g., your last birthday, the last party you attended)?
1 (poor) 2 3 4 5 (excellent)

6. How do you rate your ability to imagine future events (e.g., how your next birthday or a party you will attend will be like)?
1 (poor) 2 3 4 5 (excellent)

7. How do you rate your ability to solve problems like the one in the picture where you have to choose between two items (A and B), the one that, mentally rotated, matches the target item at the top of the picture?
1 (poor) 2 3 4 5 (excellent)



Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2022.103360.

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