

**The Illusion Game: A Novel Experimental Paradigm Provides Evidence in
Favour of a General Factor of Visual Illusion Sensitivity and Personality
Correlates**

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Abstract

25 Visual illusions highlight how the brain uses contextual and prior information to inform our
26 perception of reality. Unfortunately, illusion research has been hampered by the difficulty
27 of adapting these stimuli to experimental settings. In this set of studies, we used the
28 parametric framework for visual illusions implemented in the *Pyllusion* software to
29 generate 10 different classic illusions (Delboeuf, Ebbinghaus, Rod and Frame,
30 Vertical-Horizontal, Zöllner, White, Müller-Lyer, Ponzo, Poggendorff, Contrast) varying in
31 strength. We tested the objective effect of the illusions on errors and reaction times in a
32 perceptual discrimination task, from which we extracted participant-level performance
33 scores (n=250). Our results provide evidence in favour of the existence of a general factor
34 (labelled Factor *i*) underlying the sensitivity to different illusions. Moreover, we report a
35 positive relationship between illusion sensitivity and personality traits such as
36 Agreeableness, Honesty-Humility, and negative relationships with Psychoticism,
37 Antagonism, Disinhibition, and Negative Affect.

38 *Keywords:* visual illusions, illusion game, Pyllusion, personality, general factor

39 Word count: 5096

40 **The Illusion Game: A Novel Experimental Paradigm Provides Evidence in**
41 **Favour of a General Factor of Visual Illusion Sensitivity and Personality**
42 **Correlates**

43 **Introduction**

44 Visual illusions are fascinating stimuli capturing a key feature of our neurocognitive
45 systems. They eloquently show that our brains did not evolve to be perfect perceptual
46 devices providing veridical accounts of physical reality, but integrate prior knowledge and
47 contextual information - blended together in our subjective conscious experience (Carbon,
48 2014). Despite the historical and intensive interest within the fields of visual perception
49 (Day, 1972; Eagleman, 2001; Gomez-Villa et al., 2022), consciousness science (Caporuscio
50 et al., 2022; Lamme, 2020), and psychiatry (Gori et al., 2016; Notredame et al., 2014;
51 Razeghi et al., 2022; Teufel et al., 2015), several important issues remain open.

52 Notably, the presence of a common mechanism underlying the effect of different
53 illusions has been contested (Cretenoud, Francis, et al., 2020; Cretenoud et al., 2019a;
54 Hamburger, 2016); and the nature of the underlying processes - whether related to
55 low-level features of the visual processing system (Cretenoud et al., 2019b; Gori et al.,
56 2016) or to top-down influences of prior beliefs (Caporuscio et al., 2022; Teufel et al., 2018)
57 are strongly debated. The existence of dispositional correlates of illusion sensitivity - for
58 example, higher illusion resistance has been reported in schizophrenia and autism (Giaouri
59 & Alevriadou, 2011; Keane et al., 2014; Notredame et al., 2014; Park et al., 2022; Pessoa et
60 al., 2008), as well as in individuals with stronger aggression and narcissism traits (Konrath
61 et al., 2009a; Zhang et al., 2017) - is another area of controversy.

62 One key challenge hindering the further development of illusion research is the
63 relative difficulty in adapting visual illusions to an experimental setting, which typically
64 requires the controlled modulation of the specific variables of interest. To address this
65 issue, we first developed a parametric framework to manipulate visual illusions, which we

66 implemented and made accessible in the open-source software *Pyllusion* (Makowski et al.,
 67 2021). This software allows us to generate different types of classic visual illusions (e.g.,
 68 Müller-Lyer, Ponzo, Delboeuf, Ebbinghaus, ...) with a continuous and independent
 69 modulation of two parameters: *illusion strength* and *task difficulty* (see **Figure 1**).

Parametric Framework for Visual Illusions

Example with the Müller-Lyer Illusion



The Müller-Lyer Illusion is traditionally presented as two segments (the **red targets**), which perception is biased by the **context** (the arrows). Here, the lower segment appears longer despite being of the same length.

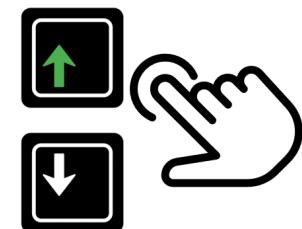


In this illusion, the **task difficulty** corresponds to the difference between the lengths of the red target segments, and the **illusion strength** corresponds to the angle of the arrows.

Example of Stimuli



- ✓ Task difficulty: **easy**
(upper line is 2 times longer)
- ✓ Illusion Strength: **strong**
(angle is sharp)
- ✓ Illusion Direction (left): **incongruent**
(the illusion makes the task harder)
- ✓ Illusion Direction (right): **congruent**
(the illusion makes the task easier)



- ✓ Task difficulty: **hard**
(upper line is only 1.1 times longer)
- ✓ Illusion Strength: **weak**
(angle is flat)
- ✓ Illusion Direction (left): **incongruent**
(the illusion makes the task harder)
- ✓ Illusion Direction (right): **congruent**
(the illusion makes the task easier)



Task: For these stimuli, the correct response is always the « up » arrow, indicating the longer red segment. We measured the reaction time and the errors (in this case, the « down » arrow).



Stimuli created with the open-source software *Pyllusion* (Makowski et al., 2021)

Figure 1. The parametric framework for visual illusions (Makowski et al., 2021) applied to the Müller-Lyer illusion (above). Below are examples of stimuli showcasing the manipulation of two parameters, task difficulty and illusion strength.

