

**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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24

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 a general factor (labelled Factor
34 *i*) underlying the sensitivity to different illusions. Moreover, we report a positive
35 relationship between illusion sensitivity and personality traits such as Agreeableness,
36 Honesty-Humility, and negative relationships with Psychoticism, Antagonism,
37 Disinhibition, and Negative Affect. Data and code are available in open-access.

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

39 Word count: 5114

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 longstanding interest within the fields of visual perception (Day, 1972;
49 Eagleman, 2001; Gomez-Villa et al., 2022), consciousness science (Caporuscio et al., 2022;
50 Lamme, 2020), and psychiatry (Gori et al., 2016; Notredame et al., 2014; Razeghi et al.,
51 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 et al., 2019; Cretenoud, Francis, et al., 2020;
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., 2019; Gori et al., 2016)
56 or to top-down influences of prior beliefs (Caporuscio et al., 2022; Teufel et al., 2018) are
57 strongly debated. The existence of dispositional correlates of illusion sensitivity is another
58 area of controversy, with some studies reporting higher illusion resistance in patients with
59 schizophrenia and autism (Giaouri & Alevriadou, 2011; Keane et al., 2014; Notredame et
60 al., 2014; Park et al., 2022; Pessoa et al., 2008) and in individuals with stronger aggression
61 and narcissism traits (Konrath et al., 2009; Zhang et al., 2017).

62 One key challenge hindering the further development of illusion research is the
63 relative difficulty of 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 with a
 68 continuous and independent modulation of two parameters: *illusion strength* and *task*
 69 *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.

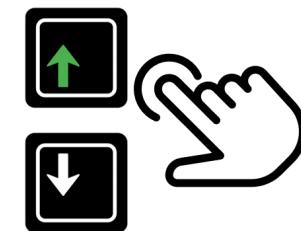


In this illusion, the **task difficulty** corresponds to the difference between the lengths of the red target segments, and the **illusion strength** corresponds to the angle of the arrows.

Example of Stimuli



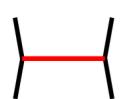
- ✓ Task difficulty: **easy**
(upper line is 2 times longer)
- ✓ Illusion Strength: **strong**
(angle is sharp)
- ✓ Illusion Direction (left): **incongruent**
(the illusion makes the task harder)
- ✓ Illusion Direction (right): **congruent**
(the illusion makes the task easier)



- ✓ 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 the extent to
75 which they perceive two identical targets as different (Lányi et al., 2022), or having them
76 adjust the targets to match a reference stimulus relying only on their perception
77 (Grzeczkowski et al., 2018; Mylniec & Bednarek, 2016). Alternatively, *Pyllusion* allows the
78 creation of illusions in which the targets are objectively different (e.g., one segment is truly
79 more or less longer than the other), and in which the illusion varies in strength (the biasing
80 angle of the arrows 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 strength and task difficulty can be manipulated
91 continuously, and separately modeled statistically. Then, we will further utilize the
92 paradigm to assess whether 10 different classic illusions (Delboeuf, Ebbinghaus, Rod and
93 Frame, Vertical-Horizontal, Zöllner, White, Müller-Lyer, Ponzo, Poggendorff, Contrast)
94 share a common latent factor. Finally, we will investigate how the the inter-individual
95 sensitivity to illusions relates to dispositional variables, such as demographic characteristics
96 and 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 administered (with new randomized orders of blocks and trials). In total, each
119 participant saw 56 different trials per 10 illusion type, repeated 2 times (total = 1120
120 trials), to which they had to respond “as fast as possible without making errors” (i.e., an
121 explicit double constraint to mitigate the inter-individual variability in the speed-accuracy

122 trade off). The task was implemented using *jsPsych* (De Leeuw, 2015), and the
123 instructions for each illusion 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. Demographic variables (age, gender, and
130 ethnicity) were self-reported on a voluntary basis.

