Is the perception of illusions abnormal in schizophrenia?

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Abstract

There seems to be no common factor for visual perception, i.e., performance in visual tasks correlates only weakly with each other. Similar results were found with visual illusions. One may expect common visual factors for individuals suffering from pathologies that alter brain functioning, such as schizophrenia. For example, patients who are more severely affected by the disease, e.g., stronger positive symptoms, may show increased illusion magnitudes. Here, in the first experiment, we used a battery of seven visual illusions and a mental imagery questionnaire. Illusion magnitudes for the seven illusions did not differ significantly between the patients and controls. In addition, correlations between the different illusions and mental imagery were low. In the second experiment, we tested 59 patients (mostly outpatients) with ten visual illusions. As for the first experiment, patients and controls showed similar susceptibility to all but one visual illusion. Moreover, there were no significant correlations between different illusions, symptoms, or medication type. Thus, it seems that perception of visual illusions is mostly intact in schizophrenia.

Introduction

Numerous studies have tested illusion strength in schizophrenia patients. Results have been mixed and depend on the illusion tested (for a review, see King et al., 2016). For example, studies have found that patients perceive some illusions, such as the Müller-Lyer or the Ponzo illusion, significantly more strongly than controls (Weckowicz and Witney, 1960; Capozzoli and Marsh, 1994; Chen et al., 2011; Diržius et al., 2013; Kantrowitz et al., 2009; Tam et al., 1998). Other studies found non-significant results for the Ebbinghaus illusion and the illusory Kanizsa squares (Kantrowitz et al., 2009; Spencer and Ghorashi, 2014; Tibber et al., 2013; Yang et al., 2013), and some studies have reported that illusion magnitudes of the contrast-contrast illusion, the illusory line motion, and the Hollow mask illusion are significantly weaker in the patients (Barch et al., 2012; Crawford et al., 2010; Dakin et al., 2005; Dima et al., 2009; Emrich et al., 1997; Keane et al., 2013; Letourneau, 1974; Parnas et al., 2001; Robol et al., 2013; Sanders et al., 2013; Schneider et al., 2002; Tadin et al., 2006; Tam et al., 1998; Tibber et al., 2013; Uhlhaas et al., 2006; Yang et al., 2013). Even when it comes to the same illusions, results sometimes differ. For example, some studies found that patients are less influenced by the Ebbinghaus illusion than controls (Tibber et al., 2013; Uhlhaas et al., 2006), whereas Yang et al., (2013) found non-significant results. Similarly, for the Müller-Lyer illusion, both significant and non-significant differences were reported (for a review, see King et al., 2016). Sample sizes are rather small in many of these studies, having on average between 15 and 30 patients, so it may be that the mixed results are a matter of heterogeneous samples and a lack of power. For some of these non-significant results, it is hence unclear whether they reflect "true" null results or whether the studies are underpowered (e.g., Letourneau, 1974, n = 5; Parnas et al., 2001, n = 10; Spencer and Ghorashi, 2014, n = 17; Tibber et al., 2013, n = 24).

Recently in a sample of 144 healthy controls, we found that illusion magnitudes correlated only weakly with each other (Grzeczkowski et al., 2017). It seems that there is no common factor for visual illusions. As a side note, there were also only weak correlations in standard visual tests in young, healthy adults (Bosten and Mollon, 2010; Cappe et al., 2014) and in healthy aging (Shaqiri et al., 2015). Here, we investigated whether there is a common cause for perception of visual illusions in schizophrenia. Such a common factor could be related to the strength of visual hallucinations (Bracha et al., 1989; Ford et al., 2015; Goghari and Harrow, 2016) and increased mental imagery (Brébion et al., 2000, 1997; Oertel et al., 2009; Sack et al., 2005). Waters et al., (2014) report that more than 27% of schizophrenia patients suffer from visual hallucinations. Moreover, schizophrenia patients were found to have a reality-monitoring deficit (Brune, 2005; Frith and Corcoran, 1996), i.e., a decreased ability to discriminate real events from imagined events (Brébion et al., 2000, 1997; Oertel et al., 2009; Sack et al., 2005).

To this end, we used a battery of seven illusions and a questionnaire about the vividness of mental imagery in a first experiment with a sample of 19 schizophrenia patients and 19 controls.

In a second experiment, with a sample of 59 schizophrenia patients and 54 controls, we tested the susceptibility to ten visual illusions. Often, illusions strength is determined with binary judgments where a reference element, such as the central disk in the Ebbinghaus illusion, and a slightly larger or smaller disk are presented (King et al., 2016). Participants indicate whether this disk is larger or smaller than the reference disk. In these experiments, stimuli are hard to discriminate to obtain good estimates, and thus, attention is a crucial component. However, attention is often deficient in the patients, adding a confounding factor (Chkonia et al., 2010; Perlstein et al., 1998). To avoid this problem, we used an adjustment procedure, where participants adjusted their precepts with the computer mouse.

To preface our results, we found almost no significant differences between controls and patients in illusion magnitudes nor in the vividness of mental imagery. In addition, illusion magnitudes of the patients correlated only weakly with each other, and this was also true for controls. We suggest that the perception of illusions is largely intact in patients (for a review see King et al., 2016; Notredame et al., 2014).

1 General Methods

1.1 Participants

Participants were schizophrenia patients either from the Tbilisi Mental Health Hospital or the psychosocial rehabilitation center and healthy, age and education-matched controls, from the general population from Tbilisi (see Table 1 for details). Patients were diagnosed according to DSM-IV by means of an interview based on the SCID, information of the staff, and the study of the records. Psychopathology of schizophrenia patients was assessed by an experienced psychiatrist (EC) by Scales for the Assessment of Negative Symptoms and Scales for the Assessment of Positive Symptoms (SANS, SAPS; Andreasen, 1984a, 1984b). All participants had visual acuity of equal or greater than 0.8 for at least one eye, as measured with the Fribourg Visual Acuity Test (Bach, 1996). All participants signed informed consent before the experiment.

All procedures were in accordance with the Declaration of Helsinki and were approved by The Georgian National Council on Bioethics in Tbilisi.

Table 1. Descriptive statistics (± standard deviation) for schizophrenia patients and healthy controls for both experiments. SZ = schizophrenia patients. HC = healthy controls. SAPS/SANS = Scale for the assessment of positive/negative symptoms (global scores). VVIQ = vividness of mental imagery questionnaire. CPZ = chlorpromazine-equivalent dosage. Education score corresponds to the number of years spent at school and higher education. Illness duration is expressed in years.

	Exp. 1				Exp. 2			
	SZ	HC	$t_{[df]}$	p	SZ	HC	$t_{[df]}$	p
Sex (F/M)	5/14	5/14	-	-	14/45	26/28	-	-
Age	49 ± 9.3	40 ± 6.6	$0.42_{[36]}$	0.675	38 ± 8.3	38 ± 9.2	$0.15_{[108]}$	0.881
Age range	22 - 53	27 - 50	-	-	22 - 55	24 - 55	-	-
Education	13.3 ± 2.5	15 ± 2.8	$2.08_{[36]}$	0.045	13.3 ± 2.4	15.3 ± 2.5	$4.14_{[100]}$	<0.001
VVIQ	104 ± 22	118 ± 25	$1.94_{[36]}$	0.060	-	-	-	-
SAPS	9.3 ± 3.5	-	-	-	8.4 ± 2.3	-	-	-
SAPS range	3 - 16	-	-	-	4 - 17	-	-	-
SANS	10 ± 5.3	-	-	-	10 ± 5.1	-	-	-
SANS range	0 - 20	-	-	-	2 - 20	-	-	-
Illness duration	14 ± 9	-	-	-	14.5 ± 8	-	-	-
CPZ	610 ± 387	-	-	-	641 ± 418	-	-	-
Patients (in/out)	8/11	-	-	-	11/53	-	-	-

1.2 Apparatus

Experiment 1 was performed on a Dell Latitude E5540 computer with a 15-inch screen. Experiment 2 was performed on a desktop computer, equipped with a 24-inch, BenQ XL2420T monitor. In both experiments, the screen resolution was set up to 1920 x 1080 pixels and was refreshed at a rate of 60 Hz. Stimuli were generated with Matlab 2013b (version 3.1, 64 bits) and the Psychophysics toolbox (Brainard, 1997; Pelli, 1997). Participants sat at ~60 cm from the screen and used a Logitech LS1 computer mouse for stimuli adjustments.