70 Indeed, many visual illusions can be seen as being composed of *targets* (e.g.,

71 same-length lines), of which perception is biased by the *context* (e.g., in the Müller-Lyer
72 illusion, the same-length line segments appear to have different lengths when they end with
73 inwards or outwards pointing arrows). Past illusion studies traditionally employed
74 paradigms focusing on participants' subjective experience, by asking them to what extent
75 they perceive two identical targets as different (Lányi et al., 2022), or having them adjust
76 the targets to a reference stimulus relying only on their perception (Grzeczkowski et al.,
77 2018; Mylniec & Bednarek, 2016). Alternatively, *Pyllusion* allows the creation of illusions
78 in which the targets are objectively different (e.g., one segment is truly more or less longer
79 than the other), and in which the illusion varies in strength (the biasing angle of the arrows
80 is more or less acute).

81 This opens the door for an experimental task in which participants make perceptual
82 judgments about the targets (e.g., which segment is the longest) under different conditions
83 of objective difficulty and illusion strength. Moreover, the illusion effect can be either
84 “incongruent” (making the task more difficult by biasing the perception in the opposite
85 way) or “congruent” (making the task easier). Although visual illusions are inherently tied
86 to subjective perception, this framework allows a reversal of the traditional paradigm to
87 potentially quantify the “objective” effect of illusions by measuring its behavioral effect
88 (error rate and reaction times) on the performance in a perceptual task.

89 In the present set of preregistered studies, we will first test this novel paradigm by
90 investigating if the effect of illusion and task difficulty can be manipulated continuously,
91 and separately modeled statistically. Then, we will further utilize the paradigm to assess
92 whether 10 different classic illusions (Delboeuf, Ebbinghaus, Rod and Frame,
93 Vertical-Horizontal, Zöllner, White, Müller-Lyer, Ponzo, Poggendorff, Contrast) share a
94 common latent factor. Finally, we will investigate how the the inter-individual sensitivity
95 to illusions relates to dispositional variables, such as demographic characteristics and
96 personality.

97 In line with open-science standards, all the material (stimuli generation code,
98 experiment code, raw data, analysis script with complementary figures and analyses,
99 preregistration, etc.) is available at
100 <https://github.com/RealityBending/IllusionGameValidation>.

101 **Study 1**

102 **Aim**

103 Study 1 can be seen as a pilot experiment aiming to gather some preliminary data to
104 assess if the stimuli generated by *Pyllusion* behaves as expected for each of the 10 illusion
105 types (i.e., whether an increase of task difficulty and illusion strength leads to an increase
106 of errors); and develop an intuition about the magnitude of effects, to refine the stimuli
107 parameters to a more sensible range (i.e., not overly easy and not impossibly hard) for the
108 next study.

109 **Procedure**

110 We generated 56 stimuli for each of the 10 illusion types. These stimuli resulted from
111 the combination of 8 linearly-spread levels of task difficulty (e.g., [1, 2, 3, 4, 5, 6, 7], where
112 1 corresponds to the highest difficulty - i.e., the smallest objective difference between
113 targets) and 7 levels of illusion strength (3 values of strength on the congruent side, 3 on
114 the incongruent side, and 0; e.g., [-3, -2, -1, 0, 1, 2, 3], where negative values correspond to
115 congruent illusion strengths).

116 The 10 illusion blocks were randomly presented, and the order of the 56 stimuli
117 within the blocks was also randomized. After the first series of 10 blocks, another series
118 was done (with new randomized order of blocks and trials). In total, each participant saw
119 56 different trials per 10 illusion type, repeated 2 times (total = 1120 trials), to which they
120 had to respond “as fast as possible without making errors” (i.e., an explicit double
121 constraint to mitigate the inter-individual variability in the speed-accuracy trade off). The

122 task was implemented using *jsPsych* (De Leeuw, 2015). The instructions for each illusion
123 type are available in the experiment code.

124 **Participants**

125 Fifty-two participants were recruited via *Prolific* (www.prolificacademic.co.uk), a
126 crowd-sourcing platform providing high data quality (Peer et al., 2022). The only inclusion
127 criterion was a fluent proficiency in English to ensure that the task instructions would be
128 well-understood. Participants were incentivised with a reward of about £7.5 for completing
129 the task, which took about 50 minutes to finish.

130 We removed 6 participants upon inspection of the average error rage (when close to
131 50%, suggesting random answers), and when the reaction time distribution was implausibly
132 fast. For the remaining participants, we discarded blocks where the error rate was higher
133 than 50% (possibly indicating that instructions got misunderstood; e.g., participants were
134 selecting the shorter line instead of the longer one). Finally, we removed 692 (1.37%) trials
135 based on an implausibly short or long response time (< 150 ms or > 3000 ms).

136 The final sample included 46 participants (Mean age = 26.7, SD = 7.7, range: [19,
137 60]; Sex: 39.1% females, 56.5% males).

138 **Data Analysis**

139 The analysis of study 1 focused on the probability of errors as the main outcome
140 variable. For each illusion, we started by visualizing the average effect of task difficulty and
141 illusion strength to gain some intuition on the underlying generative model. Next, we
142 tested the performance of various logistic models differing in their specifications, such as:
143 with or without a transformation of the task difficulty (log, square root or cubic root), with
144 or without a 2nd order polynomial term for the illusion strength, and with or without the
145 illusion side (up *vs.* down or left *vs.* right) as an additional predictor. We then fitted the
146 best performing model under a Bayesian framework, and compared its visualization with

¹⁴⁷ that of a General Additive Model (GAM), which has an increased ability of mapping
¹⁴⁸ underlying potential non-linear relationships (at the expense of model simplicity).

¹⁴⁹ The analysis was carried out using *R 4.2* (R Core Team, 2022), *brms* (Bürkner, 2017),
¹⁵⁰ the *tidyverse* (Wickham et al., 2019), and the *easystats* collection of packages (Lüdecke et
¹⁵¹ al., 2021, 2019; Makowski et al., 2020; Makowski, Ben-Shachar, & Lüdecke, 2019).