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

137 The final sample included 46 participants (Mean age = 26.7, SD = 7.7, range: [19,
138 60]; Sex: 39.1% females, 56.5% males, and 4.4% other).

139 **Data Analysis**

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

¹⁴⁷ best performing model under a Bayesian framework, and compared its visualization with
¹⁴⁸ that of a General Additive Model (GAM), which has an increased ability of mapping
¹⁴⁹ underlying potential non-linear relationships (at the expense of model simplicity).

¹⁵⁰ The analysis was carried out using *R* 4.2 (R Core Team, 2022), *brms* (Bürkner, 2017),
¹⁵¹ the *tidyverse* (Wickham et al., 2019), and the *easystats* collection of packages (Lüdecke et
¹⁵² al., 2021, 2019; Makowski et al., 2020; Makowski, Ben-Shachar, & Lüdecke, 2019).

¹⁵³ Results

¹⁵⁴ The statistical models suggested that the effect of task difficulty had a cubic
¹⁵⁵ relationship with error rate for the Delboeuf and Ebbinghaus illusions (both composed of
¹⁵⁶ circular shapes), square relationship for the Rod and Frame and Vertical-Horizontal
¹⁵⁷ illusions, cubic relationship for the Zöllner and Poggendorff illusions, exponential
¹⁵⁸ relationship for the White illusion, cubic relationship for the Müller-Lyer and Ponzo
¹⁵⁹ illusions (both based on line lengths), and linear relationship for the Contrast illusion. All
¹⁶⁰ models suggested a significant effect of illusion strength and task difficulty. See details and
¹⁶¹ figures in the analysis script.

¹⁶² Discussion

¹⁶³ This study provided a clearer understanding of the magnitude of the parametric
¹⁶⁴ effects at stake and the type of interaction between them. Furthermore, it allowed us to
¹⁶⁵ better understand and test the stimuli generated by *Pyllusion*, as well as uncover incidental
¹⁶⁶ bugs and technical issues (for instance, the specification direction of the illusion strength
¹⁶⁷ was reversed for a few illusions), which were fixed in a new software release. Crucially, this
¹⁶⁸ study allowed us to refine the range of task difficulty and illusion strength values in order
¹⁶⁹ to maximize information gain.

¹⁷⁰ In most illusions, the task difficulty exhibited monotonic power-law scaled effects,
¹⁷¹ which is in line with the psychophysics literature on perceptual decisions (Bogacz et al.,

¹⁷² 2006; Ditzinger, 2010; Shekhar & Rahnev, 2021). One notable result was the illusion effect
¹⁷³ pattern for the Zöllner illusion, which suggested a non-linear relationship. By generating a
¹⁷⁴ wider range of illusion strength values, the next study will attempt at clarifying this point.

¹⁷⁵

Study 2

¹⁷⁶ **Aim**

¹⁷⁷ The aim of study 2 was two-fold. In the first part, we carefully modeled the error rate
¹⁷⁸ and the reaction time of each illusion type in order to validate our novel paradigm and
¹⁷⁹ show that the effect of illusions can be manipulated continuously. In the second part, we
¹⁸⁰ derived the participant-level scores from the models (i.e., the effect of illusion strength for
¹⁸¹ each individual) and analyzed their latent factors structure.

¹⁸² **Procedure**

¹⁸³ The paradigm of study 2 was similar to that of study 1, with the following changes:
¹⁸⁴ the illusory stimuli were re-generated within a refined space of parameters based on the
¹⁸⁵ results of study 1. Moreover, taking into account the findings of study 1, we used
¹⁸⁶ non-linearly spaced difficulty levels, depending on the best underlying model (i.e., with an
¹⁸⁷ exponential, square or cubic spacing depending on the relationship). For instance, a linear
¹⁸⁸ space of [0.1, 0.4, 0.7, 1.0] can be transformed to an exponential space of [0.1, 0.34, 0.64,
¹⁸⁹ 1.0].

