Slower access to visual awareness but otherwise intact implicit perception of emotional faces in schizophrenia-spectrum disorders

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Abstract

Schizophrenia-spectrum disorders are characterized by deficits in social domains. Extant research has reported an impaired ability to perceive emotional faces in schizophrenia. Yet, it is unclear if these deficits occur already in the access to visual awareness. To investigate this question, 23 people with schizophrenia or schizoaffective disorder and 22 healthy controls performed a breaking continuous flash suppression task with fearful, happy, and neutral faces. Response times were analysed with generalized linear mixed models. People with schizophrenia-spectrum disorders were slower than controls in detecting faces, but did not show emotion-specific impairments. Moreover, happy faces were detected faster than neutral and fearful faces, across all participants. Although caution is needed when interpreting the main effect of group, our findings may suggest an elevated threshold for visual awareness in schizophrenia-spectrum disorders, but an intact implicit emotion perception. Our study provides a new insight into the mechanisms underlying emotion perception in schizophrenia-spectrum disorders.

Key-words: Schizophrenia; Facial expression; Continuous flash suppression; Visual perception; Implicit emotion perception

1. Introduction

Schizophrenia-spectrum disorders, such as schizophrenia and schizoaffective disorder, are among the most severe and complex psychiatric disorders, characterized by a wide range of deficits in social cognition (Green, Horan, & Lee, 2015; Pinkham, 2014; Savla, Vella, Armstrong, Penn, & Twamley, 2013). Social cognition refers to the psychological mechanisms underlying social interactions, and involves the perception, interpretation, and use of social information (Pinkham, 2014). Social cognitive deficits in schizophrenia-spectrum disorders are significant predictors of poor functioning outcomes, such as social and community functioning (Couture, Penn, & Roberts, 2006; Fett et al., 2011; Horan, Lee, & Green, 2013), and remain quite stable despite medication (Kucharska-Pietura & Mortimer, 2013).

One of the most studied social cognitive abilities is the perception of emotional stimuli, namely facial expressions (Green et al., 2015). Being able to accurately perceive others' emotional state is crucial to engage in social interactions and to respond in accordance to social events (Frith, 2009). Deficits in emotional face processing in schizophrenia-spectrum disorders, namely in its explicit processing, are well established in the literature (Chan, Li, Cheung, & Gong, 2010; Kohler, Walker, Martin, Healey, & Moberg, 2010; Savla et al., 2013). These are related to structural and functional alterations in the brain regions dedicated to emotion perception (e.g., amygdala) (Green et al., 2015; Li, Chan, McAlonan, & Gong, 2010; Taylor et al., 2012), and have been considered neurocognitive markers of schizophrenia (Schoeman, Niehaus, Koen, & Leppänen, 2009). Despite inconsistent findings – in part due to the heterogeneity between studies (Edwards, Jackson, & Pattison, 2002) – difficulties are mostly encountered during the discrimination and recognition of threat-related faces, particularly fearful ones (Kohler et al., 2003; Kuharic et al., 2019; Lee, Lee, Kweon, Lee, & Lee, 2010; Norton, McBain, Holt, Ongur, & Chen, 2009; Premkumar et al., 2008; Romero-Ferreiro et al., 2016; Won et al., 2019). An impaired ability to detect social threat was also reported by Pinkham et al. (2014). Using a visual search task, the authors observed a decreased ability to detect threat in people with schizophrenia or schizoaffective disorder, compared to people without psychiatric disorders, when angry faces were presented among happy faces, but not when snakes were presented among flowers or mushrooms (Pinkham et al., 2014). Given the importance of emotional faces in the social world, this abnormal perception may explain some of the maladaptive threat appraisals that characterize psychotic experiences (Underwood, Kumari, & Peters, 2016) and that lead to social withdrawal, inappropriate social interactions, and exacerbated anxiety.