¹⁵² Results

¹⁵³ The statistical models suggested that the effect of task difficulty had a cubic
¹⁵⁴ relationship with error rate for the Delboeuf and Ebbinghaus illusions (both composed of
¹⁵⁵ circular shapes), square relationship for the Rod and Frame and Vertical-Horizontal
¹⁵⁶ illusions, cubic relationship for the Zöllner and Poggendorff illusions, exponential
¹⁵⁷ relationship for the White illusion, cubic relationship for the Müller-Lyer and Ponzo
¹⁵⁸ illusions (both based on line lengths), and linear relationship for the Contrast illusion. All
¹⁵⁹ models suggested a significant effect of illusion strength and task difficulty. See details and
¹⁶⁰ figures in the analysis script.

¹⁶¹ Discussion

¹⁶² This study provided a clearer understanding of the magnitude of the parametric
¹⁶³ effects at stake and the type of interaction between them. Furthermore, it allowed us to
¹⁶⁴ better understand and test the stimuli generated by *Pyillusion*, as well as uncover technical
¹⁶⁵ bugs and issues (for instance, the specification direction of the illusion strength was
¹⁶⁶ reversed for a few illusions), which were fixed by a new software release. Crucially, this
¹⁶⁷ study allowed us to refine the range of task difficulty and illusion strength values in order
¹⁶⁸ to maximize information gain.

¹⁶⁹ In most illusions, the task difficulty exhibited monotonic power-law scaled effects,
¹⁷⁰ which is in line with the psychophysics literature on perceptual decisions (Bogacz et al.,
¹⁷¹ 2006; Ditzinger, 2010; Shekhar & Rahnev, 2021). One notable result was the illusion effect

¹⁷² pattern for the Zöllner illusion, which suggested a non-linear relationship. By generating a
¹⁷³ wider range of illusion strength values, the next study will attempt at clarifying this point.

¹⁷⁴ **Study 2**

¹⁷⁵ **Aim**

¹⁷⁶ The aim of study 2 was two-fold. In the first part, we carefully modeled the error rate
¹⁷⁷ and the reaction time of each illusion type in order to validate our novel paradigm and
¹⁷⁸ show that the effect of illusions can be manipulated continuously. In the second part, we
¹⁷⁹ derived the participant-level scores from the models (i.e., the effect of illusion strength for
¹⁸⁰ each individual) and analyzed their latent factors structure.

¹⁸¹ **Procedure**

¹⁸² The paradigm of study 2 was similar to that of study 1, with the following changes:
¹⁸³ the illusory stimuli were re-generated within a refined space of parameters based on the
¹⁸⁴ results of study 1. Moreover, taking into account the findings of study 1, we used
¹⁸⁵ non-linearly spaced difficulty levels, depending on the best underlying model (i.e., with an
¹⁸⁶ exponential, square or cubic spacing depending on the relationship). For instance, a linear
¹⁸⁷ space of [0.1, 0.4, 0.7, 1.0] can be transformed to an exponential space of [0.1, 0.34, 0.64,
¹⁸⁸ 1.0].

¹⁸⁹ Additionally, instead of repeating each stimulus two times, we generated illusions
¹⁹⁰ using more levels of difficulty and illusion strength. As such, for each illusion type, we
¹⁹¹ generated a total of 134 stimuli that were split into two groups (67 stimuli per illusion
¹⁹² block). Furthermore, instead of a simple break screen, we added two personality
¹⁹³ questionnaires between the two series of 10 illusion blocks (see study 3).

194 **Participants**

195 Using the same recruitment procedure as in study 1, we recruited 256 participants,
196 out of which 6 were identified as outliers and excluded, leaving a final sample of 250
197 participants (Mean age = 26.5, SD = 7.6, range: [18, 69]; Sex: 48% females, 52% males).
198 Please see study 3 for the full demographic breakdown. We discarded blocks with more
199 than 50% of errors (2.16% of trials) and 0.76% trials with extreme response times (< 125
200 ms or > 4 SD above mean).

201 **Data Analysis**

202 The first part of the analysis focused on modelling the effect of illusion strength and
203 task difficulty on errors and reaction time (RT), within each illusion. In order to achieve
204 that, we started by fitting General Additive Models (GAMs), which can accommodate
205 possible non-linear effects and interactions. Errors were analyzed using Bayesian logistic
206 mixed models, and RTs of correct responses were analyzed using an ex-Gaussian family
207 with the same fixed effects entered for the location μ (mean), scale σ (spread) and
208 tail-dominance τ of the RT distribution (Balota & Yap, 2011; Matzke & Wagenmakers,
209 2009).

210 Using GAMs as the “ground-truth” models, we attempted at approximating them
211 using general linear models, which have the advantage of estimating the participant-level
212 variability of the effects (via random slopes). Following a comparison of models with a
213 combination of transformations (raw, log, square root or cubic root) on the main predictors
214 (task *difficulty* and illusion *strength*), we selected and fitted the best model (best on their
215 indices of fit), and compared their output visually (see **Figure 2**).

216 We then extracted the inter-individual variability in the effect of illusion strength and
217 its interaction with task difficulty, and used it as participant-level scores. Finally, We
218 explored the relationship of these indices across different illusions using exploratory factor

219 analysis (EFA) and structural equation modelling (SEM).

220 **Results**

221 The best models were $\log(\text{diff}) * \text{strength}$ for Delboeuf; $\sqrt{\text{diff}} * \text{strength}$ for
222 Ebbinghaus; $\log(\text{diff}) * \log(\text{strength})$ for Rod and Frame; $\sqrt{\text{diff}} * \sqrt{\text{strength}}$ for
223 Vertical-Horizontal; $\text{cbrt}(\text{diff}) * \text{strength}$ for Zöllner; $\text{diff} * \sqrt{\text{strength}}$ and
224 $\log(\text{diff}) * \text{strength}$ respectively for errors and RT in White; $\sqrt{\text{diff}} * \sqrt{\text{strength}}$
225 and $\sqrt{\text{diff}} * \text{strength}$ respectively for errors and RT in Müller-Lyer;
226 $\text{cbrt}(\text{diff}) * \text{strength}$ for Ponzo; $\text{cbrt}(\text{diff}) * \sqrt{\text{strength}}$ and $\text{cbrt}(\text{diff}) * \text{strength}$
227 respectively for errors and RT in Poggendorff; $\sqrt{\text{diff}} * \sqrt{\text{strength}}$ for Contrast. In
228 all of these models, the effects of illusion strength, task difficulty and their interaction were
229 significant.

