

PHANTASIA – THE PSYCHOLOGICAL SIGNIFICANCE OF LIFELONG VISUAL IMAGERY

VIVIDNESS EXTREMES

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Abstract:

Visual imagery typically enables us to see absent items in the mind's eye. It plays a role in memory, day-dreaming and creativity. Since coining the terms aphantasia and hyperphantasia to describe the absence and abundance of visual imagery, we have been contacted by many thousands of people with extreme imagery abilities. Questionnaire data from 2000 participants with aphantasia and 200 with hyperphantasia indicate that aphantasia is associated with scientific and mathematical occupations, whereas hyperphantasia is associated with 'creative' professions. Participants with aphantasia report an elevated rate of difficulty with face recognition and autobiographical memory, whereas participants with hyperphantasia report an elevated rate of synaesthesia. Around half those with aphantasia describe an absence of wakeful imagery in all sense modalities, while a majority dream visually. Aphantasia appears to run within families more often than would be expected by chance. Aphantasia and hyperphantasia appear to be widespread but neglected features of human experience with informative psychological associations.

1. Introduction

Visual imagery typically allows us to inspect absent items in the 'mind's eye', somewhat as if we were seeing them (Pearson, Naselaris, Holmes, & Kosslyn, 2015). For most of us such imagery is a ubiquitous element of experience, evoked by vivid memories, compelling descriptions, dreams and day-dreams (Brosch, 2018; Schacter & Addis, 2007; Smallwood & Schooler, 2015). Modulating emotion, fuelling cravings in addiction and aiding therapists in treatment (Holmes & Mathews, 2010), it is harnessed by teachers and trainers in mental practice (Munzert, 2013), and used to facilitate communication following profound brain injury (Owen et al., 2006). It plays a role in creativity in both the sciences and the arts (Shepard, 1988). Variations in the vividness of visual imagery were first studied systematically by the British psychologist, Sir Francis Galton, in the nineteenth century, who invited participants to rate the 'illumination, definition and colouring' of 'your breakfast table as you sat down to it this morning' (Galton, 1880). He recognised that in some participants 'the power of visualisation was zero'. However, this phenomenon, the apparently lifelong lack of a mind's eye, has been neglected until very recently, with the exception of a single study suggesting a prevalence of 2-3% (Faw, 2009) and our previous report, coining the term aphantasia (Zeman, Dewar, & Della Sala, 2015). Galton also reported that imagery vividness was associated with occupation (Galton, 1880), with a tendency toward fainter imagery among 'men of science', though this was subsequently challenged (Brewer & Schommer-Aikins, 2006).

Previous research, focussing on less extreme variations in imagery vividness, has associated imagery vividness and utilisation with cognitive performance and neural activity in several psychological domains. Studies on both healthy and clinical populations have linked the vividness, richness and fluency of autobiographical memory to imagery vividness (D'Argembeau & Van der Linden, 2006; Greenberg & Knowlton, 2014; Rubin & Greenberg, 1998; Vannucci, Pelagatti, Chiorri, & Mazzoni,

2016). The neural mechanisms for these effects include both activation within and connectivity to visual cortices (Daselaar et al., 2008; Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004; Sheldon, Farb, Palombo, & Levine, 2016). There is evidence for a relationship, also, between imagery strength, as assessed using the binocular rivalry paradigm, and the capacity of visual working memory (Keogh & Pearson, 2014). In the domain of visual perception, imagery vividness has been related to some higher-order perceptual skills. Gruter et al. (Gruter, Gruter, Bell, & Carbon, 2009) reported that the mean VVIQ score among individuals with congenital prosopagnosia (difficulty with familiar face recognition) was between two and three standard deviations below the normal participant mean. In contrast, Barnett and Newell (Barnett & Newell, 2008) found elevated vividness scores among individuals with synaesthesia ('merging of the senses'). Vivid 'object imagery' has been associated specifically with an enhanced ability to identify degraded figures (Blazhenkova & Kozhevnikov, 2010) and filtered visual stimuli at low spatial frequencies (Vannucci, Mazzoni, Chiorri, & Cioli, 2008) and to distinguish degrees of 'grain' (Blazhenkova & Kozhevnikov, 2010). Variations in imagery vividness are also associated with the risk of several psychiatric disorders: average imagery vividness is raised in patients with schizophrenia and their first degree relatives (Oertel et al., 2009), while higher levels predispose to more frequent flashbacks in an experimental model of Post-Traumatic Stress Disorder (Morina, Leibold, & Ehring, 2013), and to hallucinations in Parkinson's Disease (Shine et al., 2015). More broadly, these findings from the study of memory and perception and mental health resonate with a long tradition of work on individual differences in cognition, including Paivio's 'dual coding theory' and its more recent descendants (Otis, 2015). Failure to consider individual differences in the approach to solving cognitive tasks – for example the use of verbal vs visual strategies – has sometimes impeded the analysis of task performance (Logie, 2018; Pearson, 2019)).

In this paper, we revisit Galton's early discovery that in some individuals the 'powers [of visualisation] are zero'. In 2015, in a letter to this journal, we described 21 individuals with lifelong absence of the mind's eye, coining the term '*aphantasia*', adapted from Aristotle's word for the mind's eye, *φαντασία* ('phantasia')(8), to refer to this phenomenon (Zeman, Dewar, & Della Sala, 2015). Since

then, studies by other investigators have identified several potential objective correlates of aphantasia: loss of the usual priming effect of imagery in binocular rivalry (Keogh & Pearson, 2018), suggesting that the underlying cause of aphantasia is sensory rather than metacognitive; absence of the usual autonomic response to stories that would normally be expected to excite emotive imagery (Wicken, Keogh, & Pearson, 2019a); reduction in the precision of visual working memory, reported in a single case (Jacobs, Schwarzkopf, & Silvanto, 2018). A further study, in keeping with the findings of Keogh & Pearson (Keogh & Pearson, 2018) indicates that the aphantasia is likely to reflect a selective reduction in 'object imagery' as opposed to 'spatial imagery' (Bainbridge, Pounder, Eardley, & Baker, 2020). A personal account of aphantasia (Watkins, 2017) has highlighted a possible association with the recently described syndrome of Severely Deficient Autobiographical memory (Palombo, Alain, Soderlund, Khuu, & Levine, 2015). The description of aphantasia has also redirected attention to the opposite extreme of the vividness spectrum, which we have termed 'hyperphantasia', imagery 'as vivid as real seeing'. While hyperphantasia, like aphantasia, has been neglected in recent psychological research, the phenomenon may be linked 'eidetic' or 'photographic' imagery, which was a focus of attention in visual psychology in the early 20th century (Pearson, 2019).

Following extensive media interest in our 2015 paper, which stimulated a sustained surge of 'citizen science', we have been contacted by over 14,000 individuals from around the world, reporting extreme imagery. Altmetric statistics indicate that the public interest generated by our 2015 Letter places it in the top 1% of scientific outputs in this respect (Altmetric 407 on 9th February 2020), reflecting strong lay curiosity about invisible differences in imaginative experience. This large sample creates a unique opportunity to address the significance of visual imagery extremes, exploring both questions that have been unresolved since Galton's first report, such as the professional associations of extreme imagery vividness and their associated gender ratios, and questions raised by the more recent studies cited above.

On the basis of Galton's observation that scientific professions were associated overall with low imagery vividness, and the related findings of Blazhenkova & Kozhevnikov (2010), we hypothesised that individuals with aphantasia and hyperphantasia would differ in occupational preference, with a bias toward the sciences among those with aphantasia. The findings described briefly above, linking higher levels of imagery vividness to stronger autobiographical memory, and associating face recognition difficulty with lower level of imagery vividness, taken together with our previous findings (Zeman, Dewar, & Della Sala, 2015), prompted the hypothesis that individuals with aphantasia would be more likely to report difficulty in these domains. Following the observation of Barnett and Newell we anticipated an elevated rate of synaesthesia among participants with hyperphantasia. Finally, on the basis of our previous results (Zeman, Dewar, & Della Sala, 2015), we predicted that wakeful and dreaming imagery would dissociate, involvement of imagery in other sense modalities would be variable, and imagery extremes would cluster within families.

2. Methods

2.1 Questionnaires.

We responded to media-inspired contacts from members of the public reporting exceptionally faint or vivid imagery with a request that they complete two questionnaires: i) a modified version of the Vividness of Visual Imagery Questionnaire (Marks, 1973) (VVIQ), reversing the original order of the vividness scale so that higher scores correspond, intuitively, to more vivid imagery (VVIQ scores range from 16/80 – 80/80); ii) a questionnaire adapted from our previous study (Zeman, Dewar, & Della Sala, 2015), the Imagery Questionnaire (IQ), to probe potentially relevant characteristics of individuals with extreme imagery. Both questionnaires were originally sent to participants via email and completed as Microsoft Word documents. More recently they have been completed by participants on-line, using *Limesurvey* initially, and subsequently *Snapsurvey*). The IQ underwent minor modifications between administration formats for practical reasons but the essential content was preserved. One question,

relating to ‘difficulty in recognising faces or objects’ was changed to ‘difficulty in recognising faces’ as neither aphantasic or hyperphantasic participants reported object recognition difficulty. Following spontaneous mention of synaesthesia by several participants with hyperphantasia, a question about synaesthesia was added. Control participants (see below) completed the VVIQ and a modified version of the IQ (see supplementary material for full details of the questionnaires and their administration. Once again, we preserved the essential content of the questionnaire).