Despite existing models suggesting that deficits in the early stages of visual perception are the first chain of events leading to social cognitive dysfunction and poor functioning outcomes (Green, Hellemann, Horan, Lee, & Wynn, 2012; Javitt, 2009; McCleery et al., 2020), the mechanisms underlying emotional face processing in schizophrenia-spectrum disorders are far from understood. Deficits in early visual perception are described quite often in schizophrenia using non-emotional visual masking (Butler et al., 2003; Del Cul, Dehaene, & Leboyer, 2006; Green et al., 2012; Green, Lee, Wynn, & Mathis, 2011; Herzog & Brand, 2015; McCleery et al., 2020), inattentional blindness (Pitts, Martínez, & Hillyard, 2012), and attentional blink paradigms (Mathis et al., 2012). There is also evidence for an abnormal magnocellular pathway – involved in early perception by projecting visual information from the thalamus directly to the subcortical regions, and sensible to low spatial frequency – in emotional faces (Bedwell et al., 2013; Butler et al., 2009; Jahshan, Wolf, Karbi, Shamir, & Rassovsky, 2017; Marosi, Fodor, & Csukly, 2019), namely fearful ones (Kim, Shim, Song, Im, & Lee, 2015; Lee, Park, Song, Choi, & Lee, 2015). For example, people with schizophrenia, compared to healthy individuals, showed decreases in event-related potential components, reflecting early visual perception, for fearful faces with low spatial frequency (Kim et al., 2015). Consistently, two studies using the Bubbles technique[1] found that people with schizophrenia or schizoaffective disorder required more visual cues (i.e., more bubbles), used different strategies to collect visual information (e.g., underutilized the eye regions), and ignored information presented in the lower range of spatial frequencies (Clark, Gosselin, & Goghari, 2013; Lee, Gosselin, Wynn, & Green, 2011). However, these studies used explicit tasks, in which participants are asked to allocate their attention towards the facial expression. In contrast, in implicit tasks, limited visual information is provided and participants are not required to attend to the emotional content of the faces.

Whether implicit emotion perception is altered in schizophrenia-spectrum disorders remains largely unknown, as the relevant literature is sparse and mixed (Lee, Kim, & Lee, 2016). This is surprising given the current debate on whether deficits in emotional face perception in schizophrenia-spectrum disorders are better explained by automatic, bottom-up factors – determined by salience or emotional content, and typically involved in implicit tasks (Connor, Egeth, & Yantis, 2004; Theeuwes, Atchley, & Kramer, 2000) – or top-down factors – driven by observers' prior knowledges, expectations or goals, with attention being voluntarily allocated towards the stimulus, feature or location, and typically involved in explicit tasks (Connor et al., 2004; Theeuwes et al., 2000) –, as reviewed by Lee et al. (2016). Several studies found

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[1] In the Bubbles technique, participants are presented with partial visual information about an object. The visual information is displayed through an opaque field with randomly located Gaussian apertures, designated by *bubbles*. This allows to isolate the visual information that is used to recognize or categorize the objects (Clark et al., 2013; Lee et al., 2011).

an abnormal implicit perception of emotional faces in people with schizophrenia (Derntl & Habel, 2017; Liu, Zhang, Zhao, Tan, & Luo, 2016; Park, Kim, Kim, Kim, & Lee, 2011; Rauch et al., 2010; Suslow et al., 2013) and healthy individuals with high social anhedonia (Günther et al., 2017). For example, Suslow et al. (2013) observed an increased activation of the right amygdala to masked angry and happy faces (shown for 33 ms), and a stronger negative priming for masked angry faces in people with schizophrenia, compared to people without psychiatric disorders, but only in the first part of a backward masking paradigm. Liu et al. (2016) demonstrated that, when asked to indicate the direction of an arrow presented with valid fearful (compared to neutral) facial cues (showed for 100 ms), heathy individuals, but not people with schizophrenia, exhibited shorter response times (RT) and decreased event-related potential components. The authors pointed that the lack of fearful bias in schizophrenia suggests bottom-up constraints in early visual perception (Liu et al., 2016).

Other studies have instead showed that the ability to implicitly perceive emotional faces may be preserved in schizophrenia-spectrum disorders (Aichert et al., 2013; Kring, Siegel, & Barrett, 2014; Shasteen et al., 2016; van't Wout, Aleman, et al., 2007). Using a Continuous Flash Suppression (CFS) paradigm, Kring et al. (2014) found that both people with schizophrenia or schizoaffective disorder and people without psychiatry disorders rated visible neutral faces as more/less trustworthy and warm when faces were presented concurrently with subliminal happy/angry faces. The authors argued that patients (and healthy controls controls) were able to perceive the emotional content even when stimuli were presented outside visual awareness. Similar findings were reported by Shasteen et al. (2016) using a priming paradigm. In this study, both people with schizophrenia or schizoaffective disorder and people without psychiatry disorders rated Chinese pictographs as more threatening when they were preceded by briefly presented and masked angry faces, compared to neutral faces. Interestingly, the authors failed to replicate their findings when bodily emotions, rather than emotional faces, were used (Hajdúk, Klein, Bass, Springfield, & Pinkham, 2019).

