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Cognitive Psychology

Ganzflicker Reveals the Complex Relationship Between Visual Mental Imagery and Pseudo-Hallucinatory Experiences: A Replication and Expansion

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Rhythmic visual flicker is known to elicit pseudo-hallucinations, making it an up-and-coming method to investigate anomalous perceptual experiences without pharmaceutical intervention. Ganzflicker is a full-screen visual flicker that can be experienced online. In the first exploratory Ganzflicker paper ($N = 204$), we investigated whether people with different self-reported visual mental imagery abilities report different visual experiences in the Ganzflicker. Results showed that people with no-to-low imagery (aphantasia distribution) were much less likely to experience complex and vivid pseudo-hallucinations compared to people with moderate-to-vivid imagery (imagery distribution). In this follow-up, I collected data from 6664 individuals from around the world, replicated the main results of the previous study, and additionally found that people from the imagery distribution report more frequent pseudo-hallucinations for a longer duration than people from the aphantasia distribution. I also conducted new analyses across individual imagery vividness ratings. This revealed a dramatic increase in susceptibility to pseudo-hallucinations from reports of “no imagery” to “low imagery vividness” within the aphantasia distribution. There is a positive linear relationship between imagery vividness and pseudo-hallucination vividness, whereas the relationship between imagery vividness and pseudo-hallucination complexity is categorical, as indicated by a jump in the likelihood to experience complex pseudo-hallucinations from the aphantasia distribution to the imagery distribution with no evidence for within-distribution variations. Finally, word cloud analyses of written descriptions of Ganzflicker experiences revealed unique language used by individuals from each distribution. In sum, Ganzflicker is an accessible, efficient, and effective method of investigating multiple aspects of anomalous perceptual experiences in people with different mental imagery abilities.

“Ganzflicker” is a full-field, rhythmic visual flicker – a technique that is known to elicit pseudo-hallucinations and altered states of consciousness (Allefeld et al., 2011; Bartossek et al., 2021; Schwartzman et al., 2019; Sumich et al., 2018). In a recently published study (Königsmark et al., 2021), we found individual differences in reported susceptibility to visual pseudo-hallucinations after viewing 10 minutes of continuous red-and-black Ganzflicker at 7.5 Hz. In a post-experience questionnaire of 204 responses, we found that the reported complexity and vividness of pseudo-hallucinations is related to visual mental imagery vividness. Specifically, people with no visual imagery (or at most dim or vague imagery, whom we considered part of an *aphantasia* distribution, according to previous studies; e.g., Dance et al., 2021; Milton et al., 2021) are much less likely to experience vivid and complex pseudo-hallucinations than people with moderate-to-vivid visual imagery (whom we considered part of an *imagery* distribution).

Congenital aphantasia (a lack of imagery that has been present since birth and is not the result of acquired neurological trauma) affects approximately 4% of the population (Dance et al., 2022). Aphantasia is not a neuropsychological disorder, as individuals can use compensatory strategies to overcome mental imagery challenges; for example, accuracy and capacity of “visual” working memory is similar in both aphantasia and imagery groups (Keogh et al., 2021),

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and performance between the two groups is indistinguishable on classic "mental imagery" tasks (Milton et al., 2021; Pounder et al., 2021). As a result, most people with aphantasia go their lives never knowing their internal representations of the world are different from anyone else's (Zeman et al., 2015). However, Ganzflicker appears to bring imagery out into the external environment, providing a striking example of the different subjective experiences people with aphantasia and imagery can have (Königsmark et al., 2021).

A unique opportunity arose to replicate and expand on these findings when the Ganzflicker experience was shared on various online news outlets, which led to thousands of new responses on the post-experience questionnaire. In this paper, I present a large-scale analysis of Ganzflicker questionnaire responses in a sample of 6664 volunteers, attracted to the study by an article published in *The Conversation* (Reeder, 2021). In this new analysis, environmental variables were found to play a role in pseudo-hallucination proneness; particularly, people were more likely to report visual experiences if they viewed the Ganzflicker on a computer instead of a mobile phone. This points to a role of immersion in anomalous perceptual experience. I also found that reported pseudo-hallucination proneness differs between people with a completely blind mind's eye (visual imagery vividness rating = 0) compared to people with any imagery, regardless of imagery vividness rating (ratings from 1-10 on a 0-10 scale). This suggests that there are sometimes important distinctions between having low imagery and no imagery. Replicating previous results, I found differences in the reported complexity and vividness of pseudo-hallucinations between people from the aphantasia distribution (imagery vividness ratings from 0-3) and people from the imagery distribution (imagery vividness ratings from 4-10). I additionally found that people belonging to the imagery distribution reported more frequent pseudo-hallucinations for a longer duration than people from the aphantasia distribution. Finally, I conducted a new word cloud analysis, presenting insights into the different language people with aphantasia and imagery use to describe their experiences. In sum, I replicated the core results of the previous paper, and present some new analyses, in a dataset that is orders of magnitude larger than the original.

Methods

All raw (N = 6664) and final (N = 1810) anonymized data, Python visualization scripts, and JASP analysis outputs (JASP Team & others, 2019) are freely available on the Open Science Framework (OSF) under the storage folder "MEGA_ganzflicker" at the following link: https://osf.io/6dvh9/.

Participants

Participants were 6664 individuals from around the world, attracted to the Ganzflicker questionnaire by a popular science article in *The Conversation* (Reeder, 2021). The article was republished by at least 14 different publishers, including *Science Alert*, *The Daily Beast*, *Metro (UK)*, *Aphantasia Network*, and *Big Think*, reaching an eclectic audience. All versions of the article contained a link to the study page on Google Forms.

