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Visual illusions in young people reporting psychotic-like experiences

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ABSTRACT

Background and objectives: A disruption in the co-ordination of bottom-up and top-down processing is thought to underlie anomalous perceptual experiences in psychosis. Visual illusions represent a valuable methodology in exploring this disruption. Here, we examined visual illusions in a group of young people having psychotic-like experiences. We also examined the relationship between illusion susceptibility and appraisal of psychotic-like experiences as well as depression, anxiety and stress levels.

Method: 25 young people reporting psychotic-like experiences and 53 healthy participants performed an adjustment task that measured susceptibility to a battery of 13 visual illusions. Levels of depression, anxiety and stress were quantified in both groups. The clinical group also completed measures examining frequency, appraisals and emotional responses to psychotic-like experiences.

Results: A general increase of illusion susceptibility was found in the clinical group compared to the control group. However, when depression, anxiety and stress levels were controlled for, this difference disappeared. Stress turned out to be the best predictor of illusion susceptibility in the clinical group, whereas anomalous experiences, depression and anxiety were unrelated to overall illusion strength.

Limitations: This study is limited to young participants reporting significant mental health difficulties and psychotic-like experiences. Findings should be replicated in an Ultra High Risk (prodromal) group.

Conclusions: Increased levels of stress explained the enhanced vulnerability to illusions in the clinical group. This increased susceptibility suggests a perceptual style that relies too heavily on prior expectations at the expense of the true sensory evidence, potentially leading to an altered perceptual experience of the world.

1. Introduction

Perceptual abnormalities concerning both low-level, such as contrast sensitivity (e.g. Serrano-Pedraza et al., 2014; Skottun & Skoyles, 2007), and high-level visual processing, such as facial emotion recognition (e.g. Edwards, Jackson, & Pattison, 2002; Schneider et al., 2006), have often been reported in patients with psychosis. It has been proposed that genetic and environmental factors may trigger a "basic cognitive disruption" (Hemsley, 2005) at the level of the neural circuits of individuals with predisposing vulnerability, which may lead to the anomalous perceptual experiences (e.g. hallucinatory phenomena, visual distortions) typically reported by these patients. According to Hemsley, this cognitive disruption impairs the integration of incoming sensory information (i.e. "bottom-up" processing) with relevant contextual information stored in the brain (i.e. "top-down" processing). As a consequence of this mismatch in the co-ordination between bottom-up and top-down processes, individuals experiencing psychosis may exhibit a reduced ability to build a coherent internal representation of the external world and make sense of their surroundings. Accordingly, previous research has shown that visual binding, namely the ability to bind visual features into a single and coherent percept, is impaired in patients with schizophrenia, suggesting a tendency towards detail-oriented processing (e.g. Parnas et al., 2001; Silverstein et al., 2009). Higher-level integration, more generally, seems to be affected in psychosis as a result of weakened top-down modulation on visual perception (e.g. Dima et al., 2009; Gold, Fuller, Robinson, Braun, &

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Luck, 2007). More recently, studies on the processing of ambiguous sensory information have yielded mixed results with both increases and decreases of the reliance on top-down (prior) information relative to bottom-up sensory inputs in patients with schizophrenia as well as individuals with subclinical psychotic-like experiences (e.g., Schmack et al., 2013, 2015, 2017; Stuke, Weilnhammer, Sterzer, & Schmack, 2018, 2021; Weilnhammer et al., 2020).

Visual illusions are useful tools in understanding how perception works in the healthy population and in patients with anomalous perceptual experiences because they provide a predictable dissociation between sensory inputs and the subjective perception (Dima et al., 2009). In a Bayesian framework, they illustrate the brain's ability to optimally combine top-down messages (carrying prior expectations) and bottom-up messages (carrying ambiguous sensory inputs) into coherent percepts (Notredame, Pins, Deneve, & Jardri, 2014). Furthermore, visual illusions provide an opportunity to manipulate specific mechanisms of visual processing that are highly adaptive, such as perceptual constancies (Gregory, 1963), allowing researchers to investigate the functioning of and abnormalities to these specific mechanisms. Although still controversial, there is an overall trend in the literature that suggests that people with psychosis tend to be more resistant to visual illusions than non-clinical samples (for reviews, see: Notredame et al., 2014; King, Hodgekins, Chouinard, Chouinard, & Sperandio, 2017). This is especially true for those illusions that require high-level integration of contextual elements (King et al., 2017), including the Ebbinghaus illusion (e.g., Tibber et al., 2013, but see Yang et al., 2013), the Ponzo illusion (Kantrowitz, Butler, Schecter, Silipo, & Javitt, 2009) and the Oppel Kundt illusion (Letourneau, 1974). However, results for the Müller-Lyer Illusion are less conclusive with some studies reporting no effect of the illusion in patients with schizophrenia (Parnas et al., 2001; Tam, Sewell, & Deng, 1998) and others showing increased susceptibility (Kantrowitz et al., 2009; Parnas et al., 2001; Weckowicz & Witney, 1960). These discrepancies in the literature could be due to a number of confounding factors, such as heterogeneity of the samples, medication effects, task response types, and the number of illusions tested (King et al., 2017).