The mixed findings regarding implicit emotion perception may be related to the clinical heterogeneity that characterizes schizophrenia (American Psychiatric Association, 2013), but also to the use of distinct implicit tasks that recruit distinct cognitive functions, such as response inhibition (Derntl & Habel, 2017), attention orienting and execution (Liu et al., 2016), and cognitive control (Aichert et al., 2013). Besides these complex cognitive functions, some implicit tasks require an explicit judgement of the stimulus, such as subjective ratings of trustworthiness, competence, interpersonally, and threat (Kring et al., 2014; Shasteen et al., 2016). Critics have pointed out that a strict separation into two types of psychological processes – Type 1 and Type 2 thinking – does not apply to most tasks (Melnikoff & Bargh, 2018). Nonetheless, the use of paradigms that minimize the recruitment of complex cognitive functions is critical to obtain a broader understanding on emotion perception in schizophrenia-spectrum disorders.

Of relevance when investigating the bottom-up factors involved in early visual perception, is the access to visual awareness. According to the Global Neuronal Workspace (Dehaene & Changeux, 2011; Dehaene, Kerszberg, & Changeus, 1998; Mashour, Roelfsema, Changeux, & Dehaene, 2020), the access to visual awareness relies on top-down amplification by late and higher-level integrative processes, and bottom-up spread of sensory signals through the visual system. Thus, when a visual stimulus reaches a certain salience threshold at a sensory level, it triggers the activation of neuronal networks (e.g., parieto-frontal), leading to a top-down amplification. Recent studies using non-emotional stimuli have reported an elevated threshold for visual awareness in schizophrenia (Berkovitch et al., 2021; Berkovitch, Del Cul, Maheu, & Dehaene, 2018; Del Cul et al., 2006; Lefebvre et al., 2021), although its understanding is yet incomplete (Berkovitch et al., 2017). It has been proposed that this elevated threshold in schizophrenia decreases the information entering consciousness, leading to misinterpretations of stimuli and to exacerbated positive symptoms (Berkovitch et al., 2017). Considering the social cognitive deficits in schizophrenia, a disrupted access to visual awareness by stimuli with socioemotional relevance could impact the way these people perceive and make sense of their social world. Hence, studying how emotional faces enter visual awareness will help to understand the mechanisms underlying emotion deficits in schizophrenia-spectrum disorders.

In the present study, we aimed to investigate the access to visual awareness by emotional faces in schizophrenia-spectrum disorders using a breaking-CFS paradigm (b-CFS; Jiang, Costello, & He, 2007; Stein, Hebart, & Sterzer, 2011), a variant of CFS (Tsuchiya & Koch, 2005). CFS is a binocularly-rivalry technique in which a stimulus presented to one eye is suppressed from visual awareness by competing noise patterns exhibited to the other eye. When compared to more conventional paradigms (e.g., binocular rivalry, brief affective prime), CFS allows for longer suppression times by manipulating the contrast of the stimulus and suppressors (Tsuchiya & Koch, 2005). In b-CFS, the main dependent variable is the time it takes for the suppressed stimulus to "break" into visual awareness and to be consciously detected (Jiang et al., 2007; Stein et al., 2011). Shorter suppression times reflect a privileged access to visual awareness (Gayet, Van Der Stigchel, & Paffen, 2014; Yang, Brascamp, Kang, & Blake, 2014). Importantly, b-CFS is less susceptible to the interferences of complex cognitive functions (Caruana & Seymour, 2021; Caruana, Stein, Watson, Williams, & Seymour, 2019), including Theory of Mind, the ability to perceive human mental stages and to infer about others' dispositions, intentions, and beliefs (Pinkham, 2014).