1.3 Adjustment Procedure

First, all illusions were shown one by one on the screen and the adjustment procedure was explained by the experimenter. For each illusion, participants compared a reference stimulus to a target stimulus that they adjusted by displacing the computer mouse on its horizontal axis. Each participant performed two trials per illusion without time restrictions. Illusions were adjusted in the same order by each participant: Ebbinghaus, Müller-Lyer, Ponzo, simultaneous contrast, Ponzo "hallway", White's and tilt for Exp. 1; and Ebbinghaus 1, Ebbinghaus 2 "small", Ebbinghaus 3 "big", Müller-Lyer, Ponzo, Ponzo "wide", simultaneous contrast, Ponzo "grid", White's and tilt for Exp. 2. Participants were asked to make their adjustments relying on their perception and to ignore any prior knowledge they may have had of visual illusions. At the end of each experiment, participants were debriefed and they could see their own results on the computer screen.

1.4 Data Analysis

For each participant and trial, the raw data was transformed into percentage of error in the following manner: for all illusions, except the tilt illusion, the reference value of the disk diameter, length, or luminance was subtracted from the adjusted stimulus diameter, length, or luminance. That difference was then divided by the value of the reference stimulus and multiplied by 100. Similarly, for the tilt illusion, the reference angle (33 degrees) was first subtracted from the adjusted angle, then divided by the maximum possible bias (i.e., range between the inner and the surround orientation of the inducer stimulus = 69 degrees). Thus, for the tilt illusion, 1 degree of error corresponds to 1.45% of error. Therefore, an adjusted size, length, luminance, or angle that perfectly corresponded to the reference stimulus has a value of zero percentage of bias. To the contrary, 100% of bias would correspond to a doubled reference value (e.g., reference stimulus length= 4 deg, adjusted stimulus length = 8 deg).

2 Experiment 1

2.1 Stimuli

The illusion magnitudes for seven visual illusions were determined: Ebbinghaus illusion (EB), Müller-Lyer illusion (ML), Ponzo illusion (PZ), simultaneous contrast illusion (SC), Ponzo "hallway" illusion (PZh), White's illusion (WH), and tilt (TT) illusion (Figure 1). The reference stimulus for the Ebbinghaus, Müller-Lyer and tilt illusions was centered at 8 degrees to the left from the center of the screen and the adjustable stimulus at 8 degrees to the right.

2.1.1 Ebbinghaus Illusion (EB)

The reference was a white disk of 2 degrees in diameter, surrounded by sixteen smaller yellow disks (inducers), 0.5 degrees of diameter each. The distance between the centers of the reference disk and the small inducers was 1.6 degrees. Large inducers, surrounding the adjustable disk were 4 degrees in diameter. The distance between the center of the adjustable disk and the center of each large inducer was 5 degrees. At the beginning of each trial, the adjustable disk appeared with a random size in the range of 0 to 6 degrees in diameter. Both the luminance of the yellow surrounding disks and the white central disks was 128 cd/m^2. The background luminance was 1 cd/m^2.

2.1.2 Müller-Lyer illusion (ML)

The length of the reference line was 5.4 degrees and it was always presented with inward-pointing arrows. The lines composing the arrows were 1-degree long. The adjustable line was always presented with outward-pointing arrows and its starting length varied randomly between 0 and 16 degrees. The line's luminance was 128 cd/m^2.

2.1.3 Ponzo illusion (PZ)

The reference stimulus was the yellow (128 cd/m^2), 3 degrees long, horizontal, lower line. The adjustable line was the horizontal, upper yellow line. The initial length of the adjustable line varied randomly from trial to trial but never extended beyond 16 degrees. Both the reference and the adjustable lines were centered on the vertical midline of the screen and were placed at 3 degrees from the horizontal screen midline. The ends of the white diagonal lines (inducers) were placed at 3.8 degrees from the horizontal screen midline. The distances between the two upper and lower line ends were 3 and 7.6 degrees respectively.

2.1.4 Simultaneous contrast illusion (SC)

The reference and the adjustable stimuli were small squares with a side-length of 2.6 degrees placed at 3.9 degrees to the left and right of the screen center, respectively. The luminance of the reference square was 35 cd/m^2. These small squares were embedded in bigger, 7.8 degree squares. The luminance of the big square placed on the left was 15 cd/m^2 and 70 cd/m^2 for the one on the right.

2.1.5 Ponzo "hallway" illusion (PZh)

The diameter of the reference disk was 1.6 degrees. The disk was located on the top-right hand corner, 14.4 degrees from the screen's center. The adjustable disk appeared on the lower-left hand corner, 10.8 degrees from the screen's center. The luminance of both disks was 15 cd/m^2. During the adjustment, the lowest point of the adjustable disk was fixed while its center moved up. This created the impression that the disk was anchored to the image background. The background image was a 1920 x 1080 pixel resolution grayscale picture of a hallway at the EPFL campus.

2.1.6 White's illusion (WH)

The background was composed of alternating dark (1 cd/m^2) and light (128 cd/m^2) horizontal, 1.75 degree wide stripes. The gray reference rectangles on the left were 1.75 degrees tall and 3.6 degrees wide. They were presented on light bands and their luminance was 15 cd/m^2. The adjustable rectangles appearing on the right lay on dark bands and were the same size as their reference counterparts. All rectangles were at 1.6 degrees from the screen's vertical meridian. During adjustments, the rightward rectangles changed gradually in luminance, with a starting luminance chosen randomly at the beginning of each trial from between 0 and 128 cd/m^2.

2.1.7 Tilt illusion (TT)

The reference and the adjustable stimuli were disks with a diameter of 4 degrees, each containing a 0.5 cycles/deg full contrast grating texture. The reference disk was tilted 33 degrees towards the clockwise direction from vertical and was embedded in a larger disk (13 degrees in diameter) with the same spatial frequency but tilted 36 degrees towards the counter-clockwise direction. The background luminance was 15 cd/m^2. The adjustable disk appeared with a random orientation between 0 and 360 degrees.