¹⁹⁰ Additionally, instead of repeating each stimulus two times, we generated illusions
¹⁹¹ using more levels of difficulty and illusion strength. As such, for each illusion type, we
¹⁹² generated a total of 134 stimuli that were split into two groups (67 stimuli per illusion
¹⁹³ block). Furthermore, instead of a simple break screen, we added two personality
¹⁹⁴ questionnaires between the two series of 10 illusion blocks (see study 3).

195 Participants

196 Using the same recruitment procedure as in study 1, we recruited 256 participants,

197 out of which 6 were identified as outliers and excluded, leaving a final sample of 250

198 participants (Mean age = 26.5, SD = 7.6, range: [18, 69]; Sex: 48% females, 52% males).

199 Please see study 3 for the full demographic breakdown. We discarded blocks with more

200 than 50% of errors (2.16% of trials) and 0.76% trials with extreme response times (< 125

201 ms or > 4 SD above mean).

202 Data Analysis

203 The first part of the analysis focused on modelling the effect of illusion strength and

204 task difficulty on errors and reaction time (RT) within each illusion. In order to achieve

205 this, we started by fitting General Additive Models (GAMs), which can accommodate

206 possible non-linear effects and interactions. Errors were analyzed using Bayesian logistic

207 mixed models, and RTs of correct responses were analyzed using an ex-Gaussian family

208 with the same fixed effects entered for the location μ (mean), scale σ (spread) and

209 tail-dominance τ of the RT distribution (Balota & Yap, 2011; Matzke & Wagenmakers,

210 2009).

211 Using GAMs as the “ground-truth” models, we attempted at approximating them

212 using general linear models, which have the advantage of estimating the participant-level

213 variability of the effects (via random slopes). Following a comparison of models with a

214 combination of transformations (raw, log, square root or cubic root) on the main predictors

215 (task *difficulty* and illusion *strength*), we selected and fitted the best model (based on their

216 indices of fit), and compared their output visually (see **Figure 2**).

217 We then extracted the inter-individual variability in the effect of illusion strength and

218 its interaction with task difficulty, and used it as participant-level scores. Finally, we

219 explored the relationship of these indices across different illusions using exploratory factor