Participants diagnosed with schizophrenia or schizoaffective disorder and control participants without psychiatric disorders completed a b-CFS task with fearful, happy, and neutral faces, similar to previous studies in the general population (Capit˜ao et al., 2014; Gray, Adams, Hedger, Newton, & Garner, 2013; Stein, Seymour, Hebart, & Sterzer, 2014; Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009; Yang, Yeh, & Keil, 2018). Fearful faces were used because they signal a potential yet unclear threat, thus enhancing visual attention to collect more information on the surroundings (Davis et al., 2011), and their processing is particularly hampered in schizophrenia (Kim et al., 2015; Kohler et al., 2003; Kuharic et al., 2019; J.S. Lee et al., 2015; S.J. Lee et al., 2010; Norton et al., 2009; Premkumar et al., 2008; Romero-Ferreiro et al., 2016; Won et al., 2019). On the other hand, happy faces convey enjoyment and affiliation, linked to reward and attachment – although they can also signal dominance and elicit rather negative feelings in the observer (Niedenthal, Mermillod, Maringer, & Hess, 2010; Rychlowska et al., 2017) –, and their processing is relatively preserved in schizophrenia (Kring et al., 2014; Lee et al., 2010; Premkumar et al., 2008; Romero-Ferreiro et al., 2016).

We made the following hypotheses. First, we expected that people with schizophrenia-spectrum disorders would be overall slower to consciously detect the visual stimuli than people without psychiatric disorders. Second, and based on the assumption that deficits in fearful face perception in schizophrenia arise from bottom-up abnormalities (Kim et al., 2015; Lee et al., 2015; Liu et al., 2016), we expected that the detection of fearful faces would be overall slower than neutral (and possibly happy) faces in patients. In healthy individuals, we expected that detection would be overall faster for fearful than neutral (and possibly happy) faces, because of the previous reports that fearful faces gain preferential access to awareness in b-CFS (Capit˜ao et al., 2014; Gray et al., 2013; Stein et al., 2014; Tsuchiya et al., 2009; Yang, Zald, & Blake, 2007). By exploring the access to visual awareness using emotional faces, which are relevant socioemotional stimuli, the present study aims to provide new evidence about the mechanisms underlying implicit emotion perception of face stimuli in schizophrenia-spectrum disorders.

2. Methods and materials

2.1. Sample size

We set the goal to test 20 participants per group, considering previous schizophrenia studies (Bedwell et al., 2013; Derntl & Habel, 2017; Kring et al., 2014; Seymour, Rhodes, Stein, & Langdon, 2016) and constrains related to time and clinical recruitment – commonly encountered in research with humans (Lakens, 2021). The recruitment and data collection were defined to start in February 2017 and to finish no later than January 2019. After reaching the minimum sample size, additional participants were recruited to prevent data loss, and data acquisition was fully stopped at the end of the timeframe. To confirm if the study was sufficiently powered, we conducted a retrospective power analysis using the PANGEA application (Westfall, 2016), considering a medium effect size of $d = 0.45$ based on the schizophrenia (Derntl & Habel, 2017; Kohler et al., 2010; Liu et al., 2016) and the CFS literature (Hedger, Gray, Garner, & Adams, 2016). The retrospective power analysis showed a 92.5% of power considering a 3×2 mixed factor design (within-between subjects), with participants nested in groups, and 72 repetitions per emotion and participant.

2.2. Participants

Twenty-six people diagnosed with schizophrenia or schizoaffective disorder and 23 gender-, age-, and education-matched healthy individuals were recruited. Inclusion criteria included age between 18 and 40 years, native Portuguese speakers, and normal or corrected-to-normal visual acuity. Exclusion criteria consisted of the self-reported presence or history of medical disorders that may affect brain functioning, substance abuse in the past month, and substance dependence in the past six months.

Patients were identified and referred by their psychiatrists in outpatient clinics of mental health hospitals located in the centre region of Portugal. They were previously diagnosed with schizophrenia or schizoaffective disorder by their psychiatrists based on the DSM-5 criteria (American Psychiatric Association, 2013). No structured clinical interview for the clinical group was performed in the present study. Patients were on a stable medication regiment for a minimum of six weeks and had not been hospitalised within the last two months. The duration of the disorder was no longer than 10 years. All patients were medicated with antipsychotics. Two patients were excluded: one for not having a diagnosis of schizophrenia or schizoaffective disorder and one for limited mobility in the right arm.