230 For errors, most of the models closely matched their GAMs counterpart (see **Figure**
231 **2**), with the exception of Delboeuf (for which the GAM suggested a non-monotonic effect
232 of illusion strength with a local minimum at 0) and Zöllner (for which theoretically
233 congruent illusion effects were related to increased error rate).

234 For RTs, the GAMs suggested a consistent non-linear relationship between RT and
235 illusion strength: as the illusion strength increase beyond a certain threshold, the
236 participants respond faster. While this is not surprising (strong illusions are likely so
237 effective in biasing perception that it is “easier”, i.e., faster, to make the wrong decision),
238 the linear models were not designed to capture this - likely quadratic - pattern and hence
239 are not good representatives of the underlying dynamics. As such, we decided not to use
240 them for the individual scores analysis.

241 Though imperfect, we believe that the random-slope models capture inter-individual
242 differences with more accuracy (and are also more conservative estimates due shrinkage)
243 than basic empirical scores, such as the total number of errors, or the average RT. Thus, for

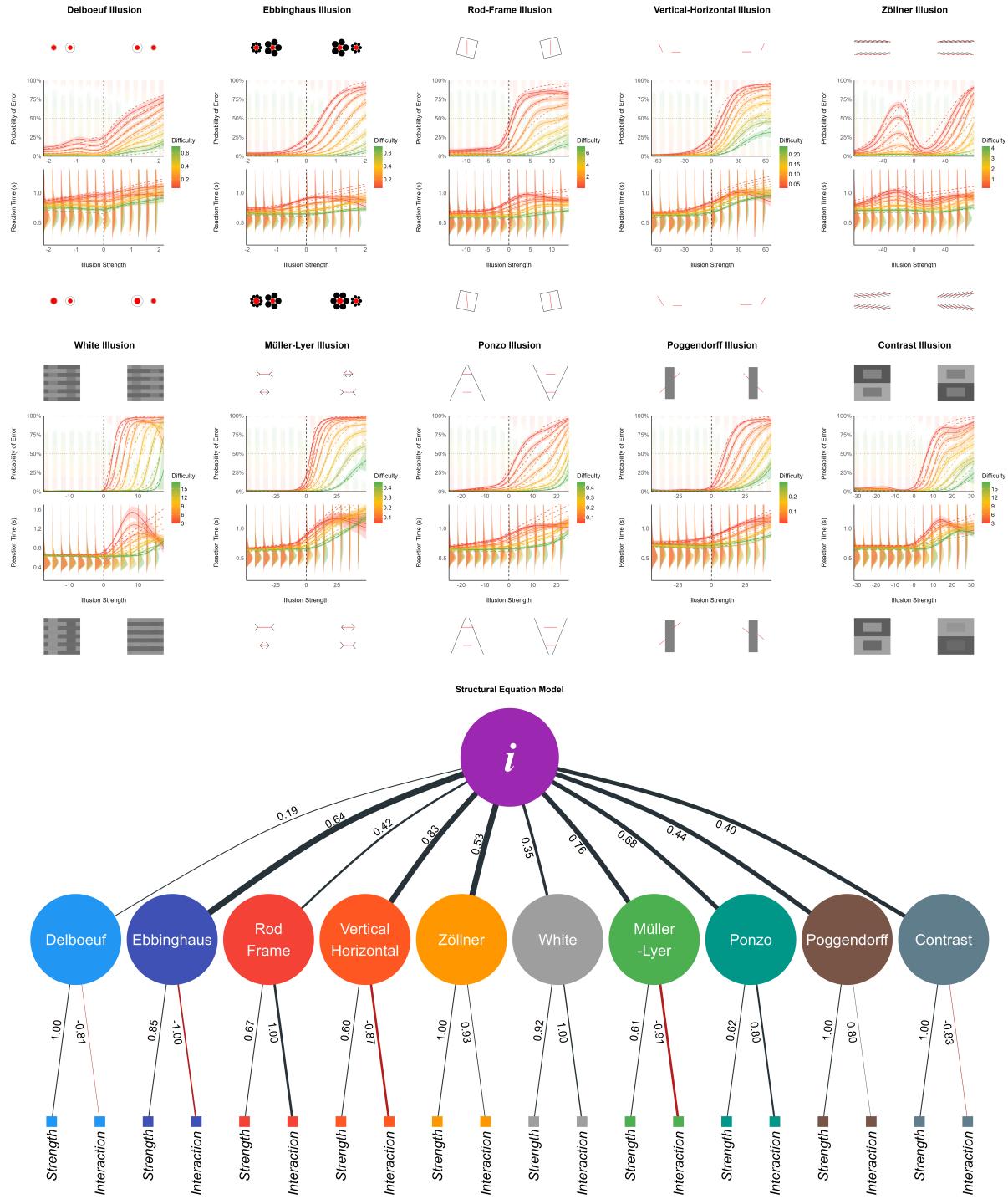


Figure 2. Top: the effect of illusion strength and task difficulty on the error rage and reaction time (RT) for each individual illusions. The solid line represent the General Additive Model (GAM), and the dashed line correspond to its approximation via linear models. Descriptive data is shown with stacked dots (errors are hanging from the top) and distributions for RTs. Negative values for illusion strength correspond to congruent (i.e., facilitating) illusion effects. Task difficulty (the objective difference between the targets of perceptual decision) levels are shown as colors, with lowest values corresponding to harder trials. Each illusion type is surrounded by 4 extreme examples of stimuli, corresponding to the hardest difficulty (on top) and the strongest illusion (on the right for incongruent illusions). Bottom: We extracted the effect slope of the illusion strength and its interaction with task difficulty for each participant. We fitted a Structural Equation Model (SEM) suggesting that these manifest variables group to first-level illusion-specific latent factors, which then load on a general factor of illusion sensitivity (Factor *i*).