The online study as it appears on the Google Form was approved by the ethics committee of the medical faculty of Otto-von-Guericke University (where the original study was conducted) on 03/09/2020, reference number 72/17. This study was conducted in accordance with the Declaration of Helsinki. All participants were given a short background on the Ganzflicker, instructions for the experience, and an epilepsy warning, prior to observing the Ganzflicker. If they wished to submit their responses on the post-experience questionnaire for research, they were additionally required to provide written informed consent by clicking a consent box following the statement: *By checking this box, I confirm that my participation is voluntary and that I am free to withdraw at any time without giving any reason. I understand that my data will be treated confidentially and any publication resulting from this work will report only data that do not identify me. I freely agree to participate in this study.* All 6664 participants reported in the current paper provided informed consent for this study.

Although participant country of residence was not collected in the questionnaire, the vast majority of readers of the *Conversation* article came from the USA (73%), followed by the UK (5.2%), Canada (4.1%), and Australia (3.3%). According to the post-experience questionnaire, 68.1% of participants reported their gender as male, 27.6% female, 2.4% other (the most common write-in answers were "transgender" and "nonbinary"), and 1.9% preferred not to say. 5707 participants reported their age (mean = 38.066, standard deviation (SD) = 15.079).

Environment

Although in the previous study there was no evidence to suggest that environmental variables affected experiences in the Ganzflicker, individuals were asked to indicate whether they had observed Ganzflicker on a computer/laptop, mobile/smart phone, or other; in a darkened room or other; while listening to the provided white noise, nothing, or other; and for less than 10 minutes, about 10 minutes, or more than 10 minutes.

In the current sample, all environmental variables contributed to the likelihood of experiencing pseudo-hallucinations, with the strongest evidence for an effect being whether the Ganzflicker was experienced on a computer/laptop or other device. Following this, people were more likely to report pseudo-hallucinations if they observed Ganzflicker for at least 10 minutes in a darkened room while listening to white noise (see Table 1 for details). Due to these effects, we removed all individuals from analysis who did not follow these instructions, or who did not report whether they followed the instructions or not. This reduced our final analyzed sample size to 1810.

In the final sample, 1597 individuals reported their age (mean = 39.746 years, SD = 23.993 years). 1810 reported their gender: 68.1% male, 27.6% female, 2.4% other, and 1.9% preferred not to say.

Stimuli

Stimuli were the same as in the previous study (Königsmark et al., 2021). To summarize, the Ganzflicker was a full-screen red-and-black visual flicker at 7.5 Hz (colors al-

Table 1. A summary of subjective reports about various environmental factors and total experiment time, split by whether participants ultimately reported seeing pseudo-hallucinations during the Ganzflicker (PH-Y) or not (PH-N).

Factor	*PH-Y (N = 4854) 72.8%*	*PH-N (N = 1810) 27.2%*	*Total (N = 6664) 100%*	*BF_{10}*
Environmental factors:				
Computer	3195 77.8%	910 22.2%	4105 100%	
Mobile	1345 63.4%	775 36.6%	2120 100%	
Other	254 72.4%	97 27.6%	351 100%	Contingency tables test: 2.051e+28, *N* = 6576
White Noise-Yes	3498 75.7%	1121 24.3%	4619 100%	
White Noise-No	1356 66.3%	689 33.7%	2045 100%	Contingency tables test: 9.486e+11, *N* = 6664
Darkness-Yes	3677 75.3%	1207 24.7%	4884 100%	
Darkness-No	1176 66.1%	603 33.9%	1779 100%	Contingency tables test: 1.725e+10, *N* = 6663
Total experiment time:				
<10min.	1693 70.2%	718 29.8%	2411 100%	
~10min.	2369 76.5%	727 23.5%	3096 100%	
>10min.	358 74.9%	120 25.1%	478 100%	Contingency tables test: 1823.189, *N* = 5985

ternating at 15 Hz), and the post-experience questionnaire was created with Google Forms. Screenshots of the questionnaire can be found in the supplementary material of the previous article. The questionnaire, including the link to the Ganzflicker (https://kerblooee.github.io/ganzflicker/) and white noise audio file (https://kerblooee.github.io/ganzflicker/01-White-Noise-10min.mp3), can also be found at the following link: https://forms.gle/tdKRKhva3uqC68tS9.

Procedure

The procedure was the same as in the previous study. To summarize, participants first read a short background on flicker-induced pseudo-hallucinations, then were instructed to view the Ganzflicker for around 10 minutes on a computer (rather than mobile phone), with the lights in the room turned off, and while listening to the provided white noise. Participants were warned not to click the Ganzflicker link if they had photosensitive epilepsy. They were provided two links: one that played 10 minutes of white noise, and one that would take them to the Ganzflicker experience.

Following the Ganzflicker experience and prior to filling out the questionnaire, participants were asked to provide consent to the use of their anonymized data in research dissemination and publication. They could not proceed to the questionnaire without providing this consent. The questionnaire took approximately 10 minutes to fill out. Participants were aware that they would receive no compensation for taking part and provided their data purely in the interest of contributing to scientific progress.

The questionnaire first asked participants to optionally provide their age and gender. They were then asked to rate their visual and auditory imagery vividness on a scale from 0 (no mind's eye) to 10 (as vivid as real perception). Questions followed concerning how long they viewed the Ganzflicker, whether they listened to white noise, had the lights in the room turned off, and viewed the Ganzflicker on a computer or mobile phone. They were then asked to indicate how they found the Ganzflicker emotionally (this was not analyzed for the current study).