A reduced vulnerability to illusions may indicate an over-reliance on bottom-up mechanisms or an attenuation of top-down modulation since the illusory stimulus is perceived as closer to its physical reality. This suggests that people with psychosis are characterized by a distinct perceptual style where individual visual features are more accurately perceived, rather than a generalised cognitive deficit as previously thought (Heinrichs & Zakzanis, 1998; Notredame et al., 2014; Yang et al., 2013).

Here, we investigated for the first time illusion susceptibility in a group of young people reporting psychotic-like experiences. Psychotic-like experiences are common outside of psychotic disorders with prevalence rates of 5–8% in the general population (Van Os, Linscott, Myin-Germeys, Delespaul, & Krabbendam, 2009) and up to 47% in adolescents with anxiety and depression disorders (Wigman et al., 2012, 2014). It has been suggested that psychotic-like symptoms constitute the healthy end of a continuum of increasing severity of psychotic symptoms within the community (Unterrassner et al., 2017) and that the presence of psychotic-like symptoms in young adults is an important risk marker for both psychosis and severe non-psychotic disorders (Kelleher et al., 2012). Interestingly, perceptual abnormalities have been reported in at-risk mental states and prodromal psychosis (Yung & McGorry, 1996). The study of young people with psychotic-like experiences, instead of individuals with a diagnosis of psychosis, may help us overcome some of the above-mentioned methodological constraints, especially medication effects, illness course, and disease heterogeneity, which could be responsible for the inconsistencies in illusion susceptibility reported in earlier studies (King et al., 2017). Following the general trend in the schizophrenia literature, we hypothesised that a clinical group of individuals with psychotic-like experiences would generally be more resistant to visual illusions than a non-clinical control group.

2. Materials and method

2.1. Participants

A clinical group of 25 young individuals who reported psychotic-like experiences took part in this cross-sectional study (for a summary of demographic information, see Table 1). Participants were recruited from the Youth Mental Health Teams. The Youth Mental Health Teams provide support in the community for individuals aged between 14 and 25 years who are experiencing a range of non-psychotic mental health difficulties (Hodgekins et al., 2018; Wilson et al., 2018). It should be noted that these young individuals have received a formal diagnosis of mental disorders in order to access mental health care services. Hence, we refer to this group as a clinical group. Exclusion criteria applied to the clinical group included: i) current or historical experience of a psychotic episode; ii) severe learning disability or a diagnosis of Autism Spectrum Disorder; iii) visual impairment which could not be corrected by visual aids; iv) insufficient proficiency in the English language; v) a score below six concerning psychotic-like experiences (e.g. seeing or hearing things other people cannot), irrespective of symptom duration, measured using the Prodromal Questionnaire (PQ) (Ising et al., 2012).

A control group of 74 participants was initially recruited from the community of a university. The following exclusion criteria were applied to the control group: i) a diagnosis of psychosis or Autism Spectrum Disorder; ii) a family history of psychosis; iii) visual impairment which could not be corrected by visual aids; iv) a score above the 75th percentile (i.e., >8) on the Schizotypal Personality Questionnaire - Brief (SPQ-B). Based on this last criterion, 20 participants were removed from the analysis because of high scores on the SPQ-B, which are indicative of greater schizotypal traits (Raine & Benishay, 1995). This was done to ensure a valid distinction between the clinical and control groups.[1] An additional participant was removed because of a family history of psychosis, leaving a total of 53 control participants (for a summary of demographic information of control participants selected for the analyses, see Table 1). The clinical and the control groups did not differ in terms of age ($t_{(76)} = 1.457$, $p = .15$) and gender (X^2 (1, $N = 78$) $= 0.29$, $p = .59$). It should be noted that the control group was larger than the clinical group. This depended on the greater availability of healthy participants. According to a power analysis performed in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) with $\alpha = 0.05$ and power $= 0.80$, a sample size of 68 participants per group was deemed to

Table 1
Demographic information for the clinical (n = 25) and control (n = 53) groups.

	Clinical group	Control group
Gender		
Female	20 (80%)	45 (85%)
Male	5 (20%)	8 (15%)
Age (in years)	Range = 16-25	Range = 18-22
	M = 20,44 SD = 2,96	M = 19,79 SD = 0,93
Handedness		
Right	22 (88%)	45 (85%)
Left	3 (12%)	8 (15%)
Family history of psychosis		
Yes	4 (16%)	
No	21 (84%)	

[1] Normative data for a non-clinical sample reports a mean total score of 9.6 for the SPQ-B (Axelrod, Grilo, Sanislow, & McGlashan, 2001) and in a more recent community sample of college students, the mean on the SPQ-B was 7.78 (Kline, Wilson, Ereshefsky, Nugent, et al., 2012). Therefore, our cut-off of 8 was highly conservative (around the mean score) to ensure that the control group was unlikely to be experiencing any of the psychotic-like experiences that are measured by the SPQ-B.

be appropriate to attain a small effect size; the estimated sample size decreased to 12 participants per group to attain a medium effect size and to 6 participants for a large effect size. Therefore, our sample size is large enough to detect medium effect sizes.

Moreover, there were more female than male participants in both groups. Despite this gender imbalance in our samples, recent epidemiological studies have found no gender differences in prevalence of schizophrenia (for a review, see Barajas, Ochoa, Obiols, & Lalucat-Jo, 2015).