each illusion and within each participant, we extracted the effect of illusion strength and its interaction with task difficulty when the illusion effect was incongruent. These twenty participant-level scores were subjected to exploratory factor analysis (EFA). The Method Agreement Procedure (Lüdecke et al., 2020) suggested the presence of 7 latent factors. An oblique (*oblimin* rotation) factor solution explaining 66.69% of variance suggested separate dimensions for the effect of Zöllner, White, Poggendorff, Contrast, Ebbinghaus, Delboeuf, and a common factor for the parameters related to Müller-Lyer, Vertical-Horizontal, Ponzo and Rod and Frame. We submitted these factors to a second-level analysis and extracted two orthogonal (*varimax* rotation) factors. The first factor was loaded by all the previous dimensions with the exception of Delboeuf, which formed its own separate factor.

Finally, we tested this data-driven model ($m0$) against four other structural models using structural equation modelling (SEM): one in which the two parameters of each of the 10 illusions (illusion strength and interaction with task difficulty) loaded on separate factors, which then all loaded on a common factor ($m1$); one which the parameters were grouped by illusion type (lines, circles, contrast and angle) before loading on a common factor ($m2$); one in which all the parameters related to strength, and all the parameters related to the interaction loaded onto two respective factors, which then loaded on a common factor ($m3$); and one in which there was no intermediate level: all 20 parameters loaded directly on a common factor ($m4$).

The model $m1$, in which the parameters loaded on a first level of 10 illusion-specific factors, which then all loaded on a common factor significantly outperformed the other models. Its indices of fit were ranging from acceptable to satisfactory (CFI = .92; SRMR = .08; NNFI = .91; PNFI = .74; RMSEA = .08), and all the specified effects were significant. The illusion-specific latent factors were loaded positively by the sensitivity to illusion strength, and positively by the interaction effect with task difficulty (with the exception of Delboeuf, Ebbinghaus, Vertical-Horizontal, Müller-Lyer and Contrast, for which the

270 loading was negative). The general factor of illusion sensitivity, labelled Factor i (i - for
271 illusion), explained 48.02% of the total variance of the initial dataset, and was strongly
272 related to Vertical-Horizontal ($\beta_{std.} = 0.83$), Müller-Lyer ($\beta_{std.} = 0.76$), Ponzo
273 ($\beta_{std.} = 0.65$), Ebbinghaus ($\beta_{std.} = 0.64$); moderately to Zöllner ($\beta_{std.} = 0.53$), Poggendorff
274 ($\beta_{std.} = 0.44$), Rod and Frame ($\beta_{std.} = 0.42$), Contrast ($\beta_{std.} = 0.40$) and White
275 ($\beta_{std.} = 0.35$); and weakly to Delboeuf ($\beta_{std.} = 0.19$). We then computed, for each
276 participant, its score for the 10 illusion-specific factors and for the general Factor i .

277 We have to keep in mind that these individual scores are the result of several layers of
278 simplification: 1) the individual coefficient is that of simpler models that sometimes do not
279 perfectly capture the underlying dynamics (especially in the case of Delboeuf and Zöllner);
280 2) we only used the models on error rate, which could be biased by the speed-accuracy
281 decision criterion used by participants; 3) the structural equation model used to compute
282 the scores also incorporated multiple levels of abstractions. Thus, in order to validate the
283 individual scores, we computed the correlation between them and simple empirical scores,
284 such as the average error rate and the mean RT in the task. This analysis revealed strong
285 and significant correlations between each illusion-specific factor and the average amount of
286 errors in its respective task. Moreover, each individual score was strongly associated with
287 the average RT across multiple illusion types. This suggests that the individual scores
288 obtained from the structural equation model do capture the sensitivity of each participant
289 to visual illusions, manifesting in both the number of errors and high reaction times.

290 **Discussion**

291 This study confirmed that it was possible to continuously manipulate the effect of
292 illusion strength for 10 classical illusions. Increasing the illusion strength increased the
293 likelihood of errors, as well as the average and spread of RTs (but only up to a point, after
294 which participants become faster at responding with the wrong answer). Future studies are
295 needed to explore reaction times and try to identify the most appropriate models, and / or

296 use models that integrate errors and reaction time (e.g., drift diffusion models).

297 The effect on errors was monotonic for most illusions, with the exception of Delboeuf
298 and Zöllner. For both of them, mildly congruent illusion strengths (which theoretically
299 were supposed to be associated with less errors than incongruent effects) were related to
300 small and strong increases of errors, respectively. For the Delboeuf illusion, we believe that
301 this was due to an artifact caused by the illusion generation algorithm: the outline of the
302 target circles was always created as slightly bigger, which made the difference between
303 them more obvious at an illusion strength of 0. This was fixed in latest release of *Pyllusion*
304 (v1.2), which now generate outlines of the same size as the target circle. For the Zöllner
305 illusion, the observed non-monotonic pattern is actually consistent with previous reports
306 (Kitaoka, 2007; Kitaoka & Ishihara, 2000), suggesting an acute angle contraction effect at
307 very small as well as at sufficiently large angles (below 10 degrees for the former and
308 between 50 to 90 degrees for the latter) between the target horizontal line and the biasing
309 horizontal bars when the illusion strength is weak.