2.2 Participants.

Between June 2015 and March 2018 we received 2000 consecutive fully completed sets of questionnaires from participants with aphantasia, defined as VVIQ scores of 16-23/80, 200 from participants with hyperphantasia, defined as scores of 75-80/80, and 200 from participants with mid-range scores of 51-63/80, selected on the basis of previous work (McKelvie, 1995; Zeman, Dewar, & Della Sala, 2015) indicating mean and median VVIQ scores falling between 55 and 60 in large populations. Our aphantasic and hyperphantasic samples were opportunistic, in the sense that our participants had approached us spontaneously following publicity triggered by our original publication: we reasoned that a sample of aphantasic participants 100 times greater than we had previously reported was likely to be informative. Control participants were recruited from among 1288 members of a local Biobank, EXTEND (<http://exeter.crf.nihr.ac.uk/extend>) who had responded to a request to complete the VVIQ. We distinguished participants with extreme and moderate aphantasia and hyperphantasia (VVIQ scores 16/80 vs 17-23/80, 80/80 vs 75-79/80 respectively): as findings in the extreme and moderate groups were qualitatively similar, we primarily present the combined group data here (see supplementary material for subgroup comparisons). We excluded participants who indicated that their aphantasia was acquired (i.e. that they had previously experienced imagery, but had lost their mind’s eye) as this often resulted from events such as head injury or stroke which might have more widespread effects on cognition, unrelated to aphantasia. We did not have other exclusion criteria as we wished to capture the features of aphantasia and hyperphantasia without

further qualification in this initial study. We received approval for our questionnaire study with participants with extreme vividness scores from the Exeter Medical School Ethics Committee, and for our work with EXTEND participants from the University of Exeter Psychology Research Ethics Committee.

2.3 Analysis and Statistics.

Questionnaire data were entered into an Excel spreadsheet, and where possible coded numerically to allow statistical comparisons (see supplementary material for full details of data fields and coding categories). Coding of the questionnaires completed in Word ($n = 1460$), which asked open-ended questions, was undertaken by two researchers (JG, BH-W) who were not blind to participant group. In rare cases of disagreement, a consensus was agreed with the help of a third researcher (CW or AZ). The questionnaires completed on-line ($n = 940$) provided, where feasible, drop-down menus with response options corresponding to the coding categories, with additional opportunity for free-text responses.

Our primary analyses examine differences between the aphantasia and hyperphantasia groups (and where appropriate also the control group) on a broad range of fifteen key characteristics. Differences were first investigated using omnibus contingency chi-square. For these analyses, we corrected for multiple comparisons using Bonferroni corrections with a corrected $p = .003$ ($.05/15$). When the overall analysis was significant, we performed follow-up post-hoc comparisons with the adjusted standardised residuals to interpret the effect. Following the recommendations of Macdonald & Gardner (Macdonald, 2000), Bonferroni corrections for multiple comparisons were conducted for these post-hoc comparisons ($p = .05/\text{the number of cells in the particular contingency chi-square}$). We also conducted cell-wise comparisons to assess whether there were any differences between groups. Groups were considered to differ significantly should the cells for each group be statistically significant, according to the criteria outlined above, in the opposite direction to each other. The requirement for both cells to be significant, if anything, errs on the side of being conservative. For

each of the 15 topics, we also conducted supplementary analyses to characterise our data further. First, given that there was a higher proportion of females in the hyperphantasia group than the aphantasia and control groups, we ran analyses on males and females separately to ascertain whether the same basic patterns for the all participant comparisons still emerged. In addition, we examined whether there were any differences between the extreme aphantasia/moderate aphantasia groups and the extreme hyperphantasia/moderate hyperphantasia groups (see supplementary material). For these follow-up analyses corrections for multiple comparisons were conducted as described above for the primary analyses.

The data will be publicly archived, so far as possible, once appropriate permissions have been obtained. Study procedures and analyses were not preregistered.

3. Results

3.1 VVIQ and demographics (Table 1).

Hyperphantasic participants had a significantly higher VVIQ score than those in either the control, $t(398) = 75.042$, $p < .001$, $d = 7.505$, or aphantasia groups, $t(2198) = 421.126$, $p < .001$, $d = 33.387$. Aphantasic participants had a significantly lower VVIQ than the control group, $t(2198) = 251.475$, $p < .001$, $d = 14.146$. A contingency chi-square revealed a significant difference in gender across the groups, $\chi^2(2, 2371) = 21.704$, $p < .001$, reflecting a bias toward females in the hyperphantasia group. There was a significant difference between groups in education, $\chi^2(2, 2276) = 20.312$, $p < .001$, reflecting lower educational attainment among the control participants. Independent samples t-tests revealed no significant difference in age between the aphantasia and hyperphantasia groups, $t(2180) = .472$, $p = .637$, $d = .037$, but the control group was significantly older than both the aphantasia, $t(2160) = 12.194$, $p < .001$, $d = .974$, and hyperphantasia, $t(374) = 9.827$, $p < .001$, $d = 1.012$, groups. We consider it unlikely that these differences in age and education will have influenced the

comparisons in which the control group is included below, but note that the comparisons of primary interest in each case are those between the aphantasic and hyperphantasic groups.

Table 1 Vividness scores, age, gender and education in the three study groups

	<i>Aphantasia</i>	<i>Hyperphantasia</i>	Controls
VVIQ (mean)	17.06	78.16	57.49
	(SD = 1.983)	(SD = 1.663)	(SD = 3.522)
Age (mean)	41.31	41.87	56.80
	(SD = 16.307)	(SD = 13.971)	(SD = 15.489)
Gender (male:female)	993:981	65:132	94:106
	(50.3%:49.7%)	(33%:67%)	(47%:53%)
Education level (No degree/Degree or > 15 years education)	629:1264	59:126	97:101
	(33%:67%)	(32%:68%)	(49%:51%)

3.2 Autobiographical memory (Figure 1a).

An omnibus contingency chi-square yielded a significant difference in autobiographical memory between groups, $\chi^2 (6, 2379) = 233.125, p < .001$. Post-hoc comparisons revealed that people with hyperphantasia were more likely to report good memory than either people with aphantasia or the control group. Conversely, the aphantasia group were more likely to say their memory was bad than the hyperphantasia and control groups, whilst the control group were more likely to say their memory was normal than the hyperphantasia and aphantasia groups. Similar patterns emerged for female and male participants analysed separately (see SI).

3.3 Face recognition (Figure 1b).

There was a significant difference between groups, $\chi^2 (2, 2078) = 84.621, p < .001$, with participants in the aphantasia group reporting significantly higher levels of face recognition difficulties than

participants in either the hyperphantasia or control groups. Similar patterns emerged for female and male participants analysed separately (see supplementary material).

3.4 Visual imagery in dreams (Figure 2a).

There was a significant difference between groups, $\chi^2 (2, 2398) = 146.264, p < .001$. Post-hoc comparisons revealed that participants in the aphantasia group were less likely to experience visual imagery in dreams than either the hyperphantasia or the control groups (specifically, 20.7% of aphantasic participants reported that they dream without images, while 7.5% reported that they do not dream at all; comparable percentages in the control group were 6.5% and 0.5%, and in the hyperphantasic group 0.5% and 0%). The same basic pattern emerged for male and female participants analysed separately (see supplementary material). The participants who reported avidual dreams described narrative, textual, conceptual, auditory and emotional dream content.

3.5 Influence of mood (Figure 2b).

There was a significant difference across groups, $\chi^2 (4, 2396) = 648.685, p < .001$ with the aphantasia group significantly less likely to report that mood influenced their imagery than participants in either the hyperphantasia or control groups. These results were the same for both male and female participants.

3.6 Synaesthesia (Figure 2c).

The omnibus chi-square yielded a significant effect, $\chi^2 (2, 629) = 68.051, p < .001$. Post-hoc analyses showed that participants with aphantasia were significantly less likely to report the experience of synaesthesia than participants in the hyperphantasia group. The control group did not differ from the expected values. For females the results were identical to the all-participant analyses. For males, there was again a difference between groups, $\chi^2 (2, 273) = 13.230, p < .001$, with the hyperphantasia group

more likely to experience synaesthesia than chance, although none of the cell-wise comparisons were significant.

3.7 The 'windows task' (Figure 3a).

This task required participants to count the number of windows in the house or apartment mentally. There was a significant difference in the distributions, $\chi^2 (4, 2281) = 1719.768$, $p < .001$ with the aphantasia group significantly less likely than either the hyperphantasia or the control group to use visual imagery strategies to accomplish this task. Instead, the aphantasia participants were significantly more likely to use alternative, non-imagery, strategies - including the use of avisual spatial imagery, kinaesthetic imagery and amodal 'knowledge' - than the hyperphantasia and control groups. These results were identical when considering males and females separately.

3.8 Effect of eye opening (Figure 3b).

The omnibus chi-square revealed an overall significant effect, $\chi^2 (4, 2396) = 136.673$, $p < .001$ with the aphantasia group significantly less likely to report an effect of eye opening vs eye closure on imagery vividness than the control group. This same pattern emerged for both male and female participants (see supplementary material for full analyses).

3.9 Occupation (Figure 4).

The *remaining analyses* were conducted only on data from the aphantasia and hyperphantasia groups, as they relate to the experience or occurrence of extreme imagery or, in the case of occupation, to level of education, which was lower in the control group and would be expected to have a confounding effect.

For occupation, the contingency chi-square revealed a significant result, $\chi^2 (21, 1752) = 84.516$, $p < .001$. Post-hoc analyses revealed that people in the aphantasia group were significantly less likely to be in 'Arts, Design, Entertainment, Sports, and Media Occupations' than hyperphantasia participants.