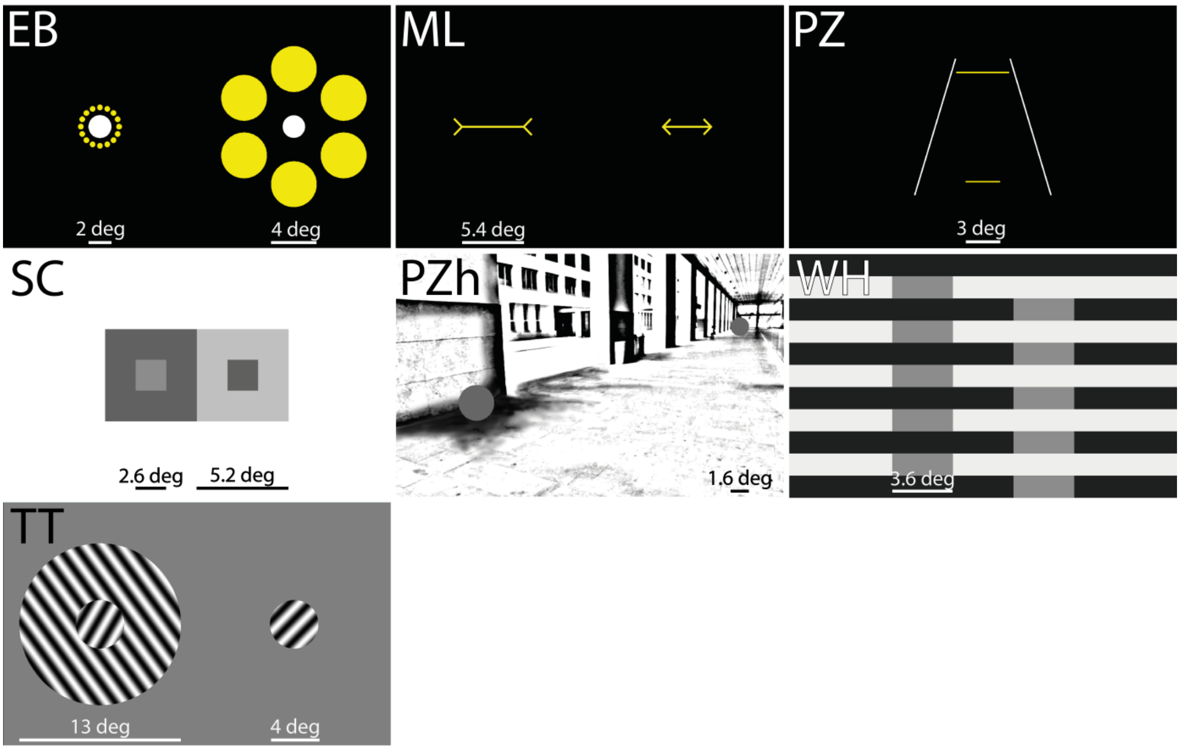

Figure 1. The seven visual illusions used in Exp. 1. In the Ebbinghaus illusion (EB), participants adjusted the size of the right white disk to the size of the white disk on the left. In the Müller-Lyer illusion (ML), participants adjusted the length of the line on the right to the one on the left. In the Ponzo (PZ) illusion, participants adjusted the length of the upper horizontal yellow line to match that of the lower horizontal yellow line. In the simultaneous contrast illusion (SC), participants adjusted the luminance of the right center square to the left center square. In the Ponzo "hallway" illusion (PZh), participants adjusted the size of the lower-left gray disk to that of the upper-right gray disk. In the White's illusion (WH), participants adjusted the luminance of gray bars on the right to the luminance of the bars on the left. In the tilt illusion

(TT), participants adjusted the orientation of the right disk to that of the left disk embedded in the counter-clockwise tilted surround. For each illusion, participants performed two adjustment trials.

2.2 Vividness of visual imagery questionnaire

Prior to the illusion magnitude assessments, participants completed the vividness of visual imagery questionnaire (VVIQ; Marks, 1973). Participants were asked to generate mental images described in each of sixteen items, and then to estimate the vividness of these mental images by circling the corresponding number in a five-point scale (1 - no image at all, you only « know » you are thinking of an object; 2 - vague and dim; 3 - moderately clear and vivid; 4 - clear and reasonably vivid; 5 - perfectly clear and vivid as normal vision). The VVIQ was first completed with open- and then with closed-eyes when generating mental images. Scores from both eyes were summed to give a final VVIQ score.

2.3 Results

2.3.1 Test-retest reliability

We determined illusions magnitude with 2 trials for each observer. To determine test-retest reliability, we correlated the two trials. Test-retest reliability was highly significant for the control group for all the seven illusions (Table 2, second row). For the schizophrenia patients (Table 2, first row), correlations were significant for five out of seven illusions, but not for the Müller-Lyer and the White's illusion. After correction for multiple comparisons (Bonferroni, p = 0.0036), all significant correlations except for the tilt illusion remained significant. Test-retest reliability of VVIQ is high (e.g., Burton and Fogarty, 2003).

Table 2. Test-retest reliability expressed as Bravais-Pearson's *R* correlations between the first and the second trial for seven visual illusions for schizophrenia patients (SZ, first row) and age-matched, healthy controls (HS, second row).

	EB	ML	PZ	SC	PZh	WH	TT
SZ	.78 ★★★	.19	.85 ★★★	.87 ★★★	.89 ★★★	.44	.58 ★★
HC	.82 ★★★	.84 ★★★	.90 ★★★	.89 ★★★	.98 ★★★	.76 ★★★	.74 ★★★

★★ $p < 0.01$; ★★★ $p < 0.004$ (corrected)

2.3.2 Illusion magnitudes

Next, we averaged the illusion magnitudes for the 2 trials (Figure 2). Independent samples *t*-tests were performed to compare illusion magnitudes between controls and patients separately for each illusion. None of the comparisons was significantly different. Corrections for multiple comparisons were not applied.

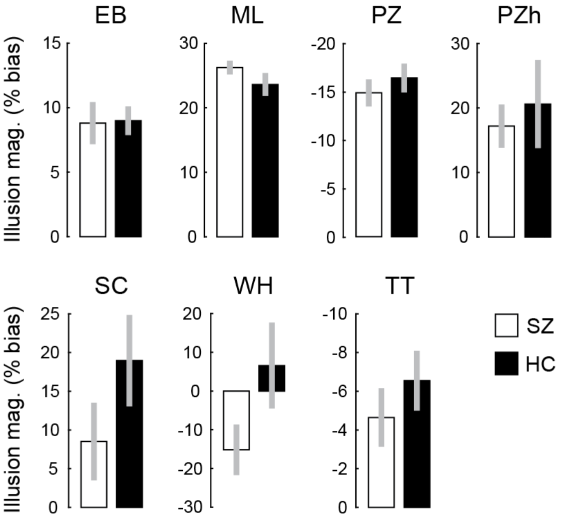

Figure 2. Average illusion magnitudes for healthy controls (HC, white) and schizophrenia patients (SZ, black). Illusion magnitudes were not significantly different between patients and controls. We did not apply Bonferroni corrections for multiple comparisons. Hence, these null results are not caused by the adjustment for multiple comparisons. Error bars denote ±SEM. For details see supplementary Table 1.

2.3.3 Pairwise correlations

Next, pairwise correlations for all pairs of illusions and imagery scores were calculated for both groups separately. Additionally, for the patients, SANS and SAPS scores were included into the analysis. For the group of healthy controls, only three correlations were statistically significant (Figure 3, upper panel; see supplementary table 2 for details): the Ponzo and Müller-Lyer, the Ponzo "hallway" and Müller-Lyer, and the tilt and simultaneous contrast. For the group of schizophrenia patients, the Ponzo and Müller-Lyer, the Ponzo "hallway" and Ebbinghaus, and the White's and simultaneous contrast correlations were significant (Figure 3, lower panel; see supplementary table 3 for details). Because we had a large number of comparisons (28 for the controls and 45 for schizophrenia patients), we conducted a less conservative correction for multiple comparisons than the Bonferroni correction, i.e., the Holm-Bonferroni correction. After correction, only the correlation between the White's and the simultaneous contrast illusion remained significant (Figure 3, three black stars; see supplementary table 8 for details relative to the Holm-Bonferroni correction). On average, correlations including visual illusions and the VVIQ score were slightly higher for the controls (R = 0.28±0.17) than for the patients (R = 0.20±0.19), although that difference was not statistically significant (Table 1)