310 Finally, this study provided evidence for both the existence of illusion-specific factors,
311 as well as for a common latent factor (labelled Factor *i*) that explained about half of the
312 total variance. These participant-level scores were positively related to the error rate and
313 average reaction time, and can thus be interpreted as indices of illusion sensitivity.

314 Study 3

315 Aim

316 Study 3 aimed at investigating the links between the inter-individual scores of illusion
317 sensitivity (obtained in study 2), contextual variables (pertaining to the experiment
318 setting), such as screen size, demographic features (such as sex and age), and stable
319 dispositional variables such as “general” personality traits. Indeed, despite the abundant
320 literature on visual illusions, relatively few studies have investigated its ties with

321 participants' characteristics. Research examining the influence of demographic variables
322 such as gender and age have generally found inconsistent results (Cretenoud, Grzeczkowski,
323 et al., 2020; Grzeczkowski et al., 2017; Lo & Dinov, 2011; Papageorgiou et al., 2020).
324 Regarding links with personality, most works focused on traits associated with
325 psychopathology, such as impulsivity or sensation-seeking (Hlavatá et al., 2018; Lányi et
326 al., 2022; Pessoa et al., 2008; Zhang et al., 2017).

327 **Procedure**

328 This study was based on the data collected in study 2. The variables of interest here
329 were taken from the questionnaires that were inserted in between the two series of illusion
330 blocks. We used the *IPIP6* (24 items, Sibley et al., 2011) to measure 6 “normal”
331 personality traits (Extraversion, Openness, Conscientiousness, Agreeableness, Neuroticism
332 and Honesty-humility), and the *PID-5* (25 items, Hopwood et al., 2012) to measure
333 “pathological” personality traits (Disinhibition, Antagonism, Detachment, Negative Affect
334 and Psychoticism). The participants were the same as in study 2 (see **Figure 3**). However,
335 due to a technical issue, no personality data was recorded for the first eight participants.

336 **Data Analysis**

337 For each of the individual illusion sensitivity scores (10 illusion-specific factors and
338 the general Factor i), we tested the effect of contextual variables (screen size, screen refresh
339 rate), demographic variables (sex, education, age) and personality. As the supplementary
340 material contains the detailed results, we will here only report the significant results (based
341 on the Bayes Factor BF or the Probability of Direction pd , see Makowski, Ben-Shachar,
342 Chen, et al., 2019).

343 **Results**

344 The Bayesian correlation analysis (with narrow priors centered around a null effect)
345 between the illusion scores and contextual variables (screen size and refresh rate) provided

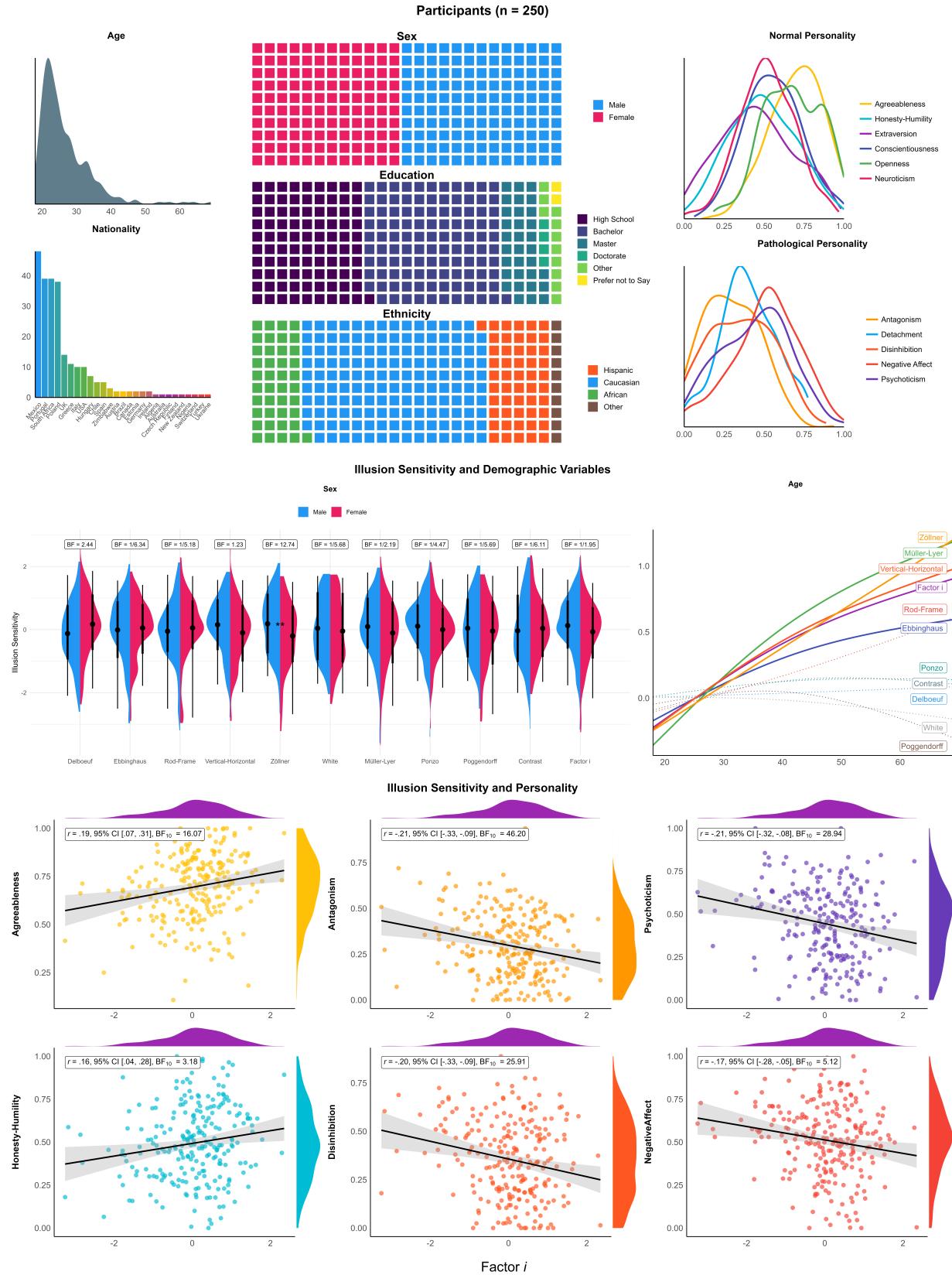


Figure 3. The upper plots show the distribution of demographic and dispositional variables. The middle plots show the relationship between illusion sensitivity scores, sex, and age (solid lines indicate significant relationships). Bottom plots show the correlation between the general factor of illusion sensitivity (Factor i), and personality traits.