In contrast, a significantly greater proportion of people with aphantasia were working in professions classified as 'Computer and Mathematical'/'Life, Physical and Social Sciences' (we combined these two categories in the analysis given their intuitive relationship, and the prior hypothesis that aphantasia was associated with scientific occupations). We excluded the 'unemployed/no answer' category from these analyses.

3.10 Age and mode of discovery (Figure 5).

The contingency chi-square revealed that there was a significant difference between groups in the age at which participants recognised that their imagery vividness lay at an extreme, $\chi^2 (2, 2194) = 47.282$, $p < .001$. Post-hoc comparisons showed that this reflected a lower likelihood for participants in the aphantasia group than for participants in the hyperphantasia group to become aware of their condition in the first two decades of life. The same pattern emerged for both male and female participants. There was also a significant difference between groups with respect to the mode of discovery, $\chi^2 (8, 2123) = 64.999$, $p < .001$. Post-hoc comparisons showed that people with hyperphantasia were significantly more likely to discover their condition via art than people with aphantasia (see supplementary material for sex-specific analyses).

3.11 Family history (Figure 6a).

There was a significant difference between the groups, $\chi^2 (3, 2133) = 48.238$, $p < .001$. Aphantasic participants were significantly more likely to report 'no family members' have a similar condition than hyperphantasic participants. Conversely, hyperphantasic participants were significantly more likely than aphantasic participants to say that 'maybe one' family member was affected (see supplementary material for sex-specific analyses). We consider whether participants with extreme imagery report 'affected' relatives more often than would be expected by chance further below.

3.12 Other modalities of imagery (Figure 6b).

35.8% of participants with aphantasia and 42.2% of participants with hyperphantasia reported that at least one other modality was unaffected (i.e. normal or vivid in the case of participants with aphantasia, normal or faint in the case of participants with hyperphantasia); conversely, 54.2% of aphantasic participants and 47.8% of hyperphantasic participants reported that all modalities of imagery were faint or vivid respectively. The chi-square was not significant, $\chi^2 (2, 2129) = 2.718, p = .257$, indicating no differences between the aphantasia and hyperphantasia groups. For male participants, there was a trend for a difference ($p = .036$) but this did not survive corrections for multiple comparisons. For females there was also no significant effect ($p = .451$).

3.13 Emotional impact, perceived advantages, relationships (Figure 7).

While an emotional impact was common, the chi-square revealed no significant differences in the distribution between the two groups, $\chi^2 (4, 2172) = 2.151, p = .708$. There was a significant difference between groups in the rate of perceived advantage, $\chi^2 (2, 2157) = 114.016, p < .001$. Post-hoc comparisons revealed that participants in the aphantasia group were significantly less likely than the participants in the hyperphantasia group to see their condition as advantageous. The aphantasia group was also more likely to say that they were unsure than the hyperphantasia group. The same pattern of results emerged for both male and female participants. Finally, many participants in both groups reported that their imagery vividness impacted their relationships (48.7% of people with aphantasia, 53% of people with hyperphantasia), attributing a predominantly negative effect (95.5% of people with aphantasia, 75.8% of people with hyperphantasia). A chi-square analysis of the frequency of the perceived effect of imagery vividness on relationships revealed no difference between the aphantasia and hyperphantasia groups $\chi^2 (2, 2158) = 1.514, p = .469$. The same results emerged when considering males and females separately ($P_s > .4$).

3.14 EXTEND study VVVIQ distribution and sibling recurrence risk (Figure 8).

0.7% of participants in the EXTEND cohort scored 16/80, 2.6% 16-23/80 while 2.6% scored 80/80 and 11.2% 75-80. The mean score was 58.6 (SD = 13.3) and the median was 60. We used EXTEND study data to calculate the sibling recurrence ratio for extreme aphantasia. Within the extreme aphantasia group, 21% reported an affected relative, of whom 19% were first degree relatives, and 6.7% were siblings, yielding a sibling recurrence risk ratio (λ_S) of 9.6, indicating a roughly tenfold increase in the likelihood of aphantasia in siblings by comparison with the general population.

4. Discussion

4.1 Key findings

In keeping with our hypotheses, these data indicate that people lying at the two extremes of the spectrum of visual imagery vividness report distinctive behavioural and psychological associations. People with hyperphantasia are more likely to be found in professions traditionally regarded as creative, while those with aphantasia are more likely to work in computing, mathematics and science. Aphantasia, in contrast to hyperphantasia, is reportedly associated with difficulty with face recognition, and many people with aphantasia describe impoverished memories of past personal events. Conversely, people with hyperphantasia are more likely than those with aphantasia to report synaesthesia. When asked to count mentally the number of windows in their home, people with hyperphantasia - and mid-range imagery - almost invariably consult a visual image while those with aphantasia describe a range of alternative strategies including the use of avisual spatial imagery, kinaesthetic imagery and amodal 'knowledge'.

We have also confirmed some anticipated dissociations. Most strikingly, people with aphantasia were more likely than those with average or vivid imagery to report an absence of dreams, or a-visual dreaming. Nonetheless, a majority (63.4%) of people with aphantasia report that they *dream visually*, in common with 98.5% of people with hyperphantasia and 89% of people with mid-range imagery vividness. Most of those who do not dream visually report experiencing dreams in atypical narrative,

textual, conceptual, auditory and emotional forms. Secondly, while about half (54.2%) of our aphantasic participants describe an absence of imagery in any sense modality – absence of the ‘mind’s ear’, for example, as well as the mind’s eye – many experience imagery in one or more modalities other than vision, most often auditory.

Sampling from a large community biobank, the *EXTEND* study (<http://exeter.crf.nihr.ac.uk/extend>), indicates that the prevalence of aphantasia, defined as extreme performance on the most widely used measure of imagery vividness, is around 0.7%, that of hyperphantasia around 2.6%. Individuals with extreme imagery typically realise that their experience is unusual at school or in early adult life, those with hyperphantasia discovering this earlier than those with aphantasia. The realisation that their imagery vividness is exceptional most often dawns when comparing their experience with that of friends and family, as a result of media reports, or while engaging in practices, like meditation, that often require visualisation. In our large sample, the sex ratio is equal among those with aphantasia, while there is a female preponderance among those with hyperphantasia. Participants report a family history of aphantasia in first degree relatives more often than would be expected by chance, suggesting a possible genetic basis for imagery vividness, although environmental factors very likely play a part.

4.2 Limitations

These findings derive from first person reports by self-selected participants. Such data are open to a range of criticisms. Metacognitive judgements are fallible (Hurlburt & Schwitzgebel, 2007). They may be influenced by a range of factors including participants’ folk psychological theories, their assumptions about researchers’ expectations and pervasive confounding factors such as mood. The ‘self-selection’ by our participants mean that the groups may be unrepresentative in, for example, their gender mix. Wide-ranging questionnaire studies of this kind use crude measures for complex constructs, such as face recognition and autobiographical memory. Our coding of participant responses was not undertaken blind to participant group and involved some judgement calls. Finally,

it is likely that our two samples, lying at opposite extremes of the vividness spectrum, are heterogeneous: our group findings may conceal important subgroup and individual differences. We briefly discuss each of these limitations in turn.

Introspective reports must be treated critically by researchers, and are certainly open to a range of potentially distorting influences (Hurlburt & Schwitzgebel, 2007). However, just as ‘disease narratives’ are often the point of departure for innovative research in medicine (e.g. Ffytche et al., 1998), so introspective reports frequently provide valuable clues in cognitive neuroscience (e.g. Blood & Zatorre, 2001). In the current study we were impressed by the consistency of the accounts of extreme imagery provided across participants who were often describing clusters of phenomena that they had been puzzled by for years. Their descriptions did not appear to be strongly influenced by psychological theory or demand characteristics, and the patterns of response did not suggest any uniform tendency to low or high item endorsement. For example individuals describing aphantasia often drew attention to the presence of visual imagery in their dreams, or of imagery in other sense modalities, and the emotional impact of recognising oneself as experiencing ‘extreme imagery’ did not differ between the two groups. We entirely agree that the first person reports provided by our participants require triangulation with more objective measures, both behavioural and neural - as we and others have done in previous studies of *acquired* aphantasia (Farah, 1984; Zeman et al., 2010) - but we believe that first person reports nevertheless provide critical, initial, data points. Our participants’ self-selection may indeed have influenced some aspects of our data. For example, if women were more likely to make contact with us than men, the gender ratios we have described may be misleading. VVIQ data from a genuinely community-based sample would remedy this defect.

The Imagery Questionnaire employed in the study was an exploratory instrument, informed by the accounts provided by the small number of people with aphantasia we had previously encountered. Some of the questions we included – such as whether ‘*your ability to recall memorable events from the past, like holidays or celebrations, [is] normal*’ – were indeed coarse-grained. We believe that such

questions are defensible in the early stages of the exploration of a new phenomenon, and that their use was to some extent justified by the significant group differences they revealed. Clearly these suggestive findings require closer analysis, using better differentiated questionnaires and more objective approaches, as above. 'Blind' coding of responses would have been advantageous, but as group membership tended to become clear rapidly on review of the questionnaires, it would have been difficult to achieve without isolating the responses to individual questions. This approach would have exceeded the resources available for this study. We took care to code responses as objectively as possible but accept that this process is not entirely objective. We hope, in due course, to be able to conduct a replication of the current study using more stringent 'blinding' in a replication sample. Finally, we agree that it is likely that both aphantasia and hyperphantasia can occur in a range of psychological contexts, and are heterogeneous. We plan to examine patterns of response within the data in future work. The current paper describes a 'first pass' designed to identify commonalities within and differences between the study groups.