Informed written consent was obtained from all participants prior to testing. For those participants aged 16–18 years old, informed consent was obtained in writing from both parent/guardian and the participant. All procedures were approved by the Ethics Committees and were carried out in accordance with the Declaration of Helsinki.

2.2. Self-report measures

Three questionnaires were administered in this study: 1) the Prodromal Questionnaire (PQ) used as a screening tool for the clinical group; 2) the Schizotypal Personality Questionnaire - Brief (SPQ-B) used as a screening tool for the control group; 3) the Depression, Anxiety, and Stress Scales (DASS) (Lovibond & Lovibond, 1995) used to measure negative emotional states in both groups.

Only participants from the clinical group completed the PQ-16. The PQ-16 is a 16-item self-report measure that assesses the presence of attenuated psychotic symptoms on a binary scale (True or False). In addition, the level of distress associated with each item is measured on a four-point scale (i.e. No, Mild, Moderate or Severe) every time the item is endorsed as true. A cut-off score of six for symptom items was used, as it is indicative of subclinical levels of psychosis (Loewy, Pearson, Vinogradov, Bearden, & Cannon, 2011). The total score referred to items endorsed on the True/False scale only, irrespective of the level of distress. The PQ-16 exhibits good psychometric properties: in a sample of 3533 general help-seekers (all young adults) the Cronbach's alpha for total score was .77 (Ising et al., 2012). Participants' suitability for the study was therefore based on the presence of psychotic-like experiences and not distress. Participants scoring below six were considered not eligible for the clinical group. This measure was chosen because it is an efficient and widely-used self-report screen for prodromal psychosis syndromes. It is also a practical screening measure, as it takes only 5 min to administer.

Only the control participants completed the SPQ-B. The SPQ-B (Raine & Benishay, 1995) is a 22-item self-report questionnaire for the measurement of dimensional schizotypy in the general population. The measure consists of three factors: cognitive-perceptual (8 items), interpersonal (8 items), and disorganized (6 items). Each item is a statement pertaining to experiences to which participants had to respond with a yes or no as to whether they relate to the statement. In the present study, moderate Cronbach's alpha values have been obtained for the subscales; $\alpha = 0.69$, $\alpha = 0.86$, and $\alpha = 0.74$, respectively. This measure was chosen because it is a widely-used non-clinical self-report scale which assesses schizotypal traits.

Finally, all the participants completed the DASS. This is a 42-item self-report scale measuring the severity of current anxiety, depression and stress/tension. Each subscale contains 14 items. Participants indicate the extent to which each statement had applied to them over the last week on a four point scale, ranging from 0 "did not apply to me at all" to 3 "applied to me very much, or most of the time", giving a total score which ranges between 0 and 126. The measure exhibited good psychometric properties with Cronbach's alpha values for each subscale well above 0.80 (Depression: $\alpha = 0.91$; Anxiety: $\alpha = 0.88$; Stress: $\alpha = 0.88$). A total score of 27 or above is indicative of symptoms within a clinical range (Crawford & Henry, 2003; Lovibond & Lovibond, 1995).

2.3. Assessment

To gain a more in-depth insight about the nature of anomalous perceptual experiences reported by participants in the clinical group, the Appraisal of Anomalous Experience (AANEX; Brett et al., 2007) was conducted. The AANEX is a semi-structured interview that measures the presence of psychotic-like experiences as well as the individual appraisals of and emotional responses to these experiences. The 12 items of the 'anomalous perception' subscale of the AANEX inventory were administered to explore psychotic-like experiences in the perceptual domain (e.g. "Have you had the experience of alterations in your vision, so that for example colors look different, you are more sensitive to light, things seem to move when you look at them, or people's faces look strange?"). Each item was rated on a three-point scale (1 = absent, 2 = unclear, 3 = present) to assess current (past month) and lifetime presence. To assess appraisals of and emotional responses to psychotic-like experiences, selected items from the Appraisals (valence, perceived controllability, externality) and Emotional Response (self-reported anxiety and excitement) sections of the AANEX were each rated on a five-point scale ranging from 1 to 5. Ratings on the 'appraisal' and 'emotional response' items were summed to provide two subscale scores, with higher scores being indicative of more negative appraisals/emotional responses. To ensure good standards of inter-rater reliability, the interviews were audio-recorded and scored independently by one of the authors, a trainee in clinical psychology and an experienced clinical psychologist. Inter-rater reliability was 94%, indicating high levels of concordance for this measure.

2.4. Visual illusions task

Participants were presented with a battery of 13 visual illusions developed by Chouinard, Unwin, Landry, and Sperandio (2016), which included the: Delboeuf, Ebbinghaus, Ehrenstein, Helmholz square, Horizontal-Vertical, Jastrow, Müller-Lyer, Oppel-Kundt, Ponzo, Poggendorf, Shepard's tabletops, Sander's parallelogram, and Square-diamond illusions (for a graphical depiction and full description of each illusion, see Table 2 and Chouinard et al., 2016). In brief, all illusions were presented in Flash player (Adobe Systems, San Jose, CA) on a computer monitor following a random order. Participants were instructed to perform an adjustment task by changing a feature (e.g. length, size, or height) of a comparison stimulus 'A' in order to match the same feature of a standard stimulus 'B' (see Fig. S1 in Supplementary materials for an example of trial). To do so, participants were asked to press one of the buttons labelled as "Increase" and "Decrease" presented at the bottom of the screen. Each button press increased or decreased the feature of the comparison stimulus by 2 pixels. Once participants had completed the adjustment, they were asked to press the button labelled as "Done". There was no time limit for the adjustment. The comparison stimulus was presented either 20 vs. 50% larger or 20 vs. 50% smaller than the target stimulus. Each illusion was presented four times for a total of 52 trials. The starting point of the comparison stimulus (i.e. 20% or 50%) as well as its location in the illusory display (i.e. stimulus 'A' or 'B') were counterbalanced within participants (for further details, see Chouinard et al., 2016).