346 weak evidence in favor of an absence of effect, with the exception of the two contrast-based
347 illusions. Anecdotal ($BF_{10} = 2.05$) and moderate evidence ($BF_{10} = 4.11$) was found for a
348 negative correlation between screen size and the sensitivity to the White and the Contrast
349 illusion, respectively. To test whether this result could be an artifact related to the highly
350 skewed screen size distribution (caused by very few participants with extreme screen sizes),
351 we re-ran a robust correlation (with rank-transformed values), which provided even
352 stronger evidence in favor of the effect existence ($BF_{10} = 28.19$, $BF_{10} = 4.31$ for White and
353 Contrast, respectively).

354 The Bayesian t-tests on the effect of sex suggested anecdotal to moderate evidence in
355 favour of the null effect for all scores, with the exception of the sensitivity to the Zöllner
356 illusion, which was higher in males as compared to females ($\Delta = -0.37$, 95% CI [-0.62,
357 -0.13], $BF_{10} = 12.74$). We fitted Bayesian linear models with the education level entered as
358 a monotonic predictor (appropriate for ordinal variables, Bürkner & Charpentier, 2020),
359 which yielded no significant effects. For age, we fitted two types of models for each score,
360 one general additive models (GAM) and a 2nd order polynomial model. These consistently
361 suggested a significant positive linear relationship between age and Factor i ($pd = 100\%$),
362 as well as the sensitivity to Müller-Lyer ($pd = 100\%$), Vertical-Horizontal ($pd = 100\%$),
363 Zöllner ($pd = 100\%$) and Ebbinghaus ($pd = 99\%$) illusions.

364 Regarding “normal” personality traits, Bayesian correlations suggested substantial
365 evidence in favor of a positive relationship between *Honesty-Humility* and Zöllner
366 ($BF_{10} > 100$), Vertical-Horizontal ($BF_{10} = 9.78$) and the Factor i ($BF_{10} = 4.00$); as well as
367 between *Agreeableness* and Vertical-Horizontal ($BF_{10} = 25.06$), Ponzo ($BF_{10} = 4.88$) and
368 the Factor i ($BF_{10} = 19.65$).

369 Regarding “pathological” personality traits, the results yielded strong evidence in
370 favor of a negative relationship between multiple illusion scores and multiple traits.
371 *Antagonism* was associated with the sensitivity to Vertical-Horizontal ($BF_{10} > 100$),

372 Müller-Lyer ($BF_{10} = 21.57$), Ponzo ($BF_{10} = 17.97$) illusions, and the Factor i
373 ($BF_{10} = 55.45$); *Psychoticism* was associated with the sensitivity to Vertical-Horizontal
374 ($BF_{10} = 66.63$) and Müller-Lyer ($BF_{10} = 35.59$) illusions, and the Factor i ($BF_{10} = 35.02$);
375 *Disinhibition* was associated with the sensitivity to Vertical-Horizontal ($BF_{10} = 25.38$),
376 Zöllner ($BF_{10} = 7.59$), Müller-Lyer ($BF_{10} = 5.89$) illusions, and the Factor i
377 ($BF_{10} = 31.42$); and *Negative Affect* was associated with Zöllner ($BF_{10} = 62.04$),
378 Vertical-Horizontal ($BF_{10} = 12.65$), Müller-Lyer ($BF_{10} = 3.17$), and the Factor i
379 ($BF_{10} = 6.39$). The last remaining trait, *Detachment*, did not share any relationship with
380 illusion sensitivity.

381 Discussion

382 We report significant links between inter-individual indices of illusion sensitivity and
383 varialbes related to experimental context, demographic characteristics and personality.
384 Firstly, screen size was found to have a significant negative relationship with the sensitivity
385 to the two contrast-based illusions, namely the White and Contrast illusions. One possible
386 explanation can be found in the mechanism by which visual systems filter through more
387 low spatial frequencies when the size of the target object is small (Dixon et al., 2014). As
388 this filtering process excludes illumination information from visual processing, smaller
389 screen sizes could yield artifactual changes in brightness perception, which in turn could
390 attenuate the illusory effect of luminance-related illusions.

391 Our results suggested an inconsistent pattern of non-significant sex-differences, with
392 the exception of greater sensitivity of males as compared to females reported to the Zöllner
393 illusion. As we do not consider this result as significant given its specificity, we note that
394 the existing literature reports, if any differences, that females exhibited greater illusion
395 sensitivity (Lo & Dinov, 2011; Miller, 2001; Papageorgiou et al., 2020). This inconsistency
396 could be due to past studies using a measure of illusion sensitivity that conflates the effect
397 of illusions *per se* with the perceptual abilities involved in the task, for which

398 gender-related differences can be found (in fact, the authors mention sex-differences in
399 visuospatial strategies as the potential mechanism underlying their findings). On the
400 contrary, the perceptual difficulty of the task and the illusion effect was independently
401 modulated in our paradigm, and statistically dissociated. Our scores of illusion sensitivity
402 might thus be less loaded with perceptual skills, thereby mitigating its effect.