Next, participants were asked to indicate if they saw anything in the Ganzflicker, and to put a check next to "Colors other than red and black", "Simple shapes or patterns (e.g., ball of light, lines, grids, spiderwebs, geometric shapes)", "Complex objects (e.g., animals, faces, buildings)", "Complex environments (e.g., cityscapes, forests)", or "Other". Participants then had the option to describe in a text box as much as they could remember about what they saw in the Ganzflicker. Next, participants indicated how long it took for images to begin to emerge ("They began to emerge immediately", "A few seconds", "1-2 minutes", "5-7 minutes", or "Other"), how frequently they experienced images ("1-2 times in the whole experience", "Infrequently", "Frequently," "Constantly", or "Other"), the vividness of the images ("Weak, faint, or insubstantial", "Clear, but not vivid", "Clear and moderately vivid", "Clear, vivid, and/or bright", "Very vivid, almost real, or popping out of the screen", or "Other"), and how long a single image lasted ("Brief moment or flash", "1-2 seconds", "Persisting several seconds", "Constant, morphing from one image to the next", or "Other"). "Other" responses were not analyzed in the current study, to keep our rating scale consistent with the previous study.

Participants were then asked the same questions about their auditory experiences. They were finally asked about any altered states of consciousness they experienced, including "Lost a sense of time", "Lost a sense of space", and "As if in a dreamlike state". Auditory experiences and altered states of consciousness were not analyzed in the current study, but the data are available on the OSF page.

Coding subjective responses

Responses on the post-Ganzflicker questionnaire concerning different features of pseudo-hallucinations were coded using the same method as described in the previous study (Königsmark et al., 2021). In summary, participants could select multiple responses for all questions, and we took the maximum value the participant selected (e.g., if a participant reported seeing both simple shapes *and* complex objects, we coded the participant as having seen complex objects). Complexity was coded from simple-to-complex on a 1-6 scale (i.e., 1 = "Colors other than red and black" and 6 = "Both complex objects and environments"), so a participant was given a complexity code of 6 if they checked the boxes next to "Complex objects" and "Complex environments", regardless of other boxes they checked. Emergence time was coded from late-to-immediate (so earlier emergence times were coded with higher values), frequency was coded from 1-2 times-to-constant (more frequent experiences were coded higher), vividness was coded from weak-to-almost real (more vivid experiences were coded higher), and duration was coded from brief-to-constantly morphing (longer durations were coded higher).

Analyses and results

To analyze the effects of different environment variables on Ganzflicker experiences, I conducted Bayesian contingency tables tests in the JASP statistical toolbox (JASP Team & others, 2019), with the prior concentration set to 1 (default), with 1000 seeds for repeatability. This revealed extremely strong evidence for an effect of all environmental variables and total experiment time on pseudo-hallucination proneness. Specifically, people were more likely to report pseudo-hallucinations, generally, if they performed the experiment on a computer (instead of a mobile phone or other device), while listening to white noise, with the lights in the room turned off, for a total viewing time of 10 minutes or more.

Group splits

Individuals were split into either an aphantasia distribution (visual imagery vividness ratings from 0-3, shown in blue in Figure 1) or an imagery distribution (visual imagery vividness ratings from 4-10, shown in orange), as done in the previous study. This is also consistent with previous research that includes "weak" or "faint" imagery vividness in the aphantasia distribution (Dance et al., 2021; Milton et al., 2021). Figure 1 shows that the distribution is bimodal, consistent with the previous study: the aphantasia distribution seems to form one half of a normal distribution, while the imagery distribution follows roughly a full normal distribution. This suggests that despite widespread readership of the popular science article, the study attracted a disproportionate number of people with aphantasia compared to general population prevalence.

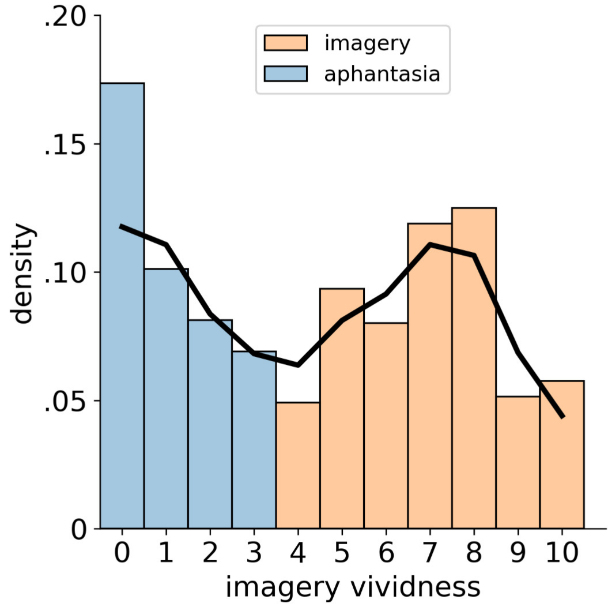

Figure 1. The distribution of imagery vividness ratings across the final sample (*N* = 1810), with vividness ratings from 0-10 on the x axis, and density of each rating plotted on the y-axis.

The density of each rating was calculated using an in-built function of the seaborn data visualization package in Python (Waskom, 2021). The aphantasia distribution (vividness ratings from 0-3) is shown in blue and the imagery distribution (vividness ratings from 4-10) is shown in orange. The kernel density estimation (KDE) line, estimating the probability density function for each vividness rating, is shown in black.