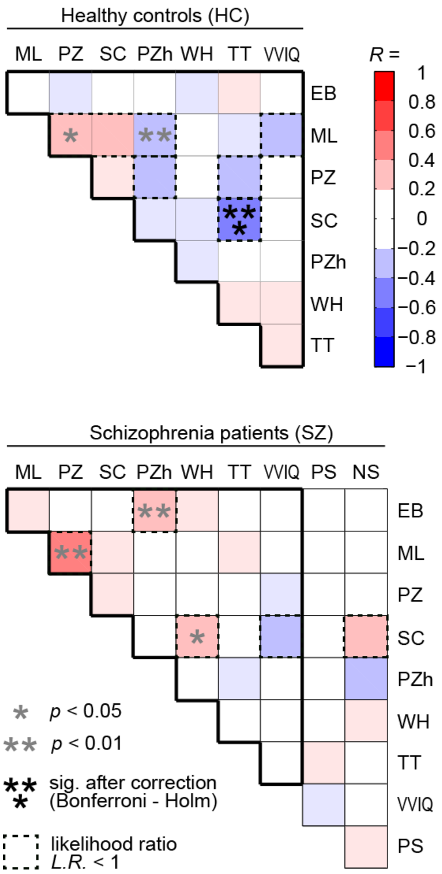

Figure 3. Correlograms for controls (HC, upper panel) and patients (SZ, lower panel). in Exp. 1 and likelihood ratios for pairwise comparisons. Colors indicate Bravais-Pearson's *R* correlation coefficient. Bold lines delineate comparisons between the variables tested in both groups, i.e., the seven illusions and the vividness of visual mental imagery score (VVIQ). Generally, correlations were low and only a few were significant. Correlations were weaker amongst schizophrenia patients. Illusion magnitudes of the Ponzo and Müller-Lyer illusions were significantly correlated in both groups. In addition in the control group, the Ponzo "hallway" and the Müller-Lyer illusion, and the tilt and the simultaneous contrast illusions were significantly correlated. In the schizophrenia group, the Ponzo "hallway" and the Ebbinghaus illusions, and the simultaneous contrast and White's illusions were significantly correlated. The VVIQ score did not correlate significantly with any other variable in none of the two groups. Similarly, SAPS and SANS scores did not correlate significantly with any other variable amongst schizophrenia patients. Only the correlations between the tilt and the simultaneous contrast illusion remained significant after correction for multiple comparisons (Bonferroni-Holm; shown as three black stars). For details, see supplementary Tables 2 and 3. A Bayesian analysis was used to evaluate the likelihood of existence or absence of relationship

between pairwise comparisons. Bayesian likelihood ratios (L.R.) greater than one indicate support for the null hypothesis (supporting the absence of an effect) and values lower than one indicate support for the alternative hypothesis (supporting the existence of an effect; dashed line boxes).

2.3.4 Bayes analysis

We adopted a Bayesian approach in order to make statements beyond the usual "*reject* or *fail to reject* the null hypothesis" outlined by Gallistel (2009) and implemented a method that was previously reported (Cappe et al., 2014). We measured for which comparisons the null hypothesis was more likely than the alternative hypothesis, given the data. The Bayesian analysis showed that the alternative hypothesis is more probable than the null hypothesis for all the pairwise comparisons that were shown to correlate significantly within the control group (Figure 3, dashed line; Ponzo - Müller-Lyer, Ponzo "hallway" - Müller-Lyer and tilt – simultaneous contrast) and amongst the schizophrenia patients (Ponzo - Müller-Lyer, Ponzo "hallway" - Ebbinghaus, Whites's – simultaneous contrast) and for some other pairwise comparisons in each group (controls, simultaneous contrast - Müller-Lyer, Ponzo "hallway" - Ponzo, tilt - Ponzo, VVIQ-Müller-Lyer; patients, VVIQ - simultaneous contrast, SANS - simultaneous contrast).

2.3.5 Rank analysis

One could expect that a participant highly susceptible to one illusion is also highly susceptible to other illusions. Similarly, if a given participant has a very vivid mental imagery, one could expect that the participant is strongly susceptible to all illusions. To the contrary, if there is no relationship between variables (here, illusion magnitudes and the VVIQ score), then participants' mean ranks are expected to be no different from chance. To test this hypothesis, we calculated each participant's rank for each variable. Then, we computed their mean ranks and compared the ranks with the ranks that would be expected from participants with random ranks (with random ranks averaged over 10,000 simulations). Results showed that neither the ranks of schizophrenia patients ($\chi^2_{(18)} = 0.36$, $p = 1$) nor of the controls ($\chi^2_{(18)} = 0.48$, $p = 1$) were significantly different from chance (Figure 4).

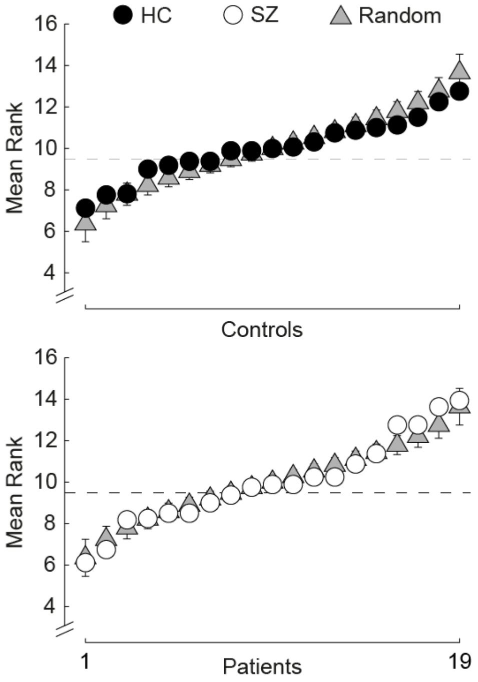

Figure 4. Ranks for each participant averaged over seven illusion magnitudes and the VVIQ score for the controls (upper panel, black disks) and the schizophrenia patients (lower panel, white disks) sorted by mean rank. Random simulated ranks, sorted by mean rank (±1 SD over 10,000 simulations, gray triangles). For both groups, i.e., patients and controls, mean ranks were not different from chance.

3 Experiment 2

Here, additionally to assessing the problem of the sample size in Exp. 1, we also asked whether different components of the same visual illusion are related and to which extent different illusions of the same kind are related. Thus, we measured the over- and the under-estimated components of the Ebbinghaus illusion separately (Figure 5; EBs: Ebbinghaus "small" and EBb: Ebbinghaus "big", respectively) and simultaneously (Figure 5; Ebbinghaus) and the susceptibility to three different variants of the Ponzo illusion (Ponzo, PZ; Ponzo "wide", PZw; and Ponzo "grid", PZg; Figure 5). Finally, for the schizophrenia patients, we included the medication type and its quantity to the analysis in order to test for their potential effects.

3.1 Methods

3.1.1 Stimuli

We determined illusion magnitudes for ten visual illusions (Figure 5). Six of them, namely the Ebbinghaus, the Müller-Lyer, the Ponzo, the White's, the simultaneous contrast and, the tilt illusions were the same as in Exp. 1. Stimuli layout and proportions were the same as in Exp. 1 but scaled by a factor of ≈1.5 because they were presented on a larger screen. Additionally, we measured the Ebbinghaus illusion with small (EBs) and big (EBb) inducers separately, and two different variants of the Ponzo illusion (PZw and PZg).

3.1.1.1 Ebbinghaus Illusions (EB, EBs and EBb)

Illusion susceptibility to three variants of the Ebbinghaus illusion was tested. First variant (EB) was the same as in Exp. 1. The second variant of the illusion (EBs) did not contain large inducers, thus the small inducers were surrounding the reference disk and the rightward, adjustable disk was not surrounded by any inducers. In the third variant (EBb), large inducers were placed around the leftward reference disk while the adjustable disk was not surrounded by any inducers.