The control group was recruited from the local community and nearby university population via social media advertisings. Additional exclusion criteria for these participants consisted of the presence or history of psychiatric disorder or treatment, as confirmed via the Portuguese version of the Mini International Neuropsychiatric Interview (MINI 5.0.0; Amorim, 2000), and the presence or history of psychotic disorders in first-degree biological relatives, as stated by the participants.

The study was approved by local institutional review boards and all participants gave written informed consent before participation. The study was conducted in accordance with the Declaration of Helsinki and the standards of the American Psychological Association. Participants did not receive any reward for their participation.

2.3. Neuropsychological assessment

We used the Trail Making Test (TMT) (Cavaco et al., 2013) to control for possible effects of neurocognitive functions. The TMT consists of two parts and is widely used to assess visuoperceptual abilities (e.g., visual search; TMT-A), working memory, and task-switching abilities (TMT-B) in the general population (Sánchez-Cubillo et al., 2009) and schizophrenia (Laere, Tee, & Tang, 2018). In our sample, the score was the time of completion of each part (in sec). Longer time of completion indicates worse performance.

We used the Portuguese version of the Zung Self-rating Anxiety Scale (SAS) (Ponciano, Vaz Serra, & Relvas, 1982) to control for possible effects of anxiety in fear detection in b-CFS (Capit˜ao et al., 2014). The SAS is a self-rating scale that covers a variety of anxiety symptoms over the period of one week. It contains 20 items in a 4-point Likert scale from 1 (*a little of time*) to 4 (*most of the time*). Items 5, 9, 13, 17, and 19 are reverse scored. Total scores range from 20 to 80, with higher scores indicating higher anxiety levels. In our sample, the SAS showed a Cronbach’s alpha of 0.76, revealing adequate levels of internal consistency. The SAS responses were missing for three patients.

2.4. Stimuli

Male faces (facing forward) displaying fearful, happy, and neutral expressions were selected from six different identities from the Karolinska Directed Emotional

Faces (AM05, AM08, AM10, AM11, AM17, AM28) (Lundqvist, Flykt, & Öhman, 1998), with comparable attractiveness and intensity, and matching of important low-level visual features across fear and happy conditions (e.g., presence of teeth).[2] To improve suppression, each face was put into grayscale. The position of the eyes across all stimuli was aligned using GIMPS software (http://www.gimp.org). A gray frame with a central oval-shaped opining was superimposed onto each face, and the oval edge of the superimposed frame was smooth with a Gaussian filter. The luminance was equalized using the SHINE toolbox (Willenbockel et al., 2010) in Matlab (http://www.mathworks.com/). Final stimuli contained the oval face in one of the four quadrants, centred at a vertical and horizontal distance of 4.6◦ of visual angle related to a central black fixation cross. The gray background was set to the mean luminance resulting from normalization.

2.5. Suppressors

For building suppressors, several Mondrian patterns were composed of randomly arranged, high contrasts and colourful circles with diameters between 1.5◦ and 5◦ of visual angles, animated at 10 Hz.

2.6. Display

The task was programmed in, and displayed with, Psychopy software (Peirce, 2007). Stimuli and overlapping suppressors were presented centred on the screen area, covering about 18◦ by 18◦ of visual angle, and surrounded by a frame of black and white lines, of equal thickness, up to about 20◦ by 20◦ of visual angle (Fig. 1). Stimuli

[2] Stimuli were adapted from a previous study conducted by our laboratory, in which only male faces were presented (Rocha et al., in prep).

were displayed on a Dell E190S monitor (pixel resolution: 1280 × 1024, refresh rate: 60 Hz, display dimension: 14.8 × 11.8 in.).

Red-blue anaglyph glasses were used to allow the presentation of different information to each eye (Engell & Quilliam, 2020; Gomes, Soares, Silva, & Silva, 2018; Korb, Osimo, Suran, Goldstein, & Rumiati, 2017; Zhou et al., 2020). In the present study, the red filter lens was used over the left eye and the blue filter lens over the right eye. Stimuli were always displayed to the left eye (red lens) and suppressors to the right eye (blue lens).