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

221 **Results**

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

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

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

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

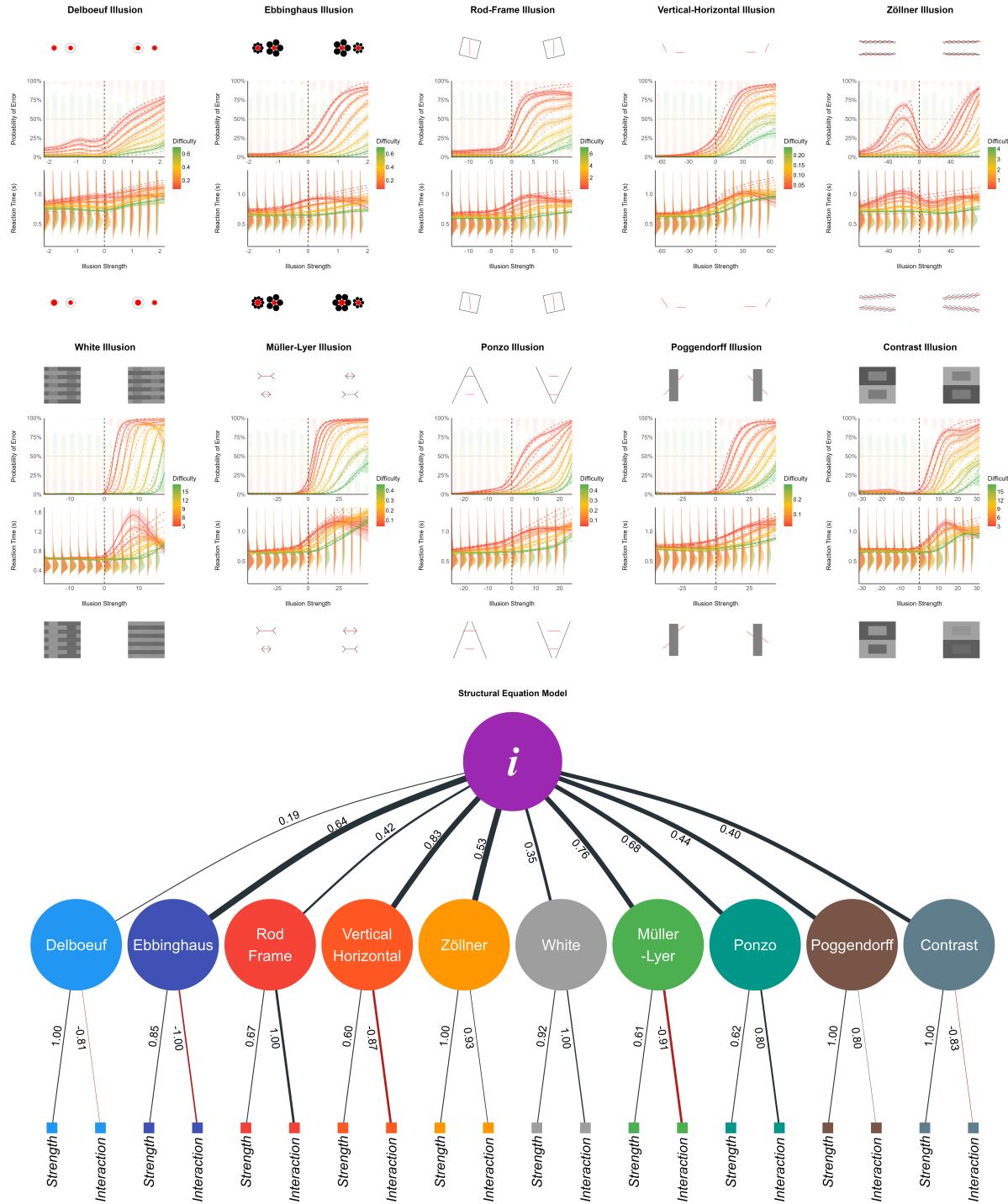


Figure 2. Top: the effect of illusion strength and task difficulty on the error rate and reaction time (RT) for each individual illusion. The solid line represents the General Additive Model (GAM), and the dashed line corresponds to its approximation via linear models. Descriptive data is shown with stacked dots (for which errors start 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 lower values corresponding to harder trials. The results for each illusion are 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 in 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 ranged 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, as well as by the interaction effect with task difficulty (with the exception of Delboeuf, Ebbinghaus, Vertical-Horizontal, Müller-Lyer and Contrast, for which the

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

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

291 Discussion

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

297 models that integrate both errors and reaction time (e.g., drift diffusion models).