3.1.1.2 Additional Ponzo illusions (PZw and PZg)

In the Ponzo "wide" illusion (PZw), participants adjusted the upper horizontal line to match its length to the lower horizontal reference line. The reference was a 4.5 degrees long line. All lines were gray (≈ 30.6 cd/m^2). The initial length of the adjustable line was randomized from trial to trial and varied from 0 to 12 degrees. Both, the reference and the adjustable lines were centered on the vertical midline of the screen and were placed at 7.2 degrees from the screen's horizontal midline. The ends of the white diagonal lines (illusion inducers) were placed at 7.2 degrees from the screen's horizontal midline. The two upper and lower line ends of inducer lines were 6 and 18 degrees apart, respectively. In the Ponzo "grid" illusion (PZg), the reference stimulus was 5 degrees long, horizontal, lower line embed in a trapezoid which was embed in a grid aiming to induce perspective (Figure 5). The adjustable line was the horizontal, upper line embed in another trapezoid of the same size placed on the horizon line. Both trapezoids were isosceles trapezoids whose big (lower) and small (upper) edges were 15 and 9.2 degrees long, respectively. The starting length of the adjustable line was randomized at each trial within a range of 0 to 22 degrees. Both, the reference and the adjustable lines were centered on the screen's vertical midline and were placed at horizontal distances from the screen's midline of 10 and 4.5 degrees, respectively. All lines had approximately the same luminance of 30.6 cd/m^2.

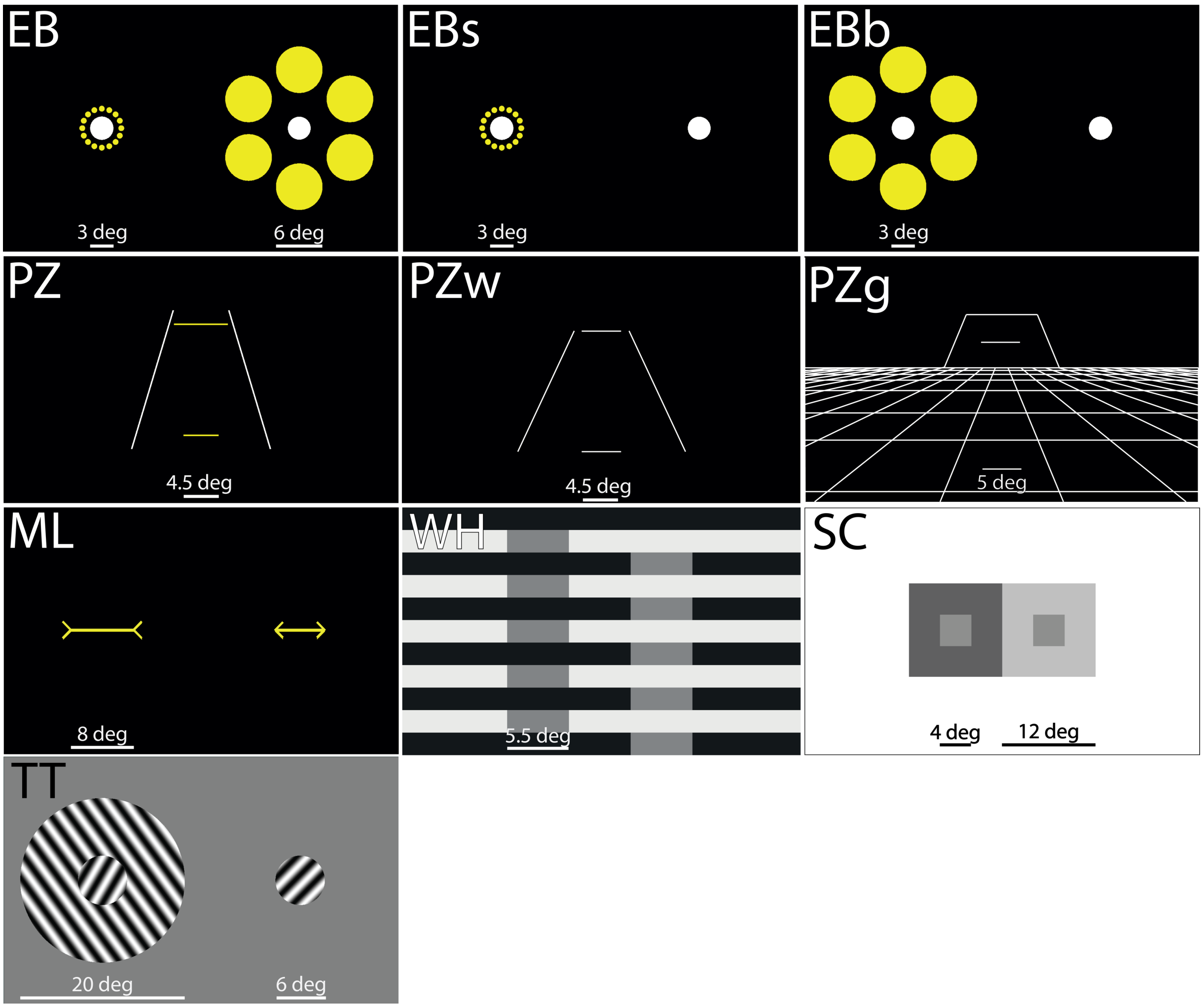

Figure 5. The susceptibility to ten visual illusions was tested in Exp. 2. We tested the susceptibility to the Ebbinghaus illusion with small and big inducers at the same time (EB) and separately (EBs and EBb). The susceptibility to three variants of the Ponzo illusions was measured: the same as in Exp. 1 (PZ), a wider version aiming to maximize the illusion (PZw) and a version with an inducing perspective grid (PZg). The

Müller-Lyer (ML), White's (WH), simultaneous contrast (SC) and the tilt (TT) illusions were the same as in Exp. 1. Likewise in Exp. 1, the task was to adjust the adjustable element of each illusion to its reference by using the computer mouse.

3.1.2 Medication

The medication type (MED) and its quantity (CPZ) were included in the part of the analysis. Schizophrenia patients were classified depending on the medication type they receive as no medication (0) typical (1), atypical (2), mixture of both (3), containing benzodiazepines (4).

3.2 Results

3.2.1 Test-retest reliability

Similarly to Exp. 1, the test-retest reliability was measured for each illusion by calculating Bravais-Pearson's correlations between both trials for each illusion. All correlations were highly significant for both groups (Table 3). Except from the patient's White's illusion, all correlations remained significant after Bonferroni correction (p = 0.0025).

Table 3. Test-retest reliability in Exp. 2. Bravais-Pearson's R correlations coefficients between the first and the second trial for ten visual illusions for schizophrenia patients (SZ, first row) and age-matched, healthy controls (HS, second row). All correlations were highly significant suggesting high reliability.

	EB	EBs	EBb	ML	PZ	PZw	PZg	SC	WH	TT
SZ	.55 ★★★	.49 ★★★	.58 ★★★	.60 ★★★	.61 ★★★	.59 ★★★	.86 ★★★	.41 ★★★	.35 ★★	.59 ★★★
HC	.56 ★★★	.72 ★★★	.48 ★★★	.45 ★★★	.76 ★★★	.61 ★★★	.83 ★★★	.85 ★★★	.52 ★★★	.48 ★★★

★★ $p < 0.01$; ★★★ $p < 0.0025$ (corrected)

3.2.2 Illusion magnitudes

Individual illusion magnitudes were calculated by averaging the adjusted bias (or error) from both trials. We compared illusion magnitudes of patients and controls for each illusion by calculating independent samples t-tests without the assumption of equal variances. Satterthwaite's approximation for the effective degrees of freedom was calculated. Amongst ten comparisons, only one comparison was significantly different (Figure 6; see supplementary Table 4 for details). Schizophrenia patients were less susceptible to the simultaneous contrast illusion (SC) than controls ($t_{[103]} = 3.33$, $p = 0.0012$). According to Cohen (1988), that effect size is medium size ($d = 0.46$). The effect remains significant after correcting for multiple comparisons ($\alpha = 0.05/10 = 0.005$; Bonferroni correction).