2.5. Statistical analyses

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS; IBM Corporation; Armonk, NY, USA) version 23 and JASP software (University of Amsterdam, Amsterdam, Netherlands) version 0.9.2.0. The strength of each visual illusion was quantified as a susceptibility index as follows: [(Perceived Size in Configuration A – Perceived Size in Configuration B)/(Perceived Size in Configuration A + Perceived Size in Configuration B); configuration A denoting the condition one would expect to see greater judgements] (e.g. Chouinard, Noulty, Sperandio, & Landry, 2013; Chouinard et al., 2016).

Table 2
Descriptions of the 13 illusory displays used in the visual illusion task.

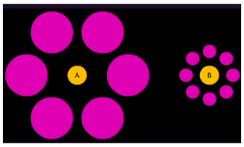
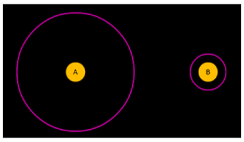
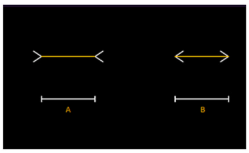
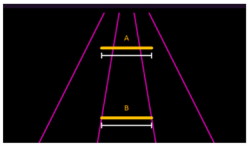
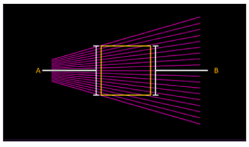
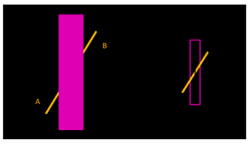
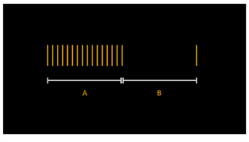
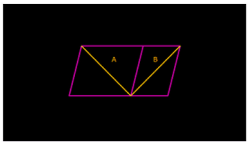
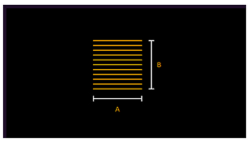
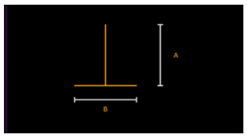
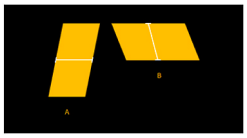
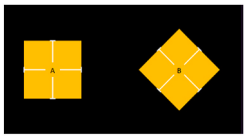
Visual illusion	Illusory display	Description
Ebbinghaus Illusion		The surrounding circles offer contextual cues to the perceived size of the inner circles. Therefore, the inner circle is perceived as larger when surrounded by small circles and smaller when surrounded by larger circles although the physical size of the inner circles is the same.
Delboeuf Illusion		The surrounding circular frame offers contextual cues to the perceived size of the inner circles. Therefore, the inner circle is perceived as larger when surrounded by a smaller circle and smaller when surrounded by a larger circle although the physical size of the inner circles is the same.
Müller-Lyer Illusion		Two lines *a* and *b* are physically the same length. However, the arrow heads modulate the perceived size of the shaft, with line *a* perceived as longer than *b*.
Ponzo Illusion		Both lines *a* and *b* are the same length. However, the converging lines make the upper line *a* to be perceived as bigger than the lower line *b*.
Ehrenstein		The two sides of the square *a* and *b* are the same length, however, due to the converging lines overlaid on the square the side labelled *a* where the lines are closer together is perceived as larger and vice versa for side *b*.
Poggendorf Illusion		The segments *a* and *b* are part of the same line that continues behind the rectangle. However, we perceive the two segments as being too far apart to meet in the middle.
Oppel Kundt Illusion		The filled space (*a*) is perceived as larger compared to the empty one (*b*), although both spaces are equal.
Sander Parallelogram		The two diagonals *a* and *b* are of equal length, however, the parallelogram surrounding them make the length of the diagonal *b* to be perceived as shorter than *a*.
Helmholtz Square		The interrupted direction (*b*) is perceived as longer than the non-interrupted direction (*a*). However, the two sides are actually of equal length.
Horizontal-Vertical Illusion		The perceived length of the vertical line *b* is longer than that of the horizontal line *a*,

Table 2 (*continued*)

Visual illusion	Illusory display	Description
		despite the fact that they are of equal length.
Shepard Illusion		The vertical upright parallelogram (*a*) is perceived as narrower and taller than its horizontal equivalent (*b*) even though they are of identical size.
Jastrow Illusion		Two pac-man like shapes are displayed on top of each other, slightly offset in their orientation. The one on the bottom (*b*) is perceived as larger than the one on top (*a*).
Square-Diamond Illusion		Two identical squares are presented side-by-side, however, one (*b*) is rotated 45°. The upright square (*a*) is perceived as smaller than the rotated square (*b*).