2.7. Procedures

Participants were tested individually. After giving their informed consent, participants completed the sociodemographic questionnaire and the SAS. Prior to testing, ocular dominance was assessed with the Miles' test (Miles, 1930) to control for the effects of ocular dominance. Participants were seated 50 cm away from the monitor, while wearing the anaglyph glasses, and asked to keep their gaze on the black fixation cross presented in the centre of the screen. Participants were instructed to indicate, as rapidly and accurately as possible, on which side of the screen (left/right) the face or *any part* of the face became visible, by pressing with their left and right index fingers either the 'f' or 'j' keys on a computer keyboard.

Each trial started with a blank frame with the black fixation cross, displayed to both eyes for 2 sec. The frame was centrally presented. The face and suppressors were simultaneously presented, with the face appearing in one of the four quadrants (upper/lower and left/right; the order of the quadrants was random and different for each participant). The opacity of the face increased linearly from 0% to 60% over the course of 1 sec, and then stayed at 60% until 6 sec after stimulus onset (SO) or until the participant's response. The opacity of the Mondrian patterns stayed at 100% until 1 sec, and then linearly decreased to 0% until 6 sec after SO or until the participant's response (Fig. 1). Immediately after participant's response, or 6 sec after SO in trials without response, a random white noise mask was presented to both eyes. The duration of the white noise mask varied randomly between 200 and 500 ms (in trials without response) or longer (in trials with response). The speed of access to visual awareness was analysed via RT (in sec), defined from the moment of SO to the moment of a response button press.

The task was preceded by 36 practice trials, which did not contain any of the stimuli used in the main task. The main task comprised 216 trials (6 identities × 3 emotions × 4 quadrants × 3 repetitions). Stimuli were presented in a semi-random order, with one mandatory break in every 60 trials. The task lasted about 40 min. Lastly, participants completed the TMT-A and TMT-B, and were fully debriefed about the purpose of the study.

2.8. Statistical analysis

Significant levels were set at $\alpha = 0.05$ and effect sizes were computed whenever possible. Sociodemographic and neuropsychological data were analysed with parametric (i.e., independent samples t-tests for continuous variables) and non-parametric tests (i.e., Fisher exact-test and Pearson for categorical variables). We adjusted the degrees of freedom in case of violation of the assumption of equal variances in the independent samples *t*-test, assessed with Levene's test. Analysis were performed in jamovi (The Jamovi Project, 2020), a software in R language (R Core Team, 2020).

Regarding b-CFS, participants with less than 80% of trials in which the face was correctly detected within the 6 sec of stimuli presentation (valid trials) were excluded (one patient: 8.33%; one healthy control: 75.46%). For RT analysis, only valid trials were considered. Outliers (1.57%) were eliminated and calculated as follows: RT faster than 500 ms or slower than *mean + 3* × *standard deviation*, computed per emotion and participant (Kerr, Hesselmann, Räling, Wartenburger, & Sterzer, 2017).

The correlation between task performance and individual-differences measure, such as psychiatric diagnosis, depends on the reliability of these variables alone, which highlights the need to evaluate the reliability of individual-differences in experimental tasks (Goodhew & Edwards, 2019; Hedge, Powell, & Sumner, 2018). We thus computed the reliability estimates for the RT of each emotion using the *average* function of the package *splithalf* (Parsons, 2020) in R (R Core Team, 2020), with 5000 random splits of the data.

RT analyses were performed with generalized linear mixed-effect models (GLMM) using the *gmer* function in the *lmer4* package (Bates, Mächler, Bolker, & Walker, 2015) in R (R Core Team, 2020). GLMMs have several advantages in comparison to more conventional approaches (e.g., they consider multiple observations within each condition and all factors than might explain the data) and do not require an absence of heteroskedasticity (Bates, 2010; Pinheiro & Bates, 2000). Our first level consisted of 9175 observations, aggregated in our second level (n = 45). We considered a Gamma distribution (to account for positive skewness) and an identity link function (Lo & Andrews, 2015).