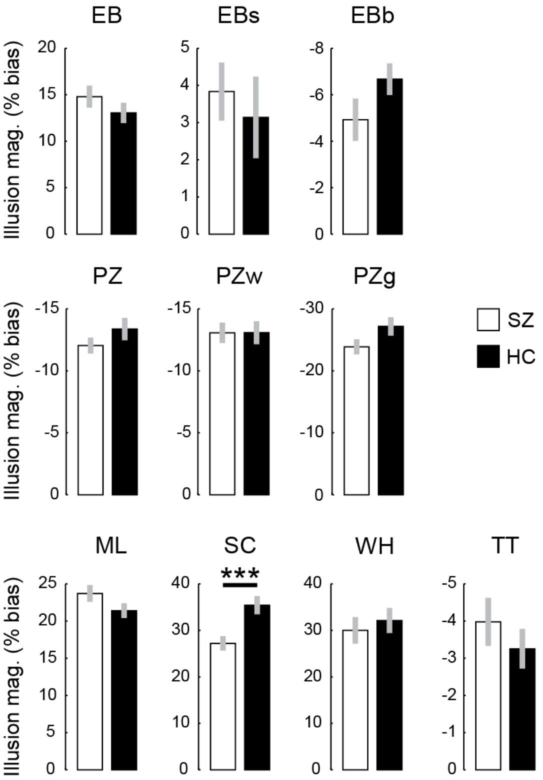

Figure 6. Exp 2: Mean illusion magnitudes as the percentage of bias (or error) for schizophrenia patients (SZ, white) and healthy controls (HC, black). Note that scales for different illusions vary. The higher the absolute value of the magnitude, the higher the illusion susceptibility. Significant difference between patients and controls was found only for the simultaneous contrast illusion (SC). Patients were significantly less susceptible to the illusion than the controls ($p = 0.0012$, $d = 0.46$) even after Bonferroni correction for multiple comparisons. For more details see supplementary Table 4. Error bars represent ±SEM.

3.2.3 Pairwise correlations

For both groups, correlations were calculated in the same manner as in Exp. 1. For the controls, correlations were calculated for the ten illusions and the age of the participants. For schizophrenia patients, the ten illusions, age, SANS and SAPS scores, the medication type (MED) and its overall quantity, expressed as chlorpromazine-equivalent dosage (CPZ) were inter-correlated. Similarly to Exp.1, a large number of correlations was calculated (45 for the controls and 105 for schizophrenia patients), thus, we conducted a less conservative, Holm-Bonferroni correction for multiple comparisons instead of the Bonferroni correction. Expectedly, the three variants of the Ponzo illusion (PZ, PZw and PZg) were strongly and positively correlated for both groups (for details, see supplementary Tables 5 and 6). For the control group, the Ebbinghaus with small inducers (EBs) was strongly correlated to the Ebbinghaus containing both, the small and the big inducers (EB), the Müller-Lyer illusion (ML) and, the Ponzo illusion with the perspective grid (PZg) but not to the Ebbinghaus with large inducers only (EBb). All other comparisons were not significantly correlated after Holm-Bonferroni correction (see the supplementary table 8 for details concerning the corrected p-values).

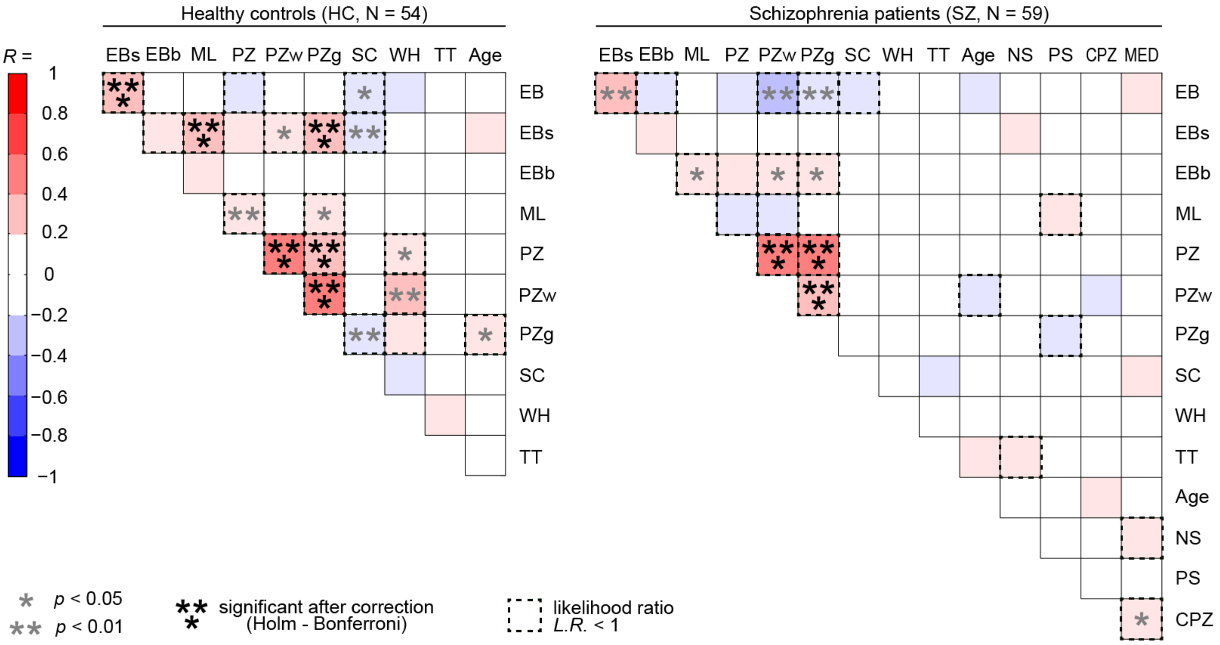

Figure 7. Correlograms for controls (left panel) and patients (right panel) in Exp. 2 and likelihood ratios for pairwise comparisons. Colors indicate Bravais-Pearson’s *R* correlation coefficients. Significant correlations are marked by gray stars, those of them remaining significant after correction for multiple comparisons (Holm-Bonferroni) are marked by black stars. Unsurprisingly, all three Ponzo illusions (PZ, PZw and PZg)

were strongly correlated in both groups. For the controls, the Ebbinghaus with small inducers (EBs) was strongly correlated to the Ebbinghaus with small and big inducers (EB), the Müller-Lyer illusion (ML), and, the Ponzo illusion with a perspective grid (PZg). All other correlations were not statistically significant after correction for multiple comparisons (Holm-Bonferroni). Amongst these significant correlations, only three were strong, namely the White's (WH) and Ponzo "wide" (PZw) correlation amongst the controls, and the Ebbinghaus (EB) and Ebbinghaus "small" (EBs), and the Ebbinghaus (EB) and the Ponzo "wide" (PZw) correlations amongst the patients.. Similarly to Exp. 1, negative (NS) and positive (PS) symptoms scores assessed with SANS and SAPS inventories, respectively, did not correlate significantly with any other variable. Interestingly, the type of medication (MED), or its overall amount (CPZ) were not related to any other variable. For all the details, see supplementary Tables 5 and 6. Bayesian likelihood ratios (L.R.) greater than one (dashed line boxes) indicate support for the null hypothesis (supporting the absence of an effect) and values lower than one indicate support for the alternative hypothesis (supporting the existence of an effect). For most of the comparisons, the L.R.s support the absence of effects.

3.2.4 Bayesian analysis

We adopted the same Bayesian analysis on all pairwise comparisons as in Exp.1 (Cappe et al., 2014; Gallistel, 2009). For both patients and controls, we measured for which comparisons the null hypothesis was more likely than the alternative hypothesis, given the data. The alternative hypothesis, (suggesting existence of an effect) was more probable than the null hypothesis (suggesting the absence of an effect) for all significantly correlated pairs within both groups (Figure 7, dashed line boxes). Additionally, Bayes analysis suggested the existence of an effect for three other, non-correlated comparisons amongst controls and nine amongst patients.