Pseudo-hallucination susceptibility

Figure 2 shows the proportion of individuals for each visual imagery vividness rating who reported having *not* seen pseudo-hallucinations at any time during Ganzflicker viewing. I display the proportion rather than counts for each rating, to better show differences in susceptibility. Counts and proportions of those who did and did not report having seen pseudo-hallucinations, split by each vividness rating, are reported in Table 2. Figure 2 shows a distinction between people who reported an imagery vividness rating of 0 (48.1% saw nothing other than the red-and-black flicker) compared to every other rating (8.3-25.0% saw nothing other than the red-and-black flicker). Interestingly, the 25.0% of individuals who did not report having seen pseudo-hallucinations came from the group with a vividness rating of 10 (imagery as vivid as real perception). Visualizing the figure, it is clear that the likelihood of seeing pseudo-hallucinations does not increase linearly from an imagery vividness rating of 0, but rather shows a large in-

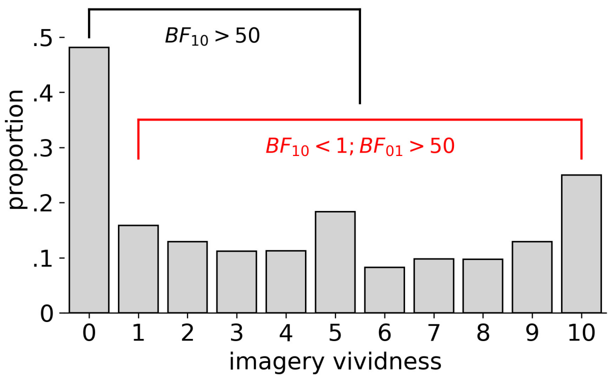

Figure 2. The distribution of reports of having seen *no* pseudo-hallucinations at any point during Ganzflicker viewing.

Imagery vividness ratings from 0-10 are on the x-axis and the proportion of individuals for each vividness rating who reported having seen no pseudo-hallucinations is on the y-axis. Bayes Factors (BF) summarize the results of contingency tables tests performed in JASP (JASP Team & others, 2019) on the difference in pseudo-hallucination proneness for each vividness rating: I found extremely strong evidence for a difference in susceptibility between complete aphantasia (vividness rating = 0) and every other vividness rating from 1-10 ($BF_{10} > 50$), whereas removing complete aphantasia from analysis revealed no compelling differences between any vividness ratings from 1-10 ($BF_{10} < 1$). BF_{01} denotes evidence in favor of the null hypothesis, and there was very strong evidence for a lack of a difference across vividness ratings from 1-10.

Imagery vividness rating	*PH-Y (N = 1463) 80.8%*	*PH-N (N = 347) 19.2%*	*Total (N = 1810) 100%*
0	163 51.90%	151 48.10%	314 100%
1	154 84.20%	29 15.80%	183 100%
2	128 87.10%	19 12.90%	147 100%
3	111 88.80%	14 11.20%	125 100%
4	79 88.80%	10 11.20%	89 100%
5	138 81.70%	31 18.30%	169 100%
6	133 91.70%	12 8.30%	145 100%
7	194 90.20%	21 9.80%	215 100%
8	204 90.30%	22 9.70%	226 100%
9	81 87.10%	12 12.90%	93 100%
10	78 75.00%	26 25.00%	104 100%

Table 2. A breakdown of the counts and proportions (%) of individuals from each imagery vividness rating who reported having seen (PH-Y) or not seen (PH-N) pseudo-hallucinations at some point during Ganzflicker viewing. Color coding is on a tri-color scale, from green (0%) to yellow (50%) to red (100%).

crease from 0 to 1, and remains relatively stable across ratings from 1-10.

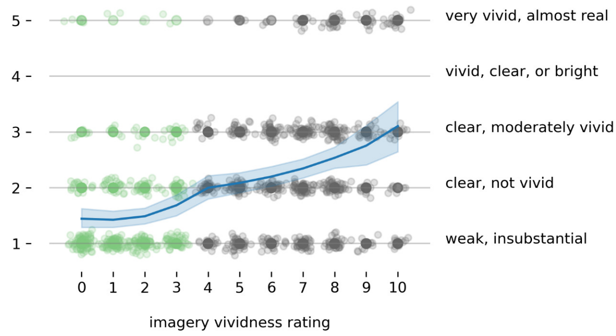

Figure 3. A scatterplot overlaid with a line plot (blue line, with 95% confidence intervals shown in blue shading) detailing the subjectively reported vividness (*N* = 1202) of pseudo-hallucinations seen during Ganzflicker viewing for each imagery vividness rating.

Imagery vividness rating is shown on the x-axis, and pseudo-hallucination vividness ratings are shown on the y-axis. Data points belonging to the aphantasia distribution are shown in green, and those belonging to the imagery distribution are shown in gray (individual data points are randomly jittered in the x and y dimensions for visibility). Reports ranged from "weak, insubstantial" to "very vivid, almost real", with the highest rating shown at the top of the plot.

Two Bayesian contingency tables tests confirmed this: with all imagery vividness ratings included, the first test revealed extremely strong evidence for a difference in pseudo-hallucination proneness between ratings ($BF_{10\ Independent\ multinomial} = 4.145e+31,\ N = 1810$). With imagery vividness ratings of 0 removed, the second test revealed no evidence for a difference in pseudo-hallucination proneness between ratings ($BF_{10\ Independent\ multinomial} = 2.271e-5,\ N = 1496$), rather showing extremely strong evidence for no difference across ratings from 1-10 ($BF_{01\ Independent\ multinomial} = 44024.313,\ N = 1496$). Additional Bayesian contingency tables tests performed for each pair of vividness ratings confirmed no differences between any ratings from 1-10 (all $BF_{10} < 1$), and extremely strong evidence for differences between 0 and every other rating (all $BF_{10} > 700$).