4.3 Future work: validation and underlying mechanisms

It will be important to investigate the associations we have described using objective measures, including tests of face recognition, autobiographical memory and synaesthesia, in future work. Free text responses, not presented here, provided alongside the codeable data in our questionnaires, suggest that extreme imagery may have affective as well as cognitive associations, in keeping with the findings of Wicken et al (Wicken, Keogh & Pearson, 2019), which should also be explored further. The resulting objective neuropsychological data, together with patterns of response within the questionnaire data, can then be used to identify possible subtypes of extreme imagery.

Alongside these behavioural approaches, neural measures have the potential to explicate our questionnaire data. Growing understanding of the neural basis of visualisation (Winlove et al., 2018), and of its normal variation (Fulford et al., 2018), suggests candidate mechanisms for extreme imagery, including alterations in connectivity between the executive control networks that organise mental

processes and the sensory cortices that represent modality-specific information. The observation in our study that many people with aphantasia nevertheless dream visually may be explained by the radical differences between the underlying neurobiology of dreaming, a ‘bottom-up’ process, orchestrated from the brain stem (Lu, Sherman, Devor, & Saper, 2006), and visualisation, a ‘top-down’ process reliant on control networks centred in frontal and parietal cortices (Winlove et al., 2018). The variability in the involvement of imagery in other sense modalities suggests that both cross-modality and modality specific factors influence imagery vividness.

As indicated in the Introduction, several studies have already made a start in identifying potential objective correlates of aphantasia using behavioural and neural markers, such as loss of the usual priming effect of imagery in binocular rivalry (Keogh & Pearson, 2018) and absence of the usual autonomic response to stories that would normally be expected to excite emotive imagery (Wicken, Keogh & Pearson, 2019).

Thirdly, the observation that extreme imagery, specifically aphantasia, may occur more frequently than would be expected in first degree relatives, hints that there may be a genetic component to imagery vividness. This requires substantiation from family studies measuring imagery vividness in relatives. If confirmed, a genome-wide association study of imagery vividness in a large participant group provides a potential method for identifying relevant genes.

Future work will also need to address the question of whether ‘extreme imagery’ constitutes a disorder. Although aphantasia occasionally occurs as a result of brain injuries or psychiatric conditions which impair an existing capacity to visualise (Bartolomeo, 2008; Farah, 1984; Zago et al., 2011), we do not at present consider lifelong aphantasia to be a medical disorder, but rather an intriguing variation in human experience, analogous to synaesthesia. We suspect that aphantasia and hyperphantasia will prove to have balanced advantages and disadvantages, perhaps reflecting a tension between two key modes of human information processing: one episodic and sensorily-rich, the other semantic and factual.

4.4 Invisible differences

We believe that the description of ‘aphantasia’ and ‘hyperphantasia’ has excited much scientific (e.g. Clemens, 2018; Keogh & Pearson, 2018), literary (Miller, 2017), philosophical (D'Aloisio-Montilla, 2017) and popular (Ross, 2016) interest over the short period since these terms were coined because they relate to a fundamental human cognitive act – ‘displaced reference’ (Bickerton, 2014), the representation of things and people in their absence. Our data speak to the remarkable, often unsuspected, variety of such imaginative experience. While Aristotle wrote that ‘the soul never thinks without a phantasma’ (Aristotle., 1968), the existence of aphantasia demonstrates that representation is indeed possible in the absence of conscious visual imagery. The delineation of these forms of extreme imagery also clarifies a vital distinction between imagery and *imagination*: people with aphantasia - who include the geneticist Craig Venter, the neurologist Oliver Sacks and the creator of Firefox, Blake Ross - can be richly imaginative, as visualisation is only one element of this more complex capacity to represent, reshape and reconceive things in their absence.

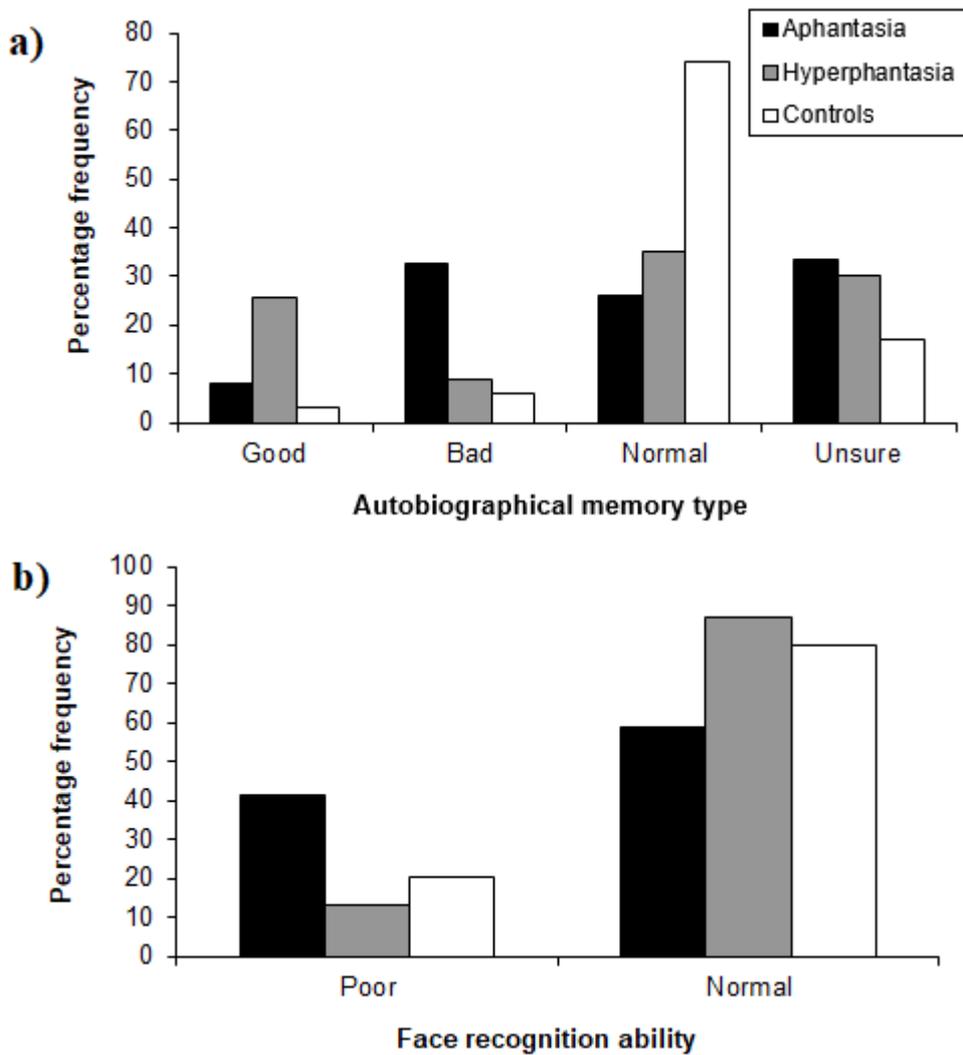


Figure 1: Percentage of participants with aphantasia, hyperphantasia and controls reporting a) good, bad or normal autobiographical memory or who were unsure; b) difficulty (poor) or no difficulty (normal) with face recognition.

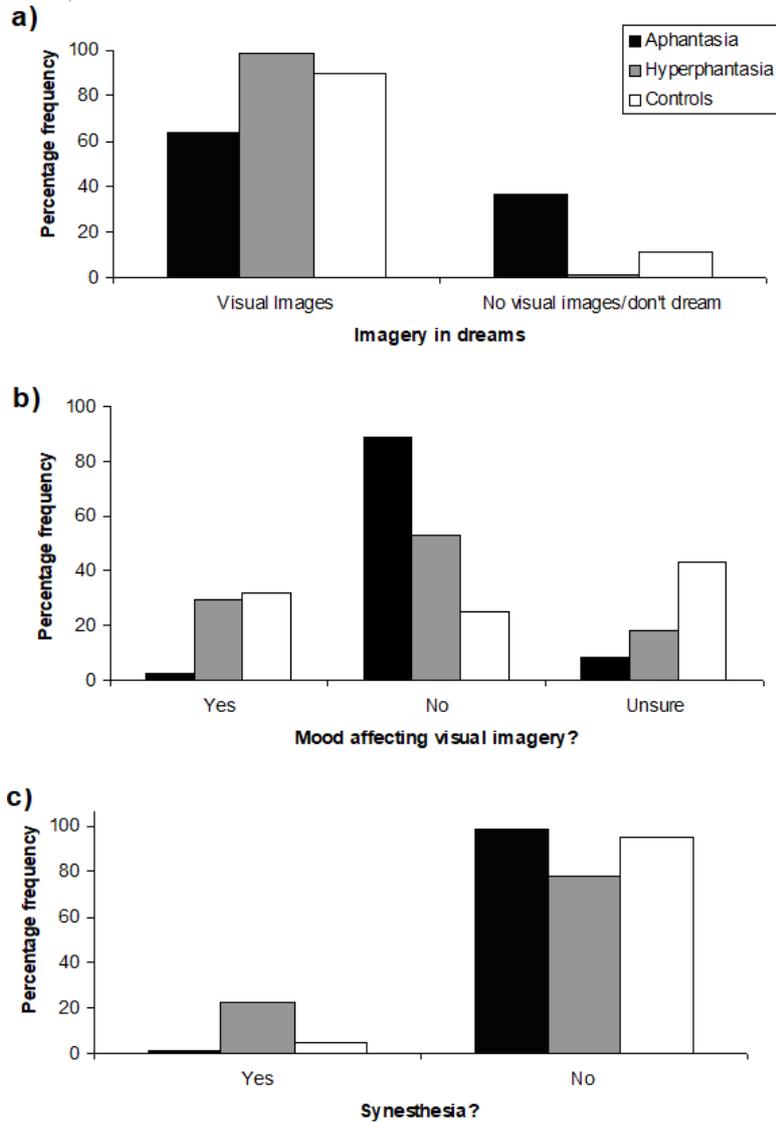


Figure 2: Percentage of participants with aphantasia, hyperphantasia and controls reporting a) visual images in dreams vs those reporting no visual imagery or absence of dreaming; b) that their mood affected the vividness of their visual imagery, or that they are unsure; c) the experience of synaesthesia.