3.2.5 Rank analysis

As in Exp. 1, we calculated mean ranks for controls and patients in order to verify if some participants are generally more or less susceptible to visual illusions. Results showed that neither the ranks of schizophrenia patients ($\chi^2_{(18)} = 0.36$, $p = 1$) nor of the controls ($\chi^2_{(18)} = 0.48$, $p = 1$) were significantly different from simulated, random ranks averaged over 10,000 simulations (Figure 8).

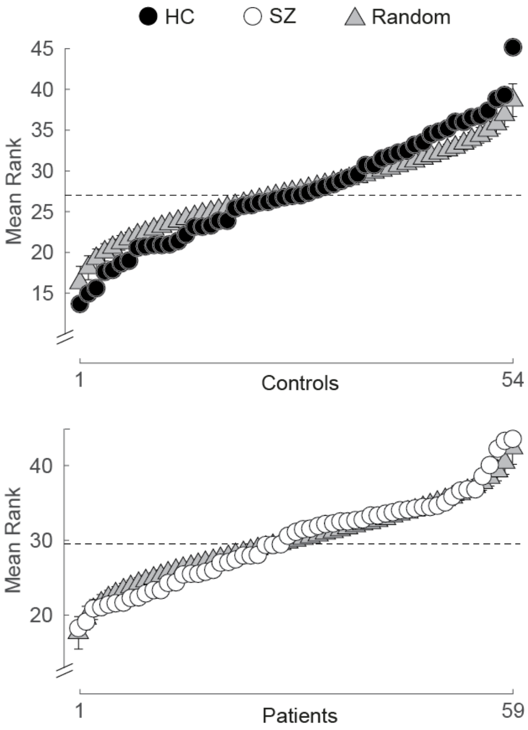

Figure 8. Mean ranks for each control participant (upper panel, black disks) and patient (lower panel, white disks) averaged over ten illusion magnitudes and sorted by mean rank. Random simulated ranks, sorted by mean rank (±1 SD over 10,000 simulations, gray triangles). Mean ranks for patients and controls were not different from chance.

3.2.6 Principal component analysis (PCA)

In order to reduce the dimensionality of our data and to identify potential hidden factors, we conducted a principal component analysis (PCA). PCA included both patients and controls and was conducted on eleven variables, i.e., the ten illusions magnitudes and age. Two principal components (PC1 and PC2) were identified by the means of the scree plot inspection (Figure 9a). The PC1, explaining 23.8% of the variability in the data was mainly composed by the three Ponzo illusions (PZg, PZ and PZw) with respective loadings of 0.52, 0.51 and 0.51 (Figure 9c, left panel; Figure 9d). The PC2, explained 17% of the variance and was dominated by loadings of EB, EBs and ML illusion, with loadings of 0.56, 0.51 and 0.40, respectively (Figure 9c, right panel; Figure 9d). For more details see supplementary Table 7. Importantly, patients did not differ from controls in their eigenvalues for PC1 and PC2 (Figure 9b), suggesting that the cumulated explained variance (PC1 + PC2 = 40.8%) was unrelated to the belonging of the participants to the patient or control group. Age did not load importantly on any of the two principal components.

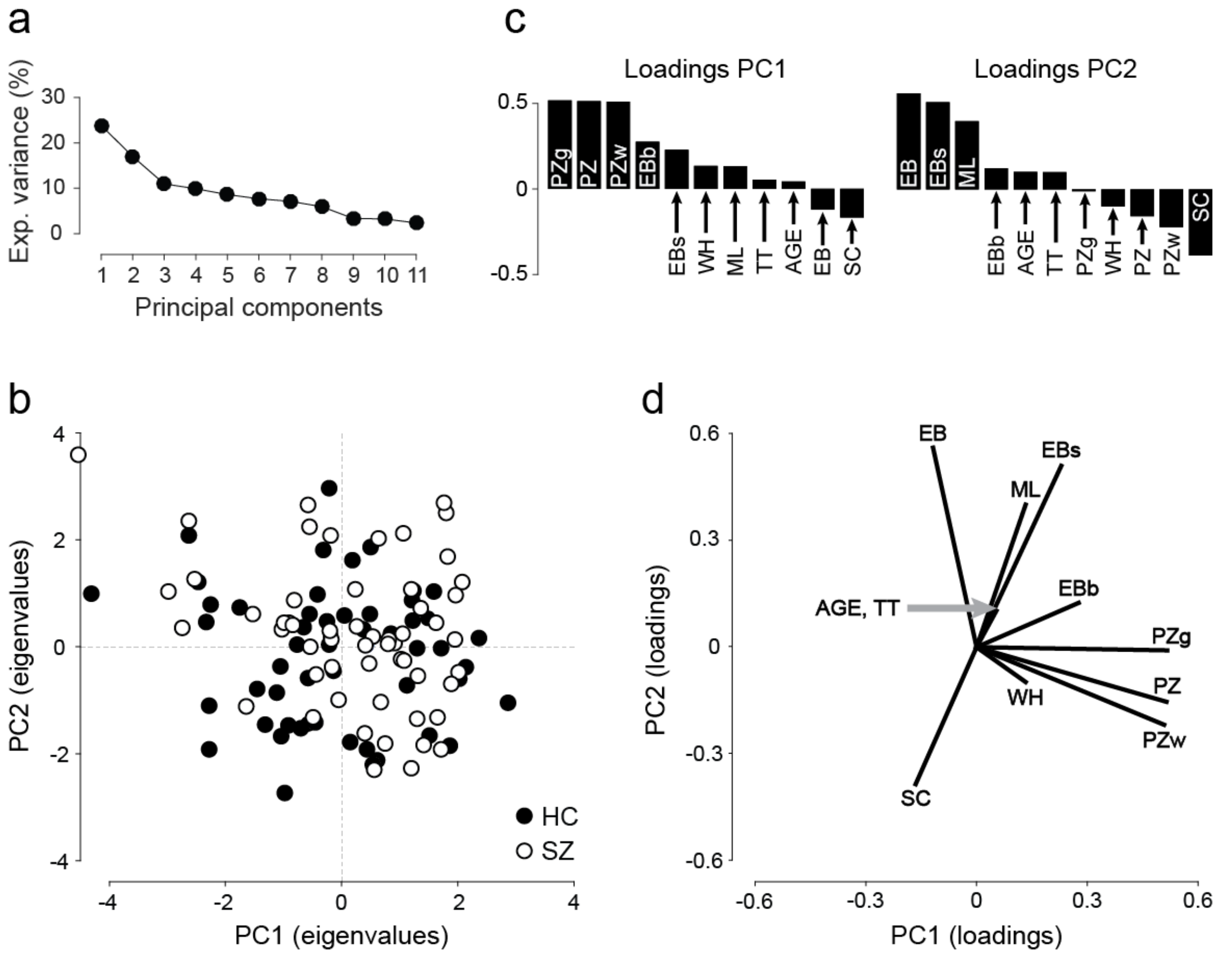

Figure 9. A principal component analysis (PCA) was performed on the data of patients (SZ) and controls (HC). The ten illusion magnitudes and the age of each observer were included in the PCA. (a) Two principal components were identified (PC1 and PC2) on the basis of scree plot inspection, accounting for 23.8% and 17% of the variability of the data. (b) Eigenvalue score plot for all the observers for PC1 and PC2. Neither PC1 nor PC2 was able to separate patients (white disks) from the controls (black disks), suggesting that most of the variability in the data (cumulated explained variance for PC1 and PC2, i.e., 40.8%) was unrelated to the disease. These results suggest that other factors than schizophrenia account for that data variability. (c) Expectedly, component coefficients (or loadings) for PC1 were mainly composed by the three Ponzo illusions (PZg, PZ and PZw). The PC2, was mainly composed by the Ebbinghaus with

small inducers (EBs), Ebbinghaus with both, small and big inducers (EB), and the Müller-Lyer illusion (ML). (d) Loading plot for the two principal components. Surprisingly, the Ebbinghaus illusion with big inducers (EBb) was more related to the Ponzo illusions rather than other two Ebbinghaus illusions (EB and EBs) whereas the Müller-Lyer illusion was related to the Ebbinghaus with small (EBs) and with both (EB) inducers but not to the Ponzo illusions. For more details see supplementary Table 7.