Vividness of pseudo-hallucinations

Due to the large number of individual responses for each vividness rating, I present the results of pseudo-hallucination vividness as a scatterplot overlaid with a trend line and confidence intervals, created using the seaborn data visualization package in Python (see Figure 3). "Vivid, clear, or bright" was a rare choice among participants, perhaps because it was hard to discriminate from "Very vivid, almost real"; none of the participants in the final dataset reported the former as their maximum rating. Visualizing the data, there seems to be a linear relationship between pseudo-hallucination vividness and imagery vividness. To test this, I performed a Bayesian Pearson correlation between pseudo-hallucination vividness ratings and imagery vividness ratings from 0-10, and found extremely strong evidence for a relationship ($r = 0.400, BF_{10} = 7.938e+43$. A Bayesian Mann-Whitney U test (shown in Table 3) revealed extremely strong evidence for a difference between the aphantasia

Table 3. A summary of the Bayesian Mann-Whitney *U* tests (Cauchy scale prior = 0.707, 1000 samples) performed in JASP, testing for a difference between the aphantasia distribution (vividness ratings 0-3) and imagery distribution (vividness ratings 4-10) for each feature of pseudo-hallucinations measured.

Pseudo-hallucination feature	BF_{10}	*W*	R^2
vividness	9.290e+8	248123.500	1.139
complexity	2.203e+6	319255.000	1.112
duration	344.863	216403.500	1.074
frequency	311.007	264674.500	1.242
emergence time	0.110	229993.000	1.062

and imagery distributions in terms of pseudo-hallucination vividness, replicating previous results.

Complexity of pseudo-hallucinations

For pseudo-hallucination complexity, the data are now visualized as a bar graph rather than a scatterplot (Figure 4). This was changed from the previous study to better show the qualitative difference between simple (geometric patterns, illusory colors) and complex pseudo-hallucinations (real-world objects and environments like faces and forests). To binarize the data for analysis, any complexity rating of 3 or below (geometric patterns, illusory colors, or both) was considered a simple experience, and any complexity rating of 4 or above (complex objects, environments, or both) was considered a complex experience. Looking at Figure 4, pseudo-hallucination complexity does not appear to increase linearly across aphantasia and imagery distributions. The proportion of individuals who experience complex pseudo-hallucinations seems to ramp up linearly across the aphantasia distribution, after which there appears to be a jump in complex reports between ratings of 3 and 4. There does not seem to be much variation in complex reports for vividness ratings between 4-10.

Looking at the breakdown of complexity reports for each imagery vividness rating in Table 4, the proportion of individuals who see complex pseudo-hallucinations is highest for imagery vividness ratings of 6 and 8, rather than ratings of 9 and 10. This further supports the hypothesis that the probability of reporting complex pseudo-hallucinations is not linearly related to imagery vividness. The percentage of individuals who reported complex pseudo-hallucinations was under 15% for all ratings below 4, but this percentage more than doubled for vividness ratings of 4 (>33% saw complex pseudo-hallucinations). The percentage dipped below 25% for vividness ratings of 5, but then stayed consistently above 30% for vividness ratings between 6 and 10, peaking at 39.5% for vividness ratings of 8.

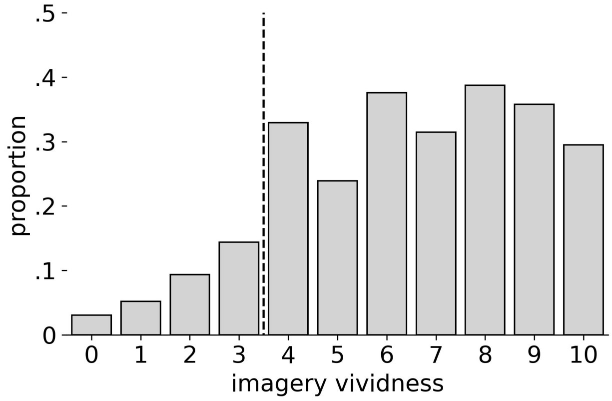

Figure 4. The distribution of reports of having seen complex pseudo-hallucinations (complexity ratings >=4) at some point during Ganzflicker viewing.

Imagery vividness ratings from 0-10 are on the x-axis and the proportion of individuals for each vividness rating who reported having seen complex pseudo-hallucinations is on the y-axis. A dotted line appears between imagery vividness ratings of 3 and 4, indicating the split between the aphantasia distribution and imagery distribution.

Imagery vividness rating	*Complex (N = 342) 24.0%*	*Simple (N = 1085) 76.0%*	*Total (N = 1427) 100%*
0	5 3.20%	152 96.80%	157 100%
1	8 5.60%	136 94.40%	144 100%
2	12 9.80%	111 90.20%	123 100%
3	16 14.50%	94 85.50%	110 100%
4	26 33.30%	52 66.60%	78 100%
5	33 24.10%	104 75.90%	137 100%
6	50 38.20%	81 61.80%	131 100%
7	61 31.60%	132 68.40%	193 100%
8	79 39.50%	121 60.50%	200 100%
9	29 35.80%	52 64.20%	81 100%
10	23 31.50%	50 68.50%	73 100%

Table 4. A breakdown of the counts and proportions (%) of individuals from each imagery vividness rating who reported having seen at most simple (complexity ratings <=3) or complex (complexity ratings >=4) pseudo-hallucinations at some point during Ganzflicker viewing. Color coding is on a tri-color scale, from green (0%) to yellow (50%) to red (100%).