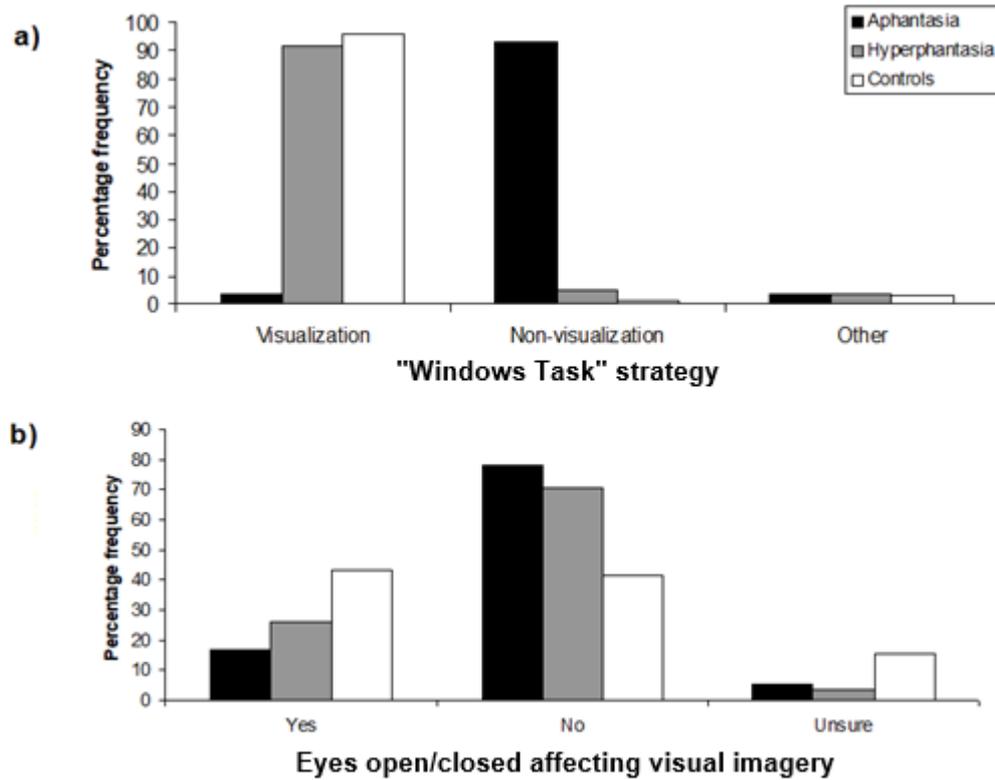


Figure 3: Percentage of participants with aphantasia, hyperphantasia and controls reporting a) the use of 'visualisation' vs 'non-visualisation' strategies to count mentally the number of windows in their house or apartment vs 'other' responses; b) that the vividness of visual imagery is affected by having their eyes open vs closed or that they are unsure.

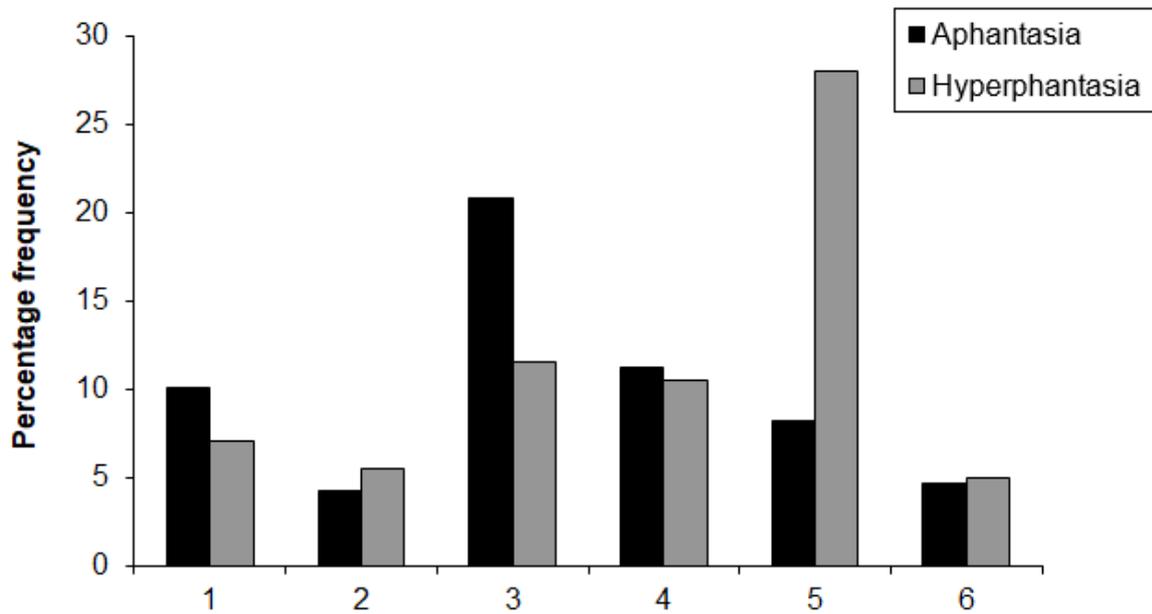


Figure 4: Percentage of participants with aphantasia and hyperphantasia reporting their occupation as being: 1 = Management, 2 = Business and financial; 3 = Computer and mathematical/Life, physical, social science; 4 = Education, training, and library; 5 = Arts, design, entertainment, sports and media; 6 = Healthcare, practitioners and technical. Only categories where the percentage frequency for either group exceeded 5% are included. A full breakdown of the distribution is displayed in Supplementary Table 1.

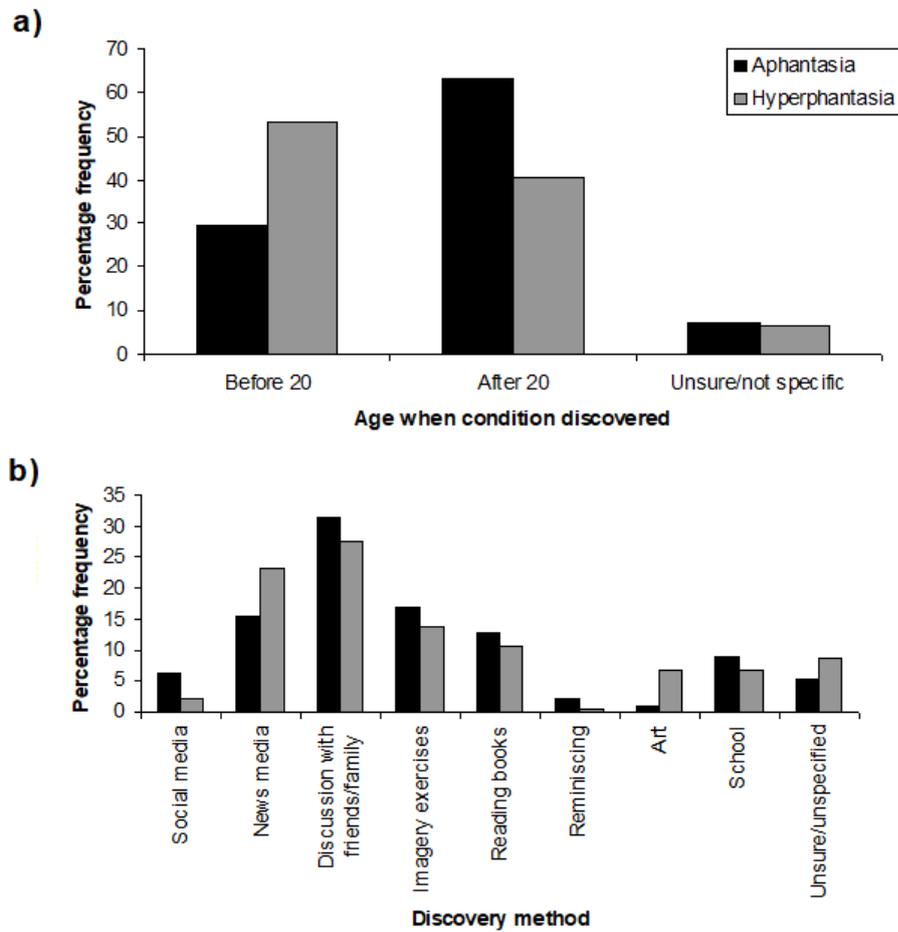


Figure 5: a) Percentage of participants with aphantasia and hyperphantasia who became aware of their extreme imagery vividness before and after the age of 20 vs those unsure; b) Mode of discovery of aphantasia and hyperphantasia.