Based on our design, the simpler model comprised untransformed RTs as the dependent variable, and group × emotion as fixed factors. Different by-actor (to ensure that the results were not driven by the specific pictures that were selected) and by-individual random effects were considered (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017; Seedorff, Oleson, & McMurray, 2019). Fixed factors (ocular dominance, handedness, habituation during the experiment, age, SAS, TMT-A, TMT-B) were individually added to the model to improve fit. Continuous fixed factors were always centred. Models failing to converge were not considered as they would increase Type I error (Seedorff et al., 2019). Models were contrasted to the simpler model for fit using the *anova* function in the *car* package (Fox & Weisberg, 2019), and the best-fitting model was selected and described in the results section. Once the winning model was identified, we used the *Anova* function in the *car* package (Fox & Weisberg, 2019) to compute the Type-III Wald Chi-squared tests, the *emmeans* package (Lenth, 2020) to compute post-hoc comparisons with Tukey correction, and the *performance* package (Lüdecke, Makowski, Waggoner, Patil, & Ben-Shachar, 2020) to compute the Intraclass Coefficient (ICC) and the R-squared. Summary tables of the winning model, performed with the *tab_model* function in the *sjPlot* package (Lüdecke, 2021), are reported in Supplementary Materials.

The accuracy was defined as the proportion of valid trials. Therefore, invalid trials included trials with incorrect responses (0.62%) and trials without response within the 6 sec (3.41%). We computed GLMM with a binominal distribution and a logit link function using the *lmer4* package (Bates et al., 2015). Models were constructed, selected, and analysed following the same pathway as RT.

3. Results

3.1. Sample characterization

The final sample consisted of 45 participants (15 women, 33.33%), with a mean age of 27.91 (*SD* = 5.51). Of those, 23 were diagnosed with schizophrenia or schizoaffective disorder and 22 had no diagnosis of psychiatric disorders. As expected, we found no significant differences in age, $t(43) = 0.11$, $p = .913$, $d = 0.03$, gender, $\chi 2(1) = 0.04$, $p = .833$, and education, $\chi^2(4) = 3.76$, $p = .440$.[3]

Of the clinical group, 22 (95.65%) were diagnosed with schizophrenia, while one (4.35%) was diagnosed with schizoaffective disorder. Sociodemographic and clinical data are described in Table 1.

3.2. Neuropsychological characterization

There was a significant difference between groups in TMT-A, $t(43) = 6.15$, $p < .001$, $d = 1.83$, with patients showing longer time of completion ($M = 44.62$, $SD = 13.77$) than controls ($M = 24.72$, $SD = 6.52$); and in TMT-B, $t(43) = 3.43$, $p = .001$, $d = 1.02$, again with patients showing longer time of completion ($M = 98.36$, $SD = 30.80$) than controls ($M = 69.11$; $SD = 26.00$). Despite patients ($M = 31.55$, $SD = 6.28$) reporting higher anxiety than controls ($M = 29.86$, $SD = 4.39$), the difference was not statistically significant, $t(40) = 1.01$, $p = .316$, $d = 0.31$.

3.3. Split-half reliability of response time

The Spearman-brown corrected reliability estimates were 0.97, 95% CI = [0.95, 0.98] for fearful faces, 0.98, 95% CI = [0.97, 0.99] for happy faces, and 0.97, 95% CI = [0.95, 0.98] for neutral faces. These estimates indicate good reliability for RTs in all emotions.

3.4. Response time

[3] Groups were statistically compared in terms of gender, age, and education for the following reasons: 1) a perfect person-by-person match was not always possible during the recruitment; 2) and two participants were excluded from the analysis.

The winning model contained the intercept for individual and by-individual random slope for the effect of emotion (1 + emotion| individual) and the intercept for actor (1|actor) as random effects; group × emotion as fixed factors; and habituation as covariate. Ocular dominance, handedness, age, SAS, TMT-A, and TMT-B did not significantly improve the model (see Table A.1 for model comparison). The model showed a marginal R-squared of 0.31 and a conditional R-squared of 0.58. The ICC was of 0.39, which emphasises the need to account for random factors (Table A.2).

Wald Chi-squared test revealed a significant main effect of group, $\chi2(1) = 7.42$, $p = .006$). People with schizophrenia or schizoaffective disorder ($M = 2.56$, $SE = 0.16$) were slower to consciously detect the stimuli than healthy individuals ($M = 2.08$, $SE = 0.17$) (Fig. 2). There was a main effect of emotion, $\chi^2(2) = 6.03$, $p = .049$. RTs for happy faces ($M = 2.24$, $SE = 0.14$) were significantly shorter than for neutral ($M = 2.36$, $SE = 0.13$, $p = .006$) and fearful faces ($M = 2.35$, $SE = 0.13$, $p < .001$), with no difference between neutral and fearful faces ($p = .931$); and a main effect of habituation, $\chi^2(1) = 532.59$, $p < .001$), with decreases in RT as the task progressed. The interaction between group and emotion was not statistically significant, $\chi^2(2) = 0.78$, $p = .677$ (Fig. 3). Similar results were found after excluding the person with schizoaffective disorder (see Supplementary Materials).