403 Our findings also suggested a positive relationship between illusion sensitivity and
404 two “normal” personality traits, namely *Honesty-Humility* and *Agreeableness*, and a
405 negative link with *Antagonism*. Although the past literature regarding the links between
406 illusion sensitivity and personality traits remain scarce, convergent evidence can be found
407 in studies reporting a negative relationship between illusion sensitivity and hostility,
408 aggression and narcissism (Konrath et al., 2009a; Pessoa et al., 2008; Zhang et al., 2017).
409 While this result’s interpretation is challenging, one possible explanation could be drawn
410 from the literature on the cognitive style known as field dependence. Since narcissism and
411 aggression tendencies are correlated with lower field dependence (D’Amour et al., 2021;
412 Ohmann & Burgmer, 2016; i.e., a lesser reliance on external cues in ambiguous contexts,
413 Witkin & Goodenough, 1976), opposite traits, such as *Honesty-Humility* and *Agreeableness*,
414 could conversely be more biased by contextual cues and thus more sensitive to illusions.

415 The positive relationship between illusion sensitivity and “positive” personality traits
416 is mirrored by a negative relationship with several other pathological traits, including
417 *Psychoticism*, *Disinhibition*, and *Negative Affect*. These results are, in general, consistent
418 with past findings and theories, suggesting a negative relationship between egocentric
419 cognitive styles and context processing (including illusion sensitivity, Konrath et al.,
420 2009b). For instance, pathological egocentric beliefs (often observed alongside
421 *Psychoticism*, Fox, 2006) have been related to reduced context integration (Fox, 2006;
422 Konrath et al., 2009b; manifesting for instance in a tendency to separate objects from their
423 surroundings when processing visual stimuli, Ohmann & Burgmer, 2016). As such, it is

424 possible to relate this higher resistance to illusions to a self-centered, decontextualized and
425 disorganized information processing style, which can be found across the aforementioned
426 maladaptive personality traits (Calamari et al., 2000; Hoyle, 2006; Msetfi et al., 2009;
427 Parkes, 1981) .

428 Furthermore, these results in favour of a link between illusion sensitivity and
429 maladaptive personality traits in a non-clinical population could be put in relation with
430 clinical findings, which could be seen as extreme cases where the relationship with illusion
431 sensitivity is the most manifest. In line with our results (in particular on *Psychoticism* and
432 *Disinhibition*), prior research has found greater illusion resistance in schizophrenia
433 (Grzeczkowski et al., 2018; Notredame et al., 2014; Pessoa et al., 2008), and in particular,
434 in association with schizotypal traits, such as cognitive disorganization (Cretenoud et al.,
435 2019b; Lányi et al., 2022).

436 **General Discussion**

437 The parametric illusion generation framework developed in Makowski et al. (2021)
438 proposes to conceptualize illusions as made of targets and distractors, both of which can be
439 manipulated independently and continuously. In the present study, we have shown that
440 such gradual modulation of illusion strength is effectively possible across 10 different types
441 of classic visual illusions. This important methodological step opens the door for new
442 illusions-based paradigms and tasks, to study the effect of illusions under different
443 conditions and to quantify illusion sensitivity using objective behavioral outcomes, such as
444 accuracy or speed.

445 The participants' sensitivities to 10 different types of visual illusions shared a
446 common part of variance, suggesting the existence of a general factor of illusion sensitivity
447 (Factor *i*). This result comes in a field of mixed findings. In fact, contrary to early studies
448 on visual illusions, more recent research have generally not found any significant evidence

449 for a common stable factor across illusions within individuals (Cretenoud, Francis, et al.,
450 2020; Cretenoud et al., 2019b; Grzeczkowski et al., 2017, 2018; Yang et al., 2012). Instead,
451 past findings suggests illusory effects are highly specific to the perceptual features of the
452 illusions at stake (Cretenoud et al., 2019b; Grzeczkowski et al., 2017). It should be noted,
453 however, that most of these studies were low-powered and/or relied on conventional
454 paradigms, such as the adjustment procedure to measure the participants' subjective
455 perception. We believe that our study presents several methodological improvements,
456 including statistical power (high number of trials per participant), homogeneous stimuli
457 (with minimal and highly controlled features) and tasks (decision-making reaction-time
458 task), and more reliable participant-level score extraction method (based on random-factors
459 models), which in our opinion contributed to the emergence of the common factor.

460 However, although the illusions were relatively different in terms of the perceptual
461 task (contrast-based, size-estimation, angle-perception), The possibility of our general
462 factor being driven by inter-individual perceptual skills variability (or other cognitive skills)
463 cannot be discarded. Future studies should investigate the relationship between perceptual
464 abilities (in a similar task, but without illusions) and illusion sensitivity, and assess the
465 psychometric properties of similar paradigms, including stability (e.g., test-retest
466 reliability) and validity.

467 Finally, we found that the sensitivity to illusions was positively associated with
468 “positive” personality traits, such as *Agreeableness* and *Honesty-Humility*, and negatively
469 associated with maladaptive traits such as *Antagonism*, *Psychoticism*, *Disinhibition* and
470 *Negative Affect*. Beyond highlighting the relevance of illusions beyond the field of visual
471 perception, these results point towards an association with high-level general-domain
472 mechanisms. While the search for the exact mechanism(s) underlying these links is an
473 important goal of future research, our findings unlock the potential of illusion-based tasks
474 as sensitive tools to capture specific inter-individual neuro-cognitive differences.

475 To conclude, we strongly invite researchers to explore and re-analyze our dataset with

476 other approaches and methods to push the understanding of visual illusions and illusion

477 sensitivity further. The task, data and analysis script are available in open-access at

478 <https://github.com/RealityBending/IllusionGameValidation>.

479 **Acknowledgments**

480 We would like to thank Tam Pham and Zen J. Lau for their contribution to

481 *Pyillusion*, as well as Prof Dólos for the inspiration.

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