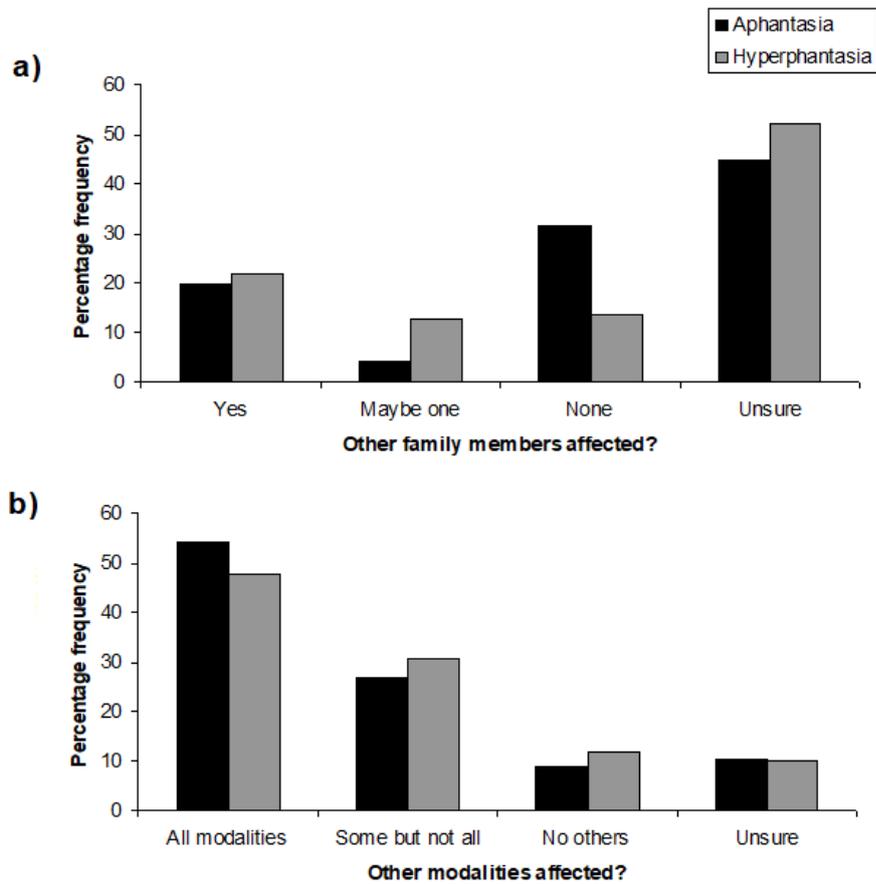


Figure 6: Percentage of participants with aphantasia and hyperphantasia reporting a) affected family members; b) that imagery in other sensory modalities was similarly affected ('all modalities' implies that all modalities are faint or absent in the case of aphantasia, extremely vivid in the case of hyperphantasia).

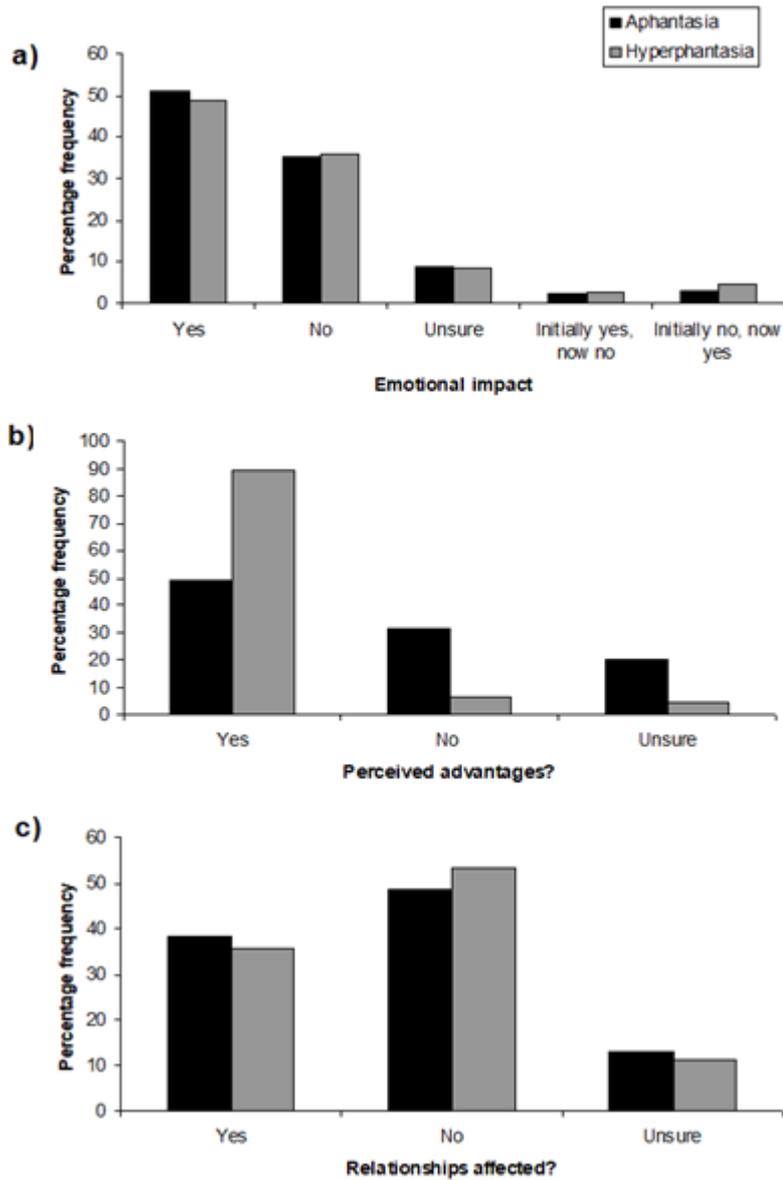


Figure 7: Percentage of participants with aphantasia and hyperphantasia reporting a) perceived advantages of their imagery status; b) an emotional impact from the discovery of their imagery status; c) that their relationships have been affected by their imagery status.

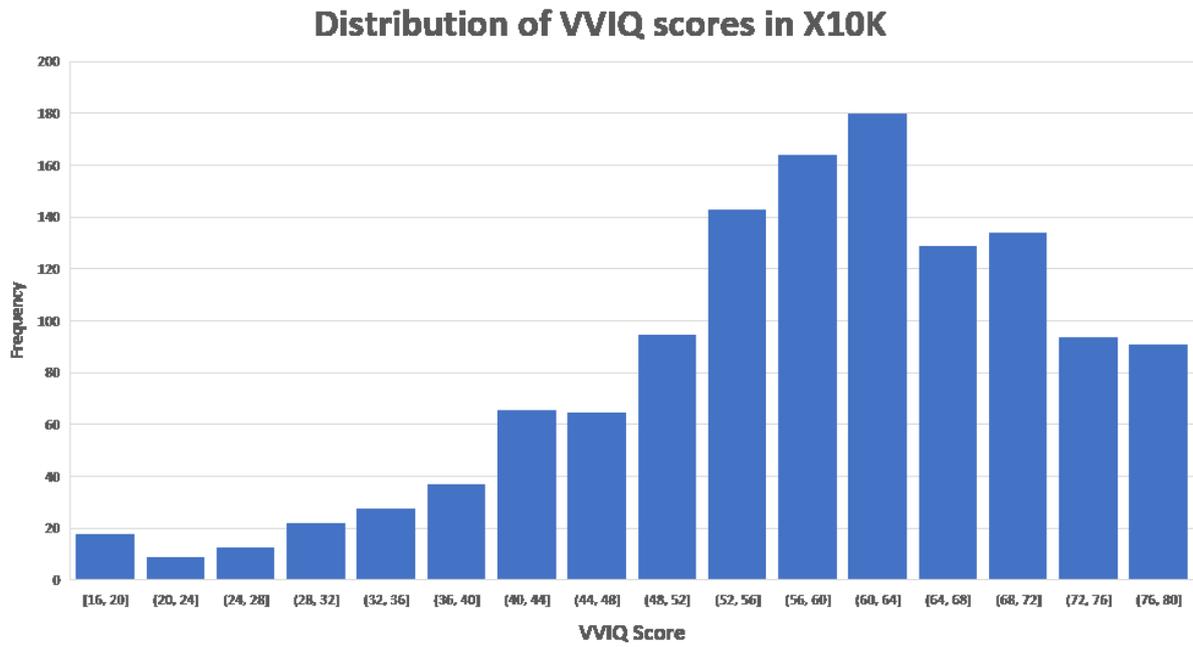


Figure 8: The distribution of VVIQ scores in the Extend (X10K) community sample (n=1288).

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Competing interests: Authors declare no competing interests.

THE PSYCHOLOGICAL SIGNIFICANCE OF LIFELONG VISUAL IMAGERY VIVIDNESS EXTREMES

SUPPLEMENTARY MATERIAL

Methods

Questionnaire: As indicated in the main text, the original aphantasia and hyperphantasia questionnaires (provided as appendices below) were sent to participants (n = 1460) via email as Word documents. The participants responded using free text. During the course of data gathering we converted the Word questionnaires into an on-line format (available at <https://wh.snapsurveys.com/s.asp?k=149725891417>). This version provides drop-down menus for responses where possible. One question, relating to 'difficulty in recognising faces or objects' was changed to 'difficulty in recognising faces' as neither aphantasic or hyperphantasic participants reported object recognition difficulty. Following spontaneous mention of synaesthesia by several participants with hyperphantasia, a question about synaesthesia was added. Control participants completed a modified version of the IQ which was administered on-line (provided as an appendix below).

Data coding: Questionnaire data were entered into an Excel spread sheet, and where possible coded numerically to allow statistical comparisons. In all cases the data were independently coded by two researchers. In rare cases of disagreement, a consensus was agreed with the help of a third researcher.