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

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

315 Study 3

316 Aim

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

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

328 **Procedure**

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

337 **Data Analysis**

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

344 **Results**

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

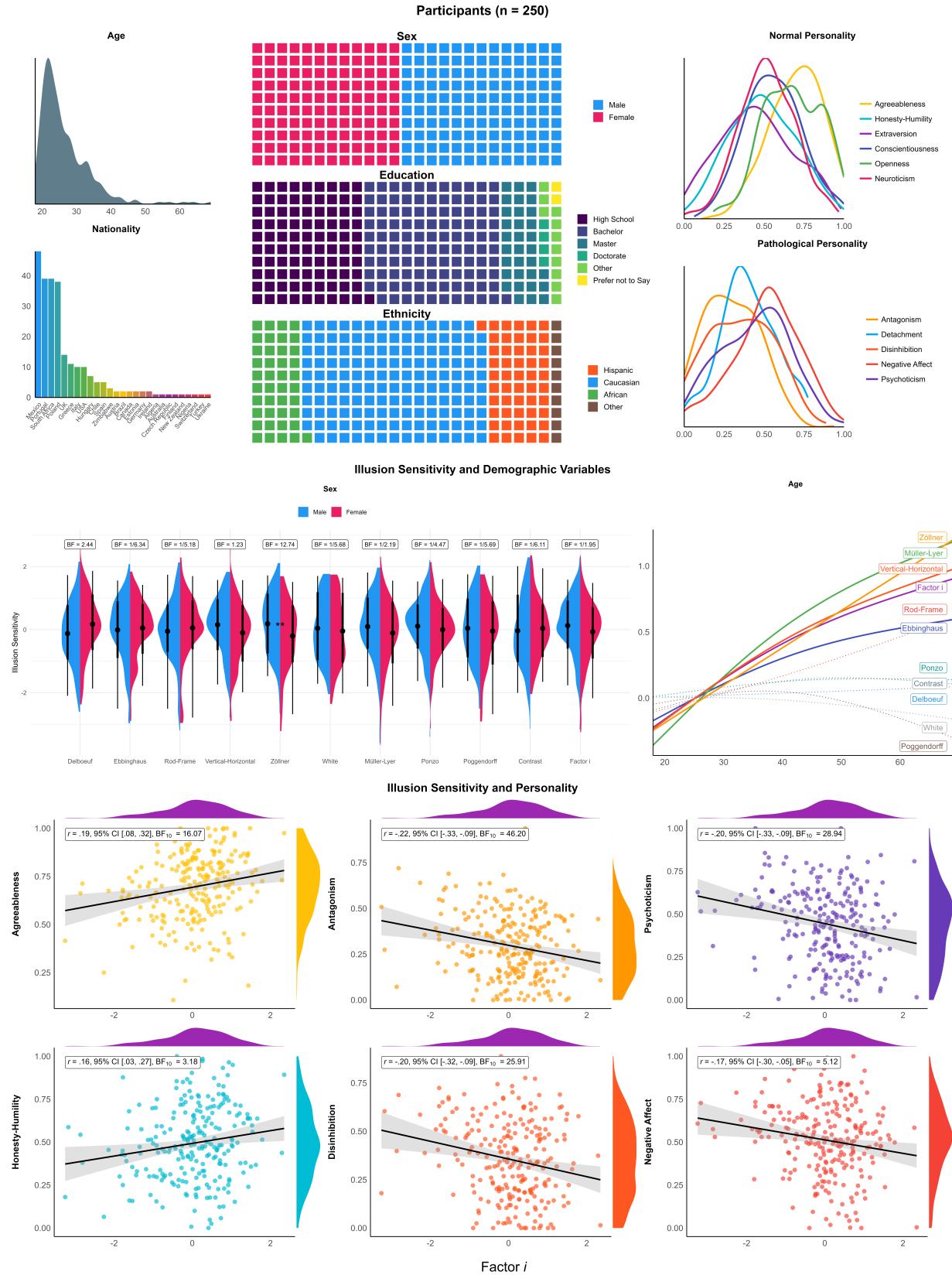


Figure 3. The upper plots show the distribution of demographic and dispositional variables. The middle plots shows the illusion sensitivity scores as a function of sex and age (solid lines indicate significant relationships). Bottom plots show the correlation between the general factor of illusion sensitivity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

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

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

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

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

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

382 Discussion

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

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

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

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

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

425 higher resistance to illusions to a self-centered, decontextualized and disorganized
426 information processing style, which can be found across the aforementioned maladaptive
427 personality traits (Calamari et al., 2000; Hoyle, 2006; Msetfi et al., 2009; 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 2019; 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 Our findings suggest that the sensitivity to 10 different types of visual illusions share
446 a common part of variance, supporting the existence of a general factor of illusion
447 sensitivity (Factor *i*). This result comes in a field of mixed findings. In fact, contrary to
448 early studies on visual illusions, more recent research have generally not found any
449 significant evidence for a common stable factor across illusions within individuals

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

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

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

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

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

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

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

480

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483

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