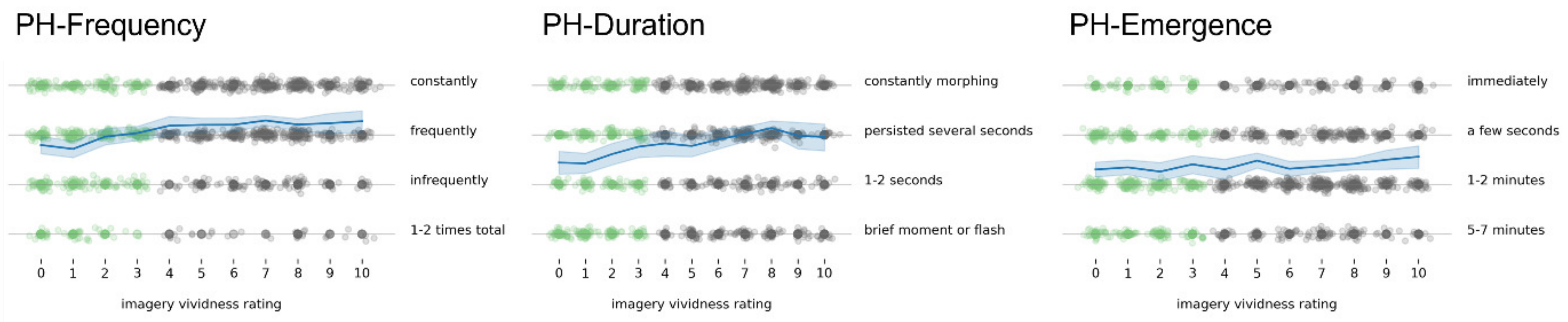

Figure 5. Scatterplots overlaid with line plots (blue line, with 95% confidence intervals shown in blue shading) detailing the subjectively reported frequency (PH-Frequency; left panel; *N* = 1371), duration (PH-Duration; middle panel; *N* = 1259) and emergence time (PH-Emergence; right panel; *N* = 1375) of pseudo-hallucinations seen during Ganzflicker viewing for each imagery vividness rating.

Imagery vividness rating is shown on the x-axis, and subjective experiences are shown on the y-axis. Data points belonging to the aphantasia distribution are shown in green, and those belonging to the imagery distribution are shown in gray (individual data points are randomly jittered in the x and y dimensions for visibility). For PH-Frequency, reports ranged from seeing pseudo-hallucinations “1-2 times in the whole experiment” to “constantly”, with the highest frequency rating shown at the top of the plot. For PH-Duration, reports ranged from pseudo-hallucinations lasting for a “brief moment or flash” to “constantly morphing from one image to another”, with the longest duration of pseudo-hallucinatory events at the top of the plot. For PH-Emergence, reports ranged from the first pseudo-hallucination taking “5-7 minutes” to “immediately” to emerge, with the shortest emergence time shown at the top of the plot.

Table 5. Lists of the most frequently used words to describe visual Ganzflicker experiences among the aphantasia and imagery distributions. The first two columns are the top 20 words for each group, the next two columns are the unique nouns of the top 200, and the final two columns are the unique descriptive words of the top 200 most frequently used words for each group.

Aphantasia top 20		*Imagery top 20*		*Aphantasia unique nouns in top 200*		*Imagery unique nouns in top 200*		*Aphantasia unique desc. in top 200*		*Imagery unique desc. in top 200*	
Word	*Count*	*Word*	*Count*	*Word*	*Count*	*Word*	*Count*	*Word*	*Count*	*Word*	*Count*
screen	439	screen	881	spiderweb/web	39	tree	124	vague	41	complex	99
line	326	shape	695	flash	33	building	94	occasionally	36	many	89
shape	303	pattern	614	rectangle	26	forest	85	blinking/blinked	34	shifting	52
pattern	283	line	572	frame	21	people	81	fuzzy	25	size	50
color	211	image	517	bar	21	scene	74	slightly	23	constant	47
red	208	color	442	monitor	20	figure	72	greenish	22	weird	47
black	180	moving	403	lightning	19	head	72	bottom	22	falling	45
time	196	eye	360	shade	17	room	66	faded	22	rapidly	45
eye	168	time	399	ball light	17	sky	65	short	21	shaped	41
light	156	light	315	texture	16	landscape	58	whole	21		
image	149	face	300			swirl	57	alternating	20		
blue	148	circle	283			animal	53	blurry	20		
circle	147	red	279			window	52	rotated	19		
moving	148	black	273			hand	52	darker	19		
green	123	tunnel	239			train	48	less	19		
center	117	blue	242			flower	48	thin	18		
point	105	felt	226			silhouette	47	diagnoal	18		
white	105	white	222			person	45	clockwise	18		
flashing	105	center	217			river	45	flickering	18		
yellow	93	spinning	206			man	44				
						wall	44				
						galaxies	43				
						road	42				
						mountain	42				
						field	42				
						diamond	41				
						bird	41				

Figure 6. Word clouds that represent the unique words used by the aphantasia and imagery distributions to described visual Ganzflicker experiences among the top 200 most frequently used words for each group.

To increase the power of this analysis, all individuals who saw pseudo-hallucinations, regardless of environmental factors or total experiment time, were included in this analysis (*N* = 4003).

To replicate the test performed in the previous study, a Bayesian Mann-Whitney *U* test (shown in Table 3) revealed extremely strong evidence for a difference between the aphantasia and imagery distributions in terms of pseudo-hallucination complexity ratings. All additional analyses were performed on binarized data (simple versus complex). I performed a 2 (aphantasia distribution, imagery distribution) x 2 (simple, complex) Bayesian contingency tables test on pseudo-hallucination complexity reports for each distribution. This revealed extremely strong evidence for a difference in pseudo-hallucination complexity reports between groups ($BF_{10\ Independent\ multinomial} = 2.191e+30$, $N = 1463$), further supporting the hypothesis that the imagery distribution is more likely to experience complex pseudo-hallucinations compared to the aphantasia distribution.