The data fields and coding categories were as follows:

- Visual imagery vividness (VVIQ) – score range 16-80
- Age - years
- Sex – male or female
- Education – initially scored in years of education (we excluded from analysis a small group of participants reporting <8 years of education in case these responses were erroneous); subsequently using the classifiers Secondary, College, Graduate, Masters, PhD
- Occupation – coded using the United States Employment Service dictionary of occupational titles (https://www.bls.gov/soc/2010/2010_major_groups.htm)
- Age of discovery – 'always known', by decade or 'recently discovered', 'unsure/not specified'
- Mode of discovery – discussion with friends & family, news + social media, school, art, reading, imagery exercises, reminiscing, school, unsure/not specified
- Emotional impact: presence – yes, no, unsure, initially yes - now no, initially no – now yes;
- Total vs brief flashes: total, brief flashes, unsure (*applicable to aphantasia only*)
- Effect of having eyes open vs closed: yes, no, unsure
- Whether lack/abundance of visual imagery affects imagery in any other senses: all, at least one other sense (but not all), none, unsure
- Dreaming: dreams with visual images, dreams without images, no dreams, unsure
- Autobiographical memory: normal, good, bad, unsure

- Face recognition: difficulty, no difficulty
- Synaesthesia: yes, no
- Influence of mood: yes, no, unsure
- Perceived advantages: yes, no, unsure
- Effect on relationships: presence – yes, no, unsure; impact - positive, negative
- Other affected family members: yes, maybe one, no, unsure; if yes, further information was requested about the degree of relationship
- ‘windows’ question: visualisation responses = visualise walking round inside of home, visualise walking round outside of home; non-visualisation responses = from memory, ‘walk, no image’, spatial knowledge, experience with windows (e.g. from cleaning them), knowledge of direction from which light falls; other

Results

Here we provide analyses of gender-specific data, where these are absent from the main text, and additional analyses comparing the extreme (VVIQ 16/80) and moderate (VVIQ 17-23/80) aphantasia and hyperphantasia (extreme 80/80, moderate 75-79) groups.

Autobiographical memory. When considering male participants alone, the significant difference across groups still emerged, $\chi^2(6, 1076) = 74.933, p < .001$. For the post-hoc comparisons, the hyperphantasia group were more likely to say they had a good memory than expected by chance. In contrast, the aphantasia group were more likely to complain of having a bad memory than either the hyperphantasia or control groups. The control group were significantly more likely to say that their memory was normal than the aphantasia group. For females, there was also a significant difference in the distribution across groups, $\chi^2(6, 1213) = 160.408, p < .001$. The same basic pattern as for the all-participant analysis emerged, with the aphantasia group reporting elevated levels of poor memory compared to both the hyperphantasia and control groups, while the hyperphantasia group reported significantly higher levels of good memory compared to the aphantasia group. Controls reported that their memory was normal significantly more than the aphantasia group. There was no significant difference in the distribution of memory ratings between the extreme aphantasia and moderate aphantasia groups or the extreme hyperphantasia and moderate hyperphantasia groups (both $P_s > .25$).

Face recognition. The same basic pattern emerged in male participants, $\chi^2(2, 997) = 15.389, p < .001$, with the aphantasia group reporting significantly elevated levels of complaints about their face recognition compared to the hyperphantasia group. The control group here, though, did not differ from the expected values. Female participants also demonstrated a difference between groups, $\chi^2(2, 1059) = 82.351, p < .001$, the aphantasia group reporting worse face recognition than both the hyperphantasia and control groups. There were no differences between either the extreme aphantasia and moderate aphantasia groups or the extreme hyperphantasia and moderate hyperphantasia groups (both $P_s > .7$).

Visual imagery in dreams. The same basic pattern emerged for male and female participants. The overall chi-square was highly significant in both cases ($P_s < .001$) and the post-hoc comparisons revealed in both the male and female groups that those with aphantasia were less likely to experience visual images in dreams than either the hyperphantasia or control groups. There was a significant

difference between the extreme aphantasia and moderate aphantasia groups, $\chi^2 (1, 1998) = 20.060$, $p < .001$, with the extreme aphantasia group significantly less likely to report having experienced visual images in dreams than the moderate aphantasia group. There were no differences between the extreme hyperphantasia and moderate hyperphantasia groups, $\chi^2 (1, 200) = .008$, $p = .930$.

Influence of mood. There was a significant difference between the extreme aphantasia and moderate aphantasia groups, $\chi^2 (2, 1998) = 14.967$, $p = .001$. Post-hoc comparisons revealed that the extreme aphantasia group reported that mood influenced their visual imagery less than the moderate aphantasia group. There was no difference between the extreme hyperphantasia group and the moderate hyperphantasia group, $\chi^2 (2, 199) = 1.765$, $p = .414$.

Synaesthesia. There was no difference in prevalence of synesthesia either between people with extreme aphantasia and moderate aphantasia or people with extreme hyperphantasia and moderate aphantasia (both $P_s > .1$).

The 'windows task'. There was a significant difference in distribution between the extreme aphantasia and moderate aphantasia groups, $\chi^2 (2, 1884) = 12.530$, $p = .002$, with participants in the extreme aphantasia group significantly less likely to use a visualization strategy and more likely to use a non-visualization strategy than people with moderate aphantasia. There were no differences between the extreme hyperphantasia and moderate hyperphantasia groups, $\chi^2 (2, 182) = 1.752$, $p = .417$.

Effect of eye opening. There was a significant difference between the extreme aphantasia group and the moderate aphantasia group, $\chi^2 (2, 1998) = 38.065$, $p < .001$. Post-hoc analyses revealed that the extreme aphantasia group reported that closing their eyes influenced their visual imagery less than the moderate aphantasia group. There was no significant difference between the extreme and moderate hyperphantasia groups, $\chi^2 (2, 200) = 4.698$, $p = .095$.

Occupation. For male participants, there was a trend for a difference between groups, $\chi^2 (21, 867) = 35.204$, $p = .027$, but this did not survive corrections for multiple comparisons. For females, there was a significant difference between groups, $\chi^2 (21, 801) = 60.355$, $p < .001$, with post-hoc analyses showing that, people with aphantasia were less likely to be in the "Arts, Design, Entertainment, Sports, and Media Occupations" category than hyperphantasia participants but there were no other significant differences. There were no differences between extreme aphantasia participants and moderate aphantasia participants ($p = .469$) and whilst there was a trend for a difference between extreme hyperphantasia participants and moderate hyperphantasia participants ($p = .023$), this did not survive corrections for multiple comparisons.

Age and mode of discovery. For age of discovery, there was a trend for a difference between extreme aphantasia and moderate aphantasia participants ($p = .023$) but this did not survive corrections for multiple comparisons. There was no difference between the extreme hyperphantasia and moderate hyperphantasia groups ($p = .283$). For mode of discovery, there were significant differences across groups when comparing males and females separately (both $P_s < .001$). However, whilst the post-hoc analyses revealed that for females, people with hyperphantasia were significantly more likely to have become aware of their condition through art than people with aphantasia, male hyperphantasics were significantly more likely to have become aware of their condition in school than male aphantasics. There were no significant differences between the extreme aphantasia and moderate aphantasia groups, $\chi^2 (8, 1928) = 6.891$, $p = .548$, but there were between the extreme hyperphantasia and moderate hyperphantasia groups, $\chi^2 (8, 195) = 23.881$, $p = .002$. Post-hoc comparisons indicated that there was greater recognition of the condition during school for people with extreme hyperphantasia than moderate hyperphantasia. No other differences approached significance.

Family history. There was also a significant difference between groups when considering just the male participants, $\chi^2 (3, 1029) = 31.575, p < .001$, with hyperphantasia participants more likely to say that “Maybe one” family member was affected than aphantasia participants. No other comparisons were statistically significant. There was also a significant effect for females, $\chi^2 (3, 1080) = 28.500, p < .001$, with post-hoc analyses revealing that people with aphantasia were more likely to say that “no family members” had the same condition than hyperphantasia participants. No other differences were significant. There was no difference in distribution of responses between the extreme aphantasia and moderate aphantasia groups, $\chi^2 (3, 1945) = 6.875, p = .076$. There was a trend for a difference between the extreme hyperphantasia and moderate aphantasia groups, $\chi^2 (3, 192) = 9.353, p = .025$, but this did not survive corrections for multiple comparisons.

Other modalities of imagery. There was a difference in distribution between the extreme aphantasia and moderate aphantasia groups, $\chi^2 (2, 1949) = 40.407, p < .001$. Post-hoc comparisons revealed that people with extreme aphantasia were more likely to say that all other modalities were affected than people with moderate aphantasia. In contrast, people with moderate aphantasia were more likely to indicate that some, but not all, modalities were affected than people with extreme aphantasia.

Emotional impact, perceived advantages, relationships. There was no difference in emotional impact when considering males and females separately ($P_s > .5$). There was also no difference between extreme aphantasia and moderate aphantasia ($p = .471$) or extreme hyperphantasia and moderate hyperphantasia ($p = .545$). With regard to perceived advantages, there was no difference between the extreme aphantasia and moderate aphantasia groups ($p = .179$) while there was a trend for a difference between the extreme hyperphantasia and moderate hyperphantasia groups ($p = .022$) which did not survive corrections for multiple comparisons. For the effect on relationships, there was no difference between extreme aphantasia and moderate aphantasia ($p = .471$) or extreme hyperphantasia and moderate hyperphantasia ($p = .545$).