Increasingly positive values represent a higher susceptibility to illusions, whereas increasingly negative values represent a change in perception in the opposite direction.

A 13 × 2 mixed analysis of variance (ANOVA) was carried out on the susceptibility scores with 'Visual illusions' (13 different illusory displays) as a within- and 'Group' (clinical vs. control) as a between-subject factor. We opted for this statistical approach as previous research using the same battery of visual illusions in individuals with different levels of autistic traits has shown that each illusion involves different mechanisms that can be selectively affected (Chouinard et al., 2016). To examine the effects of these factors independently of negative emotions, we reanalysed the data using an analysis of covariance (ANCOVA) with DASS scores as covariates. Partial eta-squared (η_p^2) were calculated to assess effect size. Greenhouse-Geisser corrections were applied whenever the assumption of sphericity was not met according to a Mauchly's sphericity test. Post-hoc pair-wise comparisons were performed to further examine any significant main effects or interaction.

Finally, we performed standard (direct) multiple regression analyses to identify which predictor best explained illusory susceptibility in the clinical and control groups separately. The criterion used to select the best predictor was based on the variable that had the highest correlation with illusion strength. The model for both groups added depression, anxiety and stress scores as predictors. Only the model for the clinical group also added standardized (i.e. z-scores) AANEX ratings (i.e. 'state', 'lifetime', 'appraisal' and 'emotional' response scores) as predictors. To complement this analysis, we also calculated Pearson's correlation coefficients (r) to highlight any associations between the above-mentioned measures.

All reported *p* values were based on two-tailed criteria and corrected for multiple comparisons using the Bonferroni method (i.e. p corr = p uncorr × total number of comparisons; Dunn, 1961).

3. Results

3.1. Self-report measures and AANEX

Table 3 reports mean, standard deviation (SD) and ranges of scores of both groups for each self-report measure and the AANEX interview. Normative data from a non-clinical sample reports a mean score of 14.31 for the depression subscale, 10.73 for the anxiety subscale, and 18.64 for the stress subscale (Brown, Chorpita, Korotitsch, & Barlow, 1997). As

Table 3
Mean, SD and ranges for the self-report measures of the clinical (n = 25) and control (n = 53) groups.

Questionnaire	Clinical group		Control group	
	Mean (*SD*)	Range	Mean (*SD*)	Range
PQ	11.88 (*2.85*)	6–15	–	–
SPQ	–	–	3.66 (*2.52*)	0–7
DASS –Depression Subscale	28.28 (*9.36*)	11–42	6.11 (*7.61*)	0–40
DASS –Anxiety Subscale	25.48 (*6.56*)	16–40	4.19 (*5.41*)	0–29
DASS –Stress Subscale	30.60 (*7.64*)	13–40	9.53 (*8.41*)	0–33
AANEX Current Anomalous Experiences	25.52 (5.55)	16–36	–	–
AANEX Lifetime Anomalous Experiences	30.80 (7.97)	17–51	–	–
AANEX Appraisals	11.52 (1.30)	9–13	–	–
AANEX Emotional Response	6.50 (0.65)	6–8	–	–

Note. PQ Prodromal Questionnaire; *SPQ* Schizotypal Personality Questionnaire - Brief; *DASS* Depression, Anxiety, and Stress Scales; *AANEX* Appraisals of Anomalous Experiences Interview.

can be seen in Table 3, the clinical group in this study scored significantly higher than the control group across all three subscales (Depression: $t_{(76)} = 11.05$, $p < .001$; Anxiety: $t_{(76)} = 15.13$, $p < .001$; Stress: $t_{(76)} = 10.58$, $p < .001$), demonstrating that the two groups differed in terms of their negative emotional states.

The percentages of DASS scores for each level of severity (Lovibond & Lovibond, 1995) for the clinical and control groups are reported in Table 4. The table shows that while none or a small percentage of the scores of the clinical group fell within the normal range for depression, anxiety and stress, the vast majority of the control participants (>80%) scored within this range. In stark contrast, participants of the clinical group typically experienced from severe to extremely severe levels of depression, anxiety and stress (80%, 100% and 80%, respectively) as opposed to less than 10% of the control group. This highlights the severity of mental health problems (i.e. high levels of depression, anxiety and stress) in the clinical group in comparison to the non-clinical group.

All participants in the clinical group had experienced at least one anomalous perceptual experience in the past month, with the mean number of experiences endorsed of 6.76 (SD = 2.77), according to the AANEX inventory. The frequency of endorsement of each of the items on the AANEX in the clinical sample is reported inSTable 1 in Supplementary materials.

Table 4
Percentages of DASS severity ratings for the clinical (n = 25) and control (n = 53) groups.