I then performed two Bayesian contingency tables tests to test for variations within each distribution. There was no evidence for a difference between vividness ratings from 0-3 in complexity reports ($BF_{10\ Independent\ multinomial} = 0.310$, $N = 556$), nor was there evidence for a difference between vividness ratings from 4-10 ($BF_{10\ Independent\ multinomial} = 7.556e-4$, $N = 907$). There was, however, strong evidence of a jump in complex reports from vividness ratings of 3 to 4 ($BF_{10 Independentmultinomial} = 13.574$, $N = 190$). These tests support the hypothesis that reports of complex pseudo-hallucinations increase non-linearly from the aphantasia distribution to the imagery distribution.

Frequency, duration, and emergence time of pseudo-hallucinations

In the previous study, we found evidence for a difference between people belonging to the imagery and aphantasia distributions in terms of pseudo-hallucination complexity and vividness, with no indication that the other measured features differed between the two groups. In the current analysis, I also found extremely strong evidence for a difference between groups in terms of pseudo-hallucination frequency and duration, but still not emergence time (most reports falling between “1-2 minutes” and “a few seconds”; see Figure 5 and Table 3).

For pseudo-hallucination frequency, most people from the aphantasia distribution are likely on the boundary between seeing infrequent and frequent pseudo-hallucinations, with most responses climbing to “frequent” by a vividness rating of 3. The 95% confidence interval lies between “frequent” and “constant” pseudo-hallucinations for vividness ratings between 4 and 10, and responses remain relatively stable from vividness ratings of 4 onward.

For pseudo-hallucination duration, individuals from the lower end of the aphantasia distribution (ratings of 0-1) were likely to report pseudo-hallucinations lasting “1-2 seconds” at most. Participants were more likely to report durations between “1-2 seconds” and “persisting several seconds” at vividness ratings of 2, and pseudo-hallucinations were likely to persist for several seconds for vividness ratings between 3 and 10.

Descriptions of visual experiences

In the post-experience questionnaire, participants were provided a text box to describe as much as they could remember about what they saw in the Ganzflicker. Due to the high number of responses in this section (*N* = 4003), I explored word frequencies for the aphantasia and imagery distributions from these descriptions. First, each description was stripped of syncategorematic words such as *of*, *the*, and *with*, leaving concrete nouns (e.g., *rectangle*, *tree*) and other words describing the experience (e.g., *weird*, *blue, flickering*). Then, I input word lists into the WordCloud class of Python (https://amueller.github.io/word_cloud/) separately for descriptions belonging to the aphantasia and imagery distributions. I then generated word clouds, as well as a ranked list of the top 200 most frequently used words (using the WordCloud.words.keys() function), along with count data (using the WordCloud.process_text(text) function). I then made lists of the top 20 most frequently used words for each group, along with lists of words within the top 200 that were unique to each group (see Table 5). Finally, I input unique words for each group into word clouds for visualization purposes (see Figure 6).

The word clouds reveal the stark difference in the frequency of simple and complex visual experiences for individuals from the aphantasia and imagery distributions. Specifically, people from the aphantasia distribution uniquely reported seeing simple patterns and shapes like rectangles, spiderwebs, and bars, whereas people from the imagery distribution uniquely reported seeing real-world objects like trees, buildings, animals, and people. Those with aphantasia also frequently described their visual experiences as vague, fuzzy, or faded, whereas people with imagery commonly described pseudo-hallucinations as complex, many, rapid, and constant. The word clouds and frequency lists therefore provide a measure of the consistency of reports, in line with coded responses described in previous paragraphs.

Discussion

This paper provides an updated analysis of pseudo-hallucinatory experiences during ~10 minutes of Ganzflicker stimulation. In a sample of 1810 participants, I replicated and expanded the results of the previous study (N = 204). To better illustrate the increase in analysis power, the entire imagery distribution (imagery vividness ratings from 4-10) was composed of 63 individuals in the previous study; in the current study, the lowest number of individuals for a single vividness rating was 89 (for ratings of 4). This additional power allowed for analyses to be performed between individual vividness ratings.

The biggest difference between individual vividness ratings can be seen in the visualization of the data for pseudo-hallucination proneness. Specifically, people with complete aphantasia (vividness rating of 0) are much less likely to experience pseudo-hallucinations while viewing the Ganzflicker compared to every other vividness rating from 1-10. This indicates that there may be an important distinction between people with complete aphantasia and those with "dim or vague" imagery. In many ways, aphantasia can be seen as a distribution, with no clear boundary between no and low imagery (including several results presented in the current paper) – but the stark drop in pseudo-hallucination proneness for only the lowest rating suggests it would be good practice for future studies to report aphantasia results with and without low imagery individuals included.

Another interesting difference between individual vividness ratings was the non-linear reporting of pseudo-hallucination complexity. There is a big jump in the proportion of complex reports at imagery vividness ratings of 4, which then remain relatively stable across vividness ratings between 4 and 10, although there is a peak around ratings of 6-8. This follows a similar pattern to pseudo-hallucination proneness (only the groups with imagery vividness ratings between 6 and 8 showed over 90% pseudo-hallucination proneness), perhaps suggesting a connection between the likelihood to experience pseudo-hallucinations and pseudo-hallucination complexity. What this connection reflects (e.g., a shared neural mechanism) will need to be followed up in a future study – however, one possible explanation is that people with extremely vivid imagery (vividness ratings of 9 and 10) may process and interpret visual information differently than those with more moderate imagery vividness (4-8), which could affect both pseudo-hallucination proneness and complexity non-linearly.