4 Discussion

Since the early days of schizophrenia research, it has been reported that patients perceive the world in a different phenomenological way than healthy controls (Bleuler, 1950; Butler et al., 2008; Sergi et al., 2006). Here, we tested whether patients perceive illusions differently than controls.

Illusion magnitude and the quest for a common factor. We tested 19 and 59 patients and 19 and 54 controls in Exp. 1 and 2, respectively. First, we found that illusion magnitudes were roughly the same in patients and controls. Second, we found very few significant correlations between the illusions in both groups and experiments. In the first experiment, we found only one significant correlation between the tilt and the simultaneous contrast illusion after we corrected for multiple comparisons (Holm-Bonferroni). In the second experiment with a higher power, the three Ponzo illusions correlated significantly for both the patients and the controls. In addition, the Ebbinghaus illusion with small inducers (EBs) was correlated to the Ponzo “grid” (PZg), to the Müller-Lyer, and unsurprisingly to the Ebbinghaus illusion with both, the big and small inducers (EB). However, other spatial illusions, such as the Ponzo and the Ebbinghaus with small and big inducers (EB) illusion did not significantly correlate with each other, in line with previous findings (Schwarzkopf et al., 2011). In general, except for these significant correlations, only 14 out of the remaining 81 correlations were significant without correction for multiple comparisons (6 for patients, 8 for controls; none of the significant correlations were the same for patients and controls; Figure 7). Thus, correlations between different visual illusions are sparse and this is even more true for schizophrenia patients, which is in line with previous results (Tibber et al., 2013; Yang et al., 2013). For instance, Tibber and colleagues (2013) found only 1 significant correlation out of 8 comparisons. Yang et al., (2013) did not find any significant inter-illusion correlations for four measures. In summary, illusion magnitudes do not strongly differ between patients and controls. In addition, there are not more correlations in the patients than in the controls. Hence, the disease does not seem to induce a common factor for illusion perception. The perception of illusions seems to be roughly intact in the patients.

Numerous theories have proposed that the perception of illusions should be different in patients and controls. For example, it was proposed that schizophrenia patients have different visual priors than controls, making their vision more veridical and leading to a decrease in illusion magnitude (Fletcher and Frith, 2009). Similarly, it has also been argued that patients have a "failure to attenuate sensory precision", which means they cannot call upon their prior experiences to interpret the current stimuli (Frith and Friston, 2013). Other theories have suggested a deficit in contextual modulation and surround inhibition in patients, which might be the consequence of a weaker interaction between adjacent neurons and, therefore, a weaker gain control in schizophrenia (e.g., Butler et al., 2008; Phillips and Silverstein, 2013; Tadin et al., 2006; Tibber et al., 2013; Yang et al., 2013). Potential mechanisms for these deficits might include reduced modulation of cortical responses in the primary visual cortex (Seymour et al., 2013) or a reduction in the population of receptive fields in the early visual cortex (Anderson et al., 2017). As a consequence, patients tend to be less affected by helpful or deleterious contexts (Dakin et al., 2005; Robol et al., 2013) and for this reason, illusion magnitudes might be smaller. Our results do not support these claims, since we found the perception of illusions is largely intact in the patients, both in terms of illusions magnitudes and their correlation structure.

Mental imagery, positive symptoms, and illusions strength. In addition, we found no correlations between illusion magnitudes and positive or negative symptoms, as determined by the SAPS and SANS, respectively, despite a wide range of symptoms in our patients (Table 1). We also found only weak correlations between mental imagery and illusion magnitudes. VVIQ scores were actually higher in controls than patients but the effect was not significant (Table 1). The VVIQ scores of the control group in this study were slightly higher than the scores of the healthy participants in a previous study (Grzeczkowski et al., 2017; 118±25 vs. 113±28). Taken together, it seems that illusion magnitudes and vividness of mental imagery are comparable to the results of healthy controls.

Test-retest reliability and statistical power. Our null results cannot be explained by poor test-retest reliability or low statistical power. First, our test-retest correlations were significant for most of the illusions in both experiments (Tables 2 and 3). For the Ponzo illusion in Exp. 1 for example, our test-retest reliability was $R = 0.89$ for the patients and $R = 0.98$ for the controls. In Exp. 2, all ten illusions showed significant test-retest correlations for both groups. Moreover, we found significant correlations between illusions that were expected to correlate, such as the Ponzo illusions in Exp 2 (Figure 7). Therefore, our method seems to be sensitive to observe differences when differences exist.

Second, with 59 patients, we had 99%, 65%, and 12% power to detect large ($R = 0.5$), medium ($R = 0.3$), and small ($R = 0.1$) effect sizes, respectively (Cohen,1988). Third, our null results are supported by a Bayes analysis showing that the acceptation of the null hypothesis is more likely than its rejection for most pairwise comparisons (Figure 3 and Figure 7, boxes with dashed line). A rank analysis further confirmed that there are no participants who are *more* or *less* susceptible to visual illusions in general (Figure 4 and Figure 8).

We like to mention that even higher test-retests might potentially be achieved by using 2 AFC tasks and more trials. For example, test-retest reliability of our healthy controls was smaller than the one of healthy controls in a previous study by Schwarzkopf et al., (2011), which used a binary procedure and had more trials per illusion. Nevertheless, Ponzo and Ebbinghaus illusions did not correlate in that study either. Here, we refrained from using a binary method to reduce attentional demands and to keep the experiment short.

Why do results differ in the literature? As mentioned, various studies have found increased or decreased illusion magnitudes in the patients as compared to controls, while other studies have found non-significant results (for a review, see King et al., 2016, Notredame et al., 2014). We found a higher variance in the performance of the patients compared to the one of controls. This may be one reason why previous results are mixed (for a review, see King et al., 2016; Notredame et al., 2014). Another reason for mixed results may be the response measure used. In our study, we used a mouse adjustment procedure, which allows participants to demonstrate quickly and directly how they perceive the illusion. In most other studies, staircase procedures were employed. Potentially, this procedure requires attentional and decisional resources that might be deficient in the patients (King et al., 2016; Chkonia et al., 2010). Finally, as mentioned above, samples are small in most studies and samples in schizophrenia research are usually heterogeneous because of the heterogeneity of the disease, differences in medication and hospitalization, and genetic differences of the different populations.

Limitations. We used an adjustment method that allowed us to rapidly and directly probe the susceptibility to illusions within a few trials. We used two trials per illusion and for most of the illusions, the correlations between these two trials were strong and significant (Table 2 and Table 3). It remains an open question whether better estimates of illusions strength could be achieved by the method of constant stimuli, which may increase both inter-illusion correlations and test-retest reliability. In addition, it may be worth to increase the number of adjustments per illusion to obtain better estimates. We measured the susceptibility to only seven but frequently used illusions. It remains an open question whether also for other illusions low correlations are found.

Conclusions. Illusion magnitudes of patients were similar to the ones of controls. In addition, we found only weak correlations between illusions magnitudes in both patients and controls. We think that it is important to publish such null results and not only significant results, as it is common practice (Francis, 2012a, 2012b; Francis et al., 2014). Otherwise, the impression may occur that patients are deteriorated in most paradigms, which is not the case. We have previously reported that contextual modulation (Roinishvili et al., 2015) and complex motion perception (Lauffs et al., 2016) are intact in schizophrenia patients, and here we report that patients perceive visual illusions in a similar way to controls.

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