Severity	Percentile	Group	Depression subscale (%)	Anxiety subscale (%)	Stress subscale (%)
Normal	0–78	Clinical	0	0	8
		Control	83	83	81
Mild	78–87	Clinical	8	0	4
		Control	8	9	6
Moderate	87–95	Clinical	12	0	8
		Control	6	4	4
Severe	95–98	Clinical	24	16	32
		Control	2	2	9
Extremely Severe	98–100	Clinical	56	84	48
		Control	2	2	0

3.2. Susceptibility to visual illusions

There was a small number of missing data in the clinical group, accounting for only 2.2% (n = 7) of all cases on the visual illusion task. These missing data-points stemmed from 6 different participants and were replaced with the average of the observed data for that particular condition. In agreement with previous findings (Chouinard et al., 2016), participants reported positive susceptibility scores in 100% and 96.2% of cases for the clinical and control groups, respectively, indicating that the visual illusion was indeed experienced by both groups. As can be seen in Table 5, the clinical group tended to be more susceptible than the control group to the majority of the tested illusions.

A 13 × 2 mixed ANOVA was carried out on susceptibility scores. The main effect of Visual illusion was significant ($F_{(6,485)} = 22.924$, $p < .001$, $\eta_p^2 = 0.23$) (Greenhouse-Geisser corrected). Post-hoc tests with Bonferroni correction revealed that the illusory effects of some illusions were larger than others (see Supplementary materials for details). The ANOVA also revealed a main effect of Group ($F_{(1,76)} = 12.454$, $p = .001$, $\eta_p^2 = 0.14$) with greater susceptibility scores in the clinical group ($M = 0.14$, $SD = 0.02$) than the control group ($M = 0.12$, $SD = 0.03$). However, group differences did not statistically vary between illusions as evidenced by a lack of interaction between Visual illusion and Group ($F_{(6,485)} = 1.405$, $p = .21$, $\eta_p^2 = 0.02$) (Greenhouse-Geisser corrected). Importantly, when DASS scores were entered as covariates in a 13 × 2 ANCOVA, the between-subjects difference disappeared ($F_{(1,73)} = 0.742$, $p = .392$, $\eta_p^2 = 0.01$), suggesting that negative emotional states of depression, anxiety, and stress could account for the overall increased susceptibility to visual illusions observed for the clinical group compared to the control group.

Finally, when we repeated the same analysis by entering each component of the DASS as a separate covariate, we found that anxiety ($F_{(1,75)} = 0.420$, $p = .519$, $\eta_p^2 = 0.006$) and stress ($F_{(1,75)} = 3.141$, $p = .08$, $\eta_p^2 = 0.04$), but not depression $F_{(1,75)} = 5.811$, $p = .018$, $\eta_p^2 = 0.072$), played a role in the between-subjects difference.

Table 5
Descriptive statistics and effect size for each illusion for the clinical (n = 25) vs. the control (n = 53) groups.

Illusory display	Group	M (*SD*)	*Difference in susceptibility (%)**
Delboeuf	Clinical	0.18 (*0.16*)	30.14
	Control	0.14 (*0.13*)	
Ebbinghaus	Clinical	0.16 (*0.10*)	28.05
	Control	0.13 (*0.06*)	
Ehrenstein	Clinical	0.14 (*0.10*)	75.05
	Control	0.08 (*0.06*)	
Helmholtz	Clinical	0.11 (*0.05*)	−5.00
	Control	0.12 (*0.06*)	
Horizontal-Vertical	Clinical	0.17 (*0.08*)	22.42
	Control	0.14 (*0.09*)	
Jastrow	Clinical	0.10 (*0.06*)	22.32
	Control	0.08 (*0.04*)	
Müller-Lyer	Clinical	0.20 (*0.04*)	15.85
	Control	0.17 (*0.06*)	
Oppel-Kundt	Clinical	0.10 (*0.07*)	40.23
	Control	0.07 (*0.10*)	
Poggendorf	Clinical	0.10 (*0.03*)	−9.75
	Control	0.11 (*0.03*)	
Ponzo	Clinical	0.18 (*0.08*)	29.19
	Control	0.14 (*0.08*)	
Sander's parallelogram	Clinical	0.20 (*0.03*)	24.82
	Control	0.16 (*0.07*)	
Shepard's tabletops	Clinical	0.20 (*0.06*)	13.09
	Control	0.18 (*0.09*)	
Square-diamond	Clinical	0.05 (*0.03*)	−15.51
	Control	0.06 (*0.04*)	

Note: *Differences between groups calculated as follows: [(clinical-control)/control] *100; group differences were not statistically different between illusions given the lack of 'Visual illusion' x 'Group' interaction.

3.3. Multiple regression analysis

To identify which variable among anomalous experiences, depression, anxiety and stress levels best predicted overall illusion strength (i.e., pooled mean of the different visual illusions), a standard (direct) multiple linear regression was carried out separately for each group. In this analysis, DASS scores were selected as predictors for entry. Note that AANEX scores (i.e., current anomalous experiences, lifetime anomalous experiences, appraisals, and emotional response) were also entered as predictors only in the model for the clinical group. The fitted regression model for overall illusion strength in the clinical group was: illusion strength = 0.101 – (0.001 x depression) + (0.001 x anxiety) + (0.002 x stress). The overall regression was not statistically significant ($F_{(3,24)}$ = 2.202, p = .12, R^2 = 0.239). Nonetheless, it was found that stress significantly predicted overall illusion strength (β = 0.002, p < .05). Depression and anxiety did not significantly add to the prediction (both p > .05). The fitted regression model for overall illusion strength in the control group was: illusion strength = 0.124 – (7.572E-5 x depression) + (0.002 x anxiety) - (0.001 x stress). The overall regression was not statistically significant ($F_{(3,52)} = 1.024$, $p = .39$, $R^2 = 0.059$). None of the variables significantly added to the prediction (all p > .05). Finally, when AANEX scores were entered as predictors, the fitted regression model for overall illusion strength in the clinical group was: illusion strength = 0.101 – (0.001 x depression) + (0.001 x anxiety) + (0.002 x stress). The overall regression was not statistically significant ($F_{(4,24)}$ = 0.668, $p = .62$, $R^2 = 0.118$). None of the variables significantly added to the prediction (all p > .05). See Table 6 for a correlation matrix of Pearson r coefficients among anomalous experiences, depression, anxiety, stress levels and overall illusion strength.