The final new technique applied in the current paper was a word cloud visualization of the most frequent words used by the aphantasia and imagery distributions to describe visual experiences in the Ganzflicker. This measure provided examples of common words used uniquely by each group, which exemplified less vivid and less complex experiences for those belonging to the aphantasia distribution. Written descriptions of Ganzflicker experiences provide a rich addition to the quantified dataset, and it would be interesting to explore other dimensions of this text, such as using machine learning techniques like word2vec (Mikolov et al., 2013) to investigate semantic similarity among words used by people with different imagery abilities.

On top of these new findings, I replicated the main results from the previous study: people from the imagery distribution are much more likely to report having seen complex and vivid pseudo-hallucinations compared to people from the aphantasia distribution. I additionally found extremely strong evidence that people from the imagery distribution report more frequent pseudo-hallucinations for a longer duration. Finally, the emergence of the first pseudo-hallucinations mainly occurred within 1-2 minutes for all participants, regardless of imagery vividness, perhaps reflecting a common influence of visual flicker on the brain.

It is important to note that although the rapid self-report format of the experiment allowed for a large, crowdsourced dataset, this method does not come without limitations. For one, I did not have a control condition to directly address the issue of false reports; for example, it is possible that participants with vivid imagery are more likely to mistake a vividly imagined object for a percept compared to individuals with no/low imagery. This could be addressed by asking participants what they see in a condition that is not conducive to pseudo-hallucinations, although such a condition may not be so trivial to identify. In a previous study on seeing faces in visual noise (a phenomenon called pareidolia; Salge et al., 2020), my colleagues and I found a correlation between pareidolia proneness and imagery vividness even when controlling for acquiescence response bias; however, when the environment became less visually ambiguous (we changed high-contrast Gaussian noise to near-uniform white noise or "visual snow"), the correlation was abolished. This suggests that visual stimulation of different kinds can elicit illusory percepts, as long as there is contrasting visual information available to misinterpret. Therefore, the issue concerning the extent to which individuals "really see" anomalous information can only be addressed with the addition of objective measures. As proposed in the previous paper, eye-tracking methods should be employed to measure individual ability to smoothly pursue dynamic pseudo-hallucinations, the logic being that it is impossible to smoothly pursue purely imagined visual stimuli (Spering & Montagnini, 2011). This is not feasible in a sample size of thousands, but could nevertheless provide converging evidence for or against the hypothesis that pseudo-hallucinations are actually experienced in the external environment.

Next, to make the post-Ganzflicker questionnaire as efficient as possible (and therefore increase the likelihood of completions), I did not include any standard questionnaires of imagery vividness (Andrade et al., 2014; Marks, 1973), although it is possible that the addition of standard measures could have improved the accuracy of self-reports. Specifically, the minimal 0-10 scale I asked participants to use to rate their visual imagery vividness is not as in-depth as an entire questionnaire requiring participants to perform imagery exercises (although these measures also have various limitations). However, as-yet unpublished data (available at https://osf.io/pwdy8/), collected across the spectrum of mental imagery abilities, show extremely high correlations between various visual imagery measures and my 0-10 scale (N = 64, Vividness of Visual Imagery Questionnaire (VVIQ) correlation with 0-10 scale: Kendall's $\tau_B = 0.813, \mathrm{BF}_{10} = 1.984\mathrm{e}+18$; Plymouth Sensory Imagery Questionnaire (PSI-Q) visual section correlation with 0-10 scale: Kendall's $\tau_B = 0.816, \mathrm{BF}_{10} = 2.781\mathrm{e}+18$), suggesting people are consistent with their ratings regardless of the specific self-report measure. Nevertheless, Ganzflicker research in smaller samples should include various standard scales, incorporating measures of imagery vividness as well as creative experiences (Merckelbach et al., 2001) and phenomenological control (Lush et al., 2021).

Finally, in terms of sampling bias, the bimodal distribution of the data (as visualized in Fig. 1) suggests an abnormally large number of individuals with aphantasia (compared to general population prevalence; Dance et al., 2022) participated in the current study. It is likely that many of these individuals, as in the previous Ganzflicker study, were already aware of their aphantasia prior to taking part. It is therefore possible that individuals may have come in with certain expectations about what they might experience in the Ganzflicker. The results cannot simply be explained by demand characteristics, because about half of people with vividness ratings of 0 still reported having seen pseudo-hallucinations (three even reported complex pseudo-hallucinations). However, implementing the previously suggested amendments in future Ganzflicker studies with smaller sample sizes would address this potential limitation.

The Ganzflicker experience produced a highly reliable pattern of reports in a diverse set of individuals from all over the world, attracted to the study by a popular science article, and not exclusively drawn from extreme imagery forums or a university student population as in the previous publication. Furthermore, the expanded dataset allowed me to perform analyses across individual imagery vividness ratings, providing new results. These findings solidify the Ganzflicker paradigm as an accessible, efficient, and effective method of investigating individual differences in anomalous perceptual experiences.

Competing interests

I declare I have no competing interests.

Data Accessibility Statement

All data are available at the project OSF page in the folder MEGA_Ganzflicker at https://osf.io/6dvh9/. This includes anonymized questionnaire responses along with a README.txt file describing different column headers; JASP outputs for every analysis reported in the paper; Python scripts for data visualization; and an additional folder containing wordcloud data and scripts, including anonymized pseudo-hallucination descriptions, additional figures, and wordcloud generator scripts.

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Supplementary Materials

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