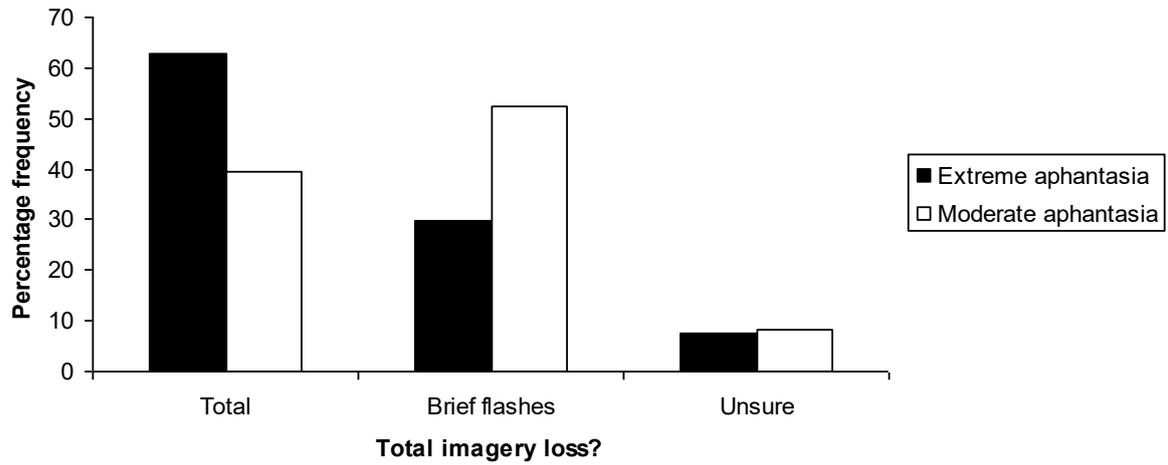
Total lack vs brief flashes (Figure S1). This variable applied only to people with aphantasia. The proportion of people in the extreme aphantasia and moderate aphantasia groups who reported their lack of visual imagery as being total vs having brief flashes of imagery is presented in Figure S1. A contingency chi-square revealed that there was a significant difference between the extreme and moderate aphantasia groups, $\chi^2 (2, 2000) = 96.671, p < .001$. Post-hoc analyses revealed that the extreme aphantasia group were more likely to report that their lack of visual imagery was total whilst more participants in the moderate group reported brief flashes.

Table**Table S1 Occupations in participants with aphantasia and hyperphantasia**

	Aphantasia (%)	Hyperphantasia (%)
Management	10.1	7.0
Business and financial	4.2	5.5
Computer and mathematical/ Life, physical and social science	20.8	11.5
Architecture and engineering	4.6	4.5
Community and social service	1.8	3.0
Legal	2.0	2.5
Education, training, and library	11.2	10.5
Arts, design, entertainment, sports and media	8.2	28
Healthcare, practitioners and technical	4.6	5
Healthcare support	0.5	0.5
Protective services	0.7	0
Food preparation and serving	0.7	1.5
Building and grounds cleaning and maintenance	0.2	0
Personal care and service	.85	0.5
Sales and related occupations	2.6	0.5
Office and admin support	3.1	3.5
Farming, fishing and forestry	0.2	0
Construction and extraction	0.8	1
Installation, maintenance, and repair	0.5	0.5
Production	0.5	0
Transportation and material moving	0.7	0.5
Military specific	0.6	0.5
Unemployed or no answer	21.0	13.5

Figure

Figure S1 Percentage of participants with extreme vs moderate aphantasia reporting the complete absence of visual imagery, occurrence of occasional 'flashes' or that they are unsure.



Appendices**1 VIVIDNESS OF VISUAL IMAGERY QUESTIONNAIRE (VVIQ)**

For each item on this questionnaire, try to form a visual image, and consider your experience carefully. For any image that you do experience, rate how vivid it is using the five-point scale described below. If you do not have a visual image, rate vividness as '1'. Only use '5' for images that are truly as lively and vivid as real seeing. Please note that there are no right or wrong answers to the questions, and that it is not necessarily desirable to experience imagery or, if you do, to have more vivid imagery.

Perfectly clear and vivid as real seeing	5
Clear and reasonably vivid	4
Moderately clear and lively	3
Vague and dim	2
No image at all, you only "know" that you are thinking of the object	1

For items 1-4, think of some relative or friend whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind's eye.

1. The exact contour of face, head, shoulders and body _____
2. Characteristic poses of head, attitudes of body etc. _____
3. The precise carriage, length of step etc., in walking _____
4. The different colours worn in some familiar clothes _____

Visualise a rising sun. Consider carefully the picture that comes before your mind's eye.

5. The sun rising above the horizon into a hazy sky _____
6. The sky clears and surrounds the sun with blueness _____
7. Clouds. A storm blows up with flashes of lightning _____
8. A rainbow appears _____

Think of the front of a shop which you often go to. Consider the picture that comes before your mind's eye.

9. The overall appearance of the shop from the opposite side of the road _____

10. A window display including colours, shapes and details
Of individual items for sale _____
11. You are near the entrance. The colour, shape and
details of the door. _____
12. You enter the shop and go to the counter. The counter
assistant serves you. Money changes hands _____

Finally think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.

13. The contours of the landscape _____
14. The colour and shape of the trees _____
15. the colour and shape of the lake _____
16. A strong wind blows on the trees and on the lake causing
waves in the water. _____

2 IMAGERY QUESTIONNAIRE (original version for participants with *aphantasia*)

Age

Gender

Handedness (hand used to write with)

Years of full-time education

Profession

Country of residence (+ county if in UK)

When did you become aware that you were unable to form mental images?

How did you become aware of this?

Did this discovery have an emotional impact on you?

Is your lack of visual imagery total, or do you sometimes experience brief flashes of imagery?

Is your ability to imagine affected by whether your eyes are open or closed?

Does your mood influence your ability to form images?

Are all types of imagery affected, or can you imagine sounds (including music), textures (by imagined touch), tastes or smells?

¹People with synaesthesia describe a 'mixing of the senses' – for example, letters, words or numbers may be involuntarily perceived in colour, or a sound might seem to have a smell.

Do you experience synaesthesia?

Do you dream normally, and in particular do you see visual images in dreams?

Is your ability to recall memorable events from the past, like holidays or celebrations, normal?

Do you have any difficulty in recognising objects or faces?

*Do you think that your lack of a 'mind's eye' has had any other effect on your thought processes?

*Did it affect your career choice?

Has it had an effect on your relationships (for example by making it more difficult to reminisce, or to imagine the faces of loved ones)?

Do you think that your lack of a mind's eye has had any particular advantages?

Do you have any relatives who have similarly noticed that they lack a mind's eye?

*Have you developed any strategies to compensate for the lack of a mind's eye?

Please count the number of windows in your house or apartment. How do you do this? Do you inspect an image of your house or apartment as you perform this task?

*Is there any particular aspect of this topic that you would like us to look into further?

Might you be willing to take part in further research on this topic?

Do you have any other comments?

Thank you very much for your help!

¹ *This question was included in only a subset of the questionnaires completed by aphantasic participants*

**We do not report the responses to these open-ended questions here*

3 IMAGERY QUESTIONNAIRE (original version for participants with *hyperphantasia*)

Age

Gender

Handedness (hand used to write with)

Years of full-time education

Profession

Country of residence (+ county if in UK)

When did you become aware that your visual imagery is exceptionally vivid?

How did you become aware of this?

Did this discovery have an emotional impact on you?

Is your ability to imagine affected by whether your eyes are open or closed?

Does your mood influence the vividness of your imagery?

Does your vivid imagination extend to the other senses, for example to vividly imagined sounds, textures, tastes and smells?

People with synaesthesia describe a 'mixing of the senses' – for example, letters, words or numbers may be involuntarily perceived in colour, or a sound might seem to have a smell. Do you experience synaesthesia?

Do you dream normally, and in particular do you see visual images in dreams?

Is your ability to recall memorable events from the past, like holidays or celebrations, normal?

Do you have any difficulty in recognising objects or faces?

*Do you think that your vivid imagery has had any other effect on your thought processes or emotions?

*Did it affect your career choice?

Has it had affected your relationships?

Do you think that your vivid imagery has had any particular advantages?

Do you have any relatives who also report especially vivid imagery?

Please count the number of windows in your house or apartment. How do you do this? Do you inspect an image of your house or apartment as you perform this task?

*Is there any particular aspect of this topic that you would like us to look into further?

Might you be willing to take part in further research on this topic?

Do you have any other comments?

Thank you very much for your help!

**We do not report the responses to these open-ended questions here*

4 CONTROL QUESTIONNAIRE

Age

Sex at birth

Dominant hand (hand used to write with)

Highest level of full-time education reached

Are you currently Employed, Unemployed, Retired or a Student?

Country of residence

Is your ability to visualise affected by whether your eyes are open or closed?

Does your mood influence your ability to form visual images?

Can you imagine sounds (including music), textures (by imagined touch), tastes or smells?

People with synaesthesia describe a 'mixing of the senses' – for example, letters, words or numbers may be involuntarily perceived in colour, or a sound might seem to have a smell. Do you experience synaesthesia?

Do you dream normally, and in particular, do you see visual images in dreams?

Is your ability to recall memorable events from the past, like holidays or celebrations, normal?

Do you have any difficulty in recognising faces?

Please count the number of windows in your house or apartment in your head (without physically looking at it). How do you do this? More specifically, do you inspect an image of your house or apartment as you perform this task?

Would you be willing to take part in further research on this topic?

Do you have any other comments?