4. Discussion

The aim of the study was to measure susceptibility to a battery of 13 visual illusions in a group of young people with psychotic-like experiences and a group of healthy controls. We also examined the relationship between susceptibility and appraisal of psychotic-like experiences as well as depression, anxiety and stress levels. Surprisingly, we observed that the clinical group was more susceptible to the visual illusions than the control group. These findings run against the dominant view in the literature of an increased resistance to illusions in individuals with psychosis (King et al., 2017; Notredame et al., 2014). Several possible explanations can account for these controversial results: 1) we examined young people with psychotic-like experiences rather than chronically ill patients, allowing us to overcome issues related to medication and treatment effects which might interfere with illusion strength (e.g., Diržius, Liutkevičius, Žukauskaitė, Leskauskas, & Bulatov, 2013); 2) we tested a battery of 13 different visual illusions rather than a single or a small number of illusions, as it is typically done in the literature (King et al., 2017); 3) we used an adjustment task rather than forced-choice response. Although the latter is frequently used to measure susceptibility to illusions, it has been criticized when making between-groups comparisons as it requires to mentally create subjective threshold criteria of perceptual difference which the illusion must break before an illusion-supporting response is reported (Skottun & Skoyles, 2014).

Interestingly, greater susceptibility to visual illusions in psychotic samples has been reported before in studies using the Müller-Lyer illusion (Capozzoli & Marsh, 1994; Diržius et al., 2013; Kantrowitz et al., 2009; Tam et al., 1998; Weckowicz & Witney, 1960) and the Roelofs effect (Chen, McBain, Norton, & Ongur, 2011). Along with the current investigation on young individuals reporting psychotic-like experiences, these findings demonstrate greater effects of contextual information in patients which seem to contradict the cognitive model proposed by Hemsley (2005) and the idea of a perceptual style that is detailed-oriented.

However, some caution should be exercised when interpreting the current findings. It should be noted that, although the clinical sample tested here cannot be strictly defined as at-risk mental state for psychosis, participants exhibited severe mental health difficulties, namely high levels of depression, anxiety and stress (see Table 4). In the literature, a co-occurrence between common mental disorders (anxiety/depression) and psychotic-like experiences has been documented (Knight et al., 2020; Varghese et al., 2011).

Notably, when negative emotions (i.e. depression, anxiety, and stress) as indexed by DASS scores were entered as covariates in the analysis, the between-groups difference disappeared, signifying that the overall increased susceptibility to visual illusions registered for the clinical group compared to the control group could be explained by the severity of mental health problems (i.e. high levels of depression, anxiety and stress) reported by the young people with psychotic-like experiences. More specifically, stress level turned out to be the major player in predicting overall illusion strength in the clinical group. Increased levels of stress are typically associated with psychotic-like experiences, including perceptual abnormalities, and the nature of such a relationship might be a direct one; namely, stress could be responsible for the development or worsening of psychotic-like experiences, or alternatively, psychotic-like experiences could be themselves stressful (Turley, Drake, Killackey, & Yung, 2019). Importantly, stress is likely to be an important risk factor of transition to schizophrenia and other psychotic disorders (Campbell & Morrison, 2007; Green, Girshkin, Teroganova, & Quidé, 2014; Yung et al., 2009) and enhanced emotional reactivity to daily life stress has been considered as a vulnerability marker for psychosis (for a review, see Myin-Germeys & van Os, 2007).

The effects of stress on the perception of visual illusions have been scarcely investigated in the literature and the little evidence available is quite inconclusive (Karpinskaia, Lyakhovetskii, & Shoshina, 2020). Interestingly, there is some evidence that seems to suggest that meditation, an effective stress-management technique, would reduce the strength of visual illusions, such as the Ames Trapezoid (Martinetti, 1976) and the Poggendorff (Tloczynski, Santucci, & Astor-Stetson, 2000) illusions. It has been proposed that meditation would enhance perceptual awareness by controlling and limiting the effects of cognition on perception, leading to a perceptual experience of the external world that is more veridical (e.g. Tloczynski et al., 2000). Future investigations should focus more directly on the relationship between stress level, perceptual abnormalities and misperceptions in individuals reporting sub-threshold psychotic experiences and how relaxation techniques, such as meditation, might affect these associations. Future studies should also apply stricter recruitment procedures to ensure a balanced male to female ratio. In fact, one limitation of the present study was the large number of female participants in both groups (>80%), which can potentially limit the generalizability of the findings. Although controversial, there is some evidence in the literature that shows gender differences in visual illusions, with females exhibiting greater susceptibility than males (Lo & Dinov, 2011; Miller, 2001). More importantly, even if

Table 6
Correlation matrix for the clinical (n = 25) and control (n = 53) groups.

Group - Overall Suscept	Depress.		Anxiety		Stress		AANEX CurrentAn.Exp.		AANEXLifetime An.Exp.		AANEX Appr.		AANEX Emot. Resp.	
	r	*p*	*r*	p	r	p	r	p	r	*p*	r	*p*	r	*p*
Clinical	.09	.68	.26	.21	.43*	.03	.25	.22	.33	.10	.15	.46	.09	.65
Control	−.09	.51	10	.48	−.06	.67								

Note. Asterisks (*) denote significance at p < .05 (two-tailed).

recent studies do not suggest gender differences in prevalence of schizophrenia (e.g., Barajas et al., 2015), gender differences have been reported in a number of variables, including age of onset, premorbid functioning, social functioning, substance abuse, and disease course (for a review, see Ochoa, Usall, Cobo, Labad, & Kulkarni, 2012). Another important limitation concerns the use of different screening tools (i.e., PQ and SPQ-B) to characterize the clinical and the control groups with respect to psychotic-like experiences. It should be noted, however, that psychotic-like symptoms and schizotypy are related constructs, as previously demonstrated (0.58 correlation in a community sample of college students, see Kline, Wilson, Ereshefsky, Nugent, et al., 2012). Therefore, lower schizotypy scores are likely to be associated with lower PQ scores. Furthermore, whilst the PQ seems to have acceptable psychometric properties in community samples, such as college students (Kline et al. 2012a, 2012b), it has been recommended that the PQ be used primarily in clinical populations for high-risk screening purposes (Loewy et al., 2011). The SPQ-B results obtained from the control group in the present study suggest that our population was not at high-risk. As such, it would have been inappropriate to administer the PQ to the non-clinical sample. Future studies should use SPQ-B in both groups to assess psychotic-like experiences, especially because there is psychometric evidence to support its acceptability for use in both community and adolescent psychiatric populations (Compton, Chien, & Bollini, 2007). The use of the same screening tool to assess and define psychotic-like experiences seems essential to ascertain that the clinical and non-clinical groups truly differ in terms of psychotic experiences and psychotic symptoms along the continuum from healthy individuals to patients (Hinterbuchinger & Mossaheb, 2021). A final note concerns the use of medication in the group of young people reporting psychotic-like experiences. Whilst we did not have access to any specific information about medication use in our clinical group, we rule out the possibility that these patients were taking antipsychotic medication, as none of them had received a diagnosis along the psychotic/schizophrenia-spectrum disorders. However, it is highly likely that these young people were taking antidepressants and medications for anxiety, given that (as also evidenced by the high scores of the DASS questionnaire) they were struggling with other mental health difficulties. Future research should take into consideration the potential impact of any medications on the perception of visual illusions (e.g., King et al., 2017).

In an attempt to interpret our findings, a hierarchical Bayesian framework might be helpful. These Bayesian models are based on the assumption that the brain builds representations of the external world by inferring the potential causes of the incoming sensory information. The brain's circuits are arranged in a hierarchy, whereby predictions (i.e. prior beliefs) are formed at the upper layers of the system and are sent as predictive signals to the lower layers. Whenever the sensory input violates these expectations, an error signal is sent to update the predictive model at upper layers. An impairment in the control of downward loops of the neural networks, in which the top-down expectations are misinterpreted as sensory evidence when they are reverberated back up in the cortical hierarchy, would be responsible for an overconfidence in the prior beliefs (i.e. hyper-priors) at the expense of the true sensory evidence, leading to a higher susceptibility to visual illusions (Jardri & Denève, 2013; Notredame et al., 2014). By the same token, hyper-priors might also explain positive symptoms in schizophrenia, such as hallucinations (i.e. abnormal perceptions that emerge unexpectedly into consciousness in the absence of any corresponding sources in the outside world): an overweighting of prior beliefs, due to an inadequate inhibitory control of downward loops, would be responsible for perceptual experiences that are based on prior expectations rather than sensory evidence to the point that the patient would only perceive what they are expecting to perceive (e.g. Fletcher & Frith, 2009). Thus, according to this hypothesis, the more weight that is attributed to prior beliefs, the more vulnerable the patients will be to hallucinatory experiences and misperceptions (for reviews, see Sterzer et al., 2018; Corlett et al., 2018). A further development of these models should also take into account the role of stress.

To conclude, we have described for the first time an overall increase in susceptibility to a variety of visual illusions in young individuals reporting psychotic-like experiences that was explained by stress level. This enhanced vulnerability to illusions might suggest a distinct perceptual style that is characterized by an overreliance on prior knowledge.

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Data statement

Data for the reported experiment are available via the Open Science Framework (OSF): https://osf.io/k6hc5/

CRediT authorship contribution statement

Irene Sperandio: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Philippe A. Chouinard:** Conceptualization, Methodology, Formal analysis, Software, Writing – review & editing. **Emily Paice:** Investigation, Data curation. **Daniel J. Griffiths-King:** Investigation, Data curation, Writing – review & editing. **Joanne Hodgekins:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

We report no potential conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbtep.2023.101839.

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