In exploratory analysis, each group was tested individually using the same factors as the winning model for the full sample. Models with by-individual random slope for the effect of emotion failed to converge, thus only the intercepts for individual (1|individual) and actor (1|actor) were included as random effects. In the control group's model (Table A.3), there was a main effect of habituation, $\chi^2(1) = 290.09$, $p < .001$; and emotion, $\chi^2(2) = 42.08$, $p < .001$, with RTs for happy faces ($M = 2.00$, $SE = 0.17$) being significantly faster than neutral ($M = 2.10$, $SE = 0.17$, $p < .001$) and fearful faces ($M =

2.09, SE = 0.17, p < .001), but with no difference between fearful and neutral faces (p = .816). Similarly, in the clinical group's model (Table A.4), there was a main effect of habituation, $\chi 2(1) = 264.78$, p < .001; and emotion, $\chi^2(2) = 41.38$, p < .001, with RTs for happy faces (M = 2.48, SE = 0.18) being significantly faster than neutral (M = 2.62, SE = 0.18, p < .001) and fearful faces (M = 2.62, SE = 0.18, p < .001), but again with no difference between fearful and neutral (p = .963).

3.5. Accuracy

The selected model for accuracy contained the intercept for individual (1|individual) and for actor (1|actor) as random effects; the group × emotion as fixed factors; and habituation as covariate (see Table A.5 for model comparison). Models with by-individual random slope for the effect of emotion failed to converge. The winning-model showed a marginal R-squared of 0.20 and a conditional R-squared of 0.49. The ICC by individual was of 0.34 and by actor was of 0.02 (Table A.6).

Wald Chi-squared test revealed a main effect of group, $\chi^2(1) = 12.42$, p < .001. People with schizophrenia or schizoaffective disorder showed a lower proportion of valid trials (M = 0.97, SE = 0.01) than controls (M = 0.99, SE = 0.01). However, from most part, this was due to some trials without response. Indeed, when these trials were excluded from the analysis (9388 observations), no main effect of group was observed, $\chi 2(1) = 0.01$, p = .964, such that the proportion of correct responses was similar in the clinical (M = 0.99, SE = 0.01) and control groups (M = 0.99, SE = 0.01). Lastly, there was a main effect of habituation, $\chi^2(1) = 126.65$, p < .001), with higher accuracy as the task progressed. No main effect of emotion, $\chi^2(2) = 4.65$, p = .098, and no significant interaction between group and emotion, $\chi^2(2) = 0.38$, p = .829, were reported. Similar results were found after excluding the person with schizoaffective disorder (see Supplementary Materials).

4. Discussion

In the present study, we investigated the access to visual awareness by emotional faces in schizophrenia-spectrum disorders by presenting fearful, happy, and neutral faces in a b-CFS paradigm. Emotional faces are important socioemotional cues whose explicit processing is compromised in schizophrenia and linked to social dysfunction (Couture et al., 2006; Kohler et al., 2010). Yet, results on the implicit processing of emotional faces are quite mixed, with tasks often requiring complex cognitive functions (Lee et al., 2016). Our study provides new insights about the mechanisms underlying implicit emotion perception in schizophrenia-spectrum disorders, by exploring how distinct facial expressions access to visual awareness in people with schizophrenia or schizoaffective disorder, compared to people without psychiatric disorders, while minimizing the recruitment of complex cognitive functions.

As expected, people with schizophrenia-spectrum disorders took significantly longer to consciously detect a stimulus presented outside visual awareness than healthy individuals. This may be related to an elevated threshold for visual awareness observed in visual masking (Berkovitch et al., 2018, 2021; Del Cul et al., 2006) and visual detection paradigms with non-emotional stimuli (Lefebvre et al., 2021), as recently reviewed (Berkovitch et al., 2017). For example, in the study by Lefebvre et al. (2021), the target was presented at an initial duration of 400 ms, followed by decreases/increases of ~13 ms in duration based on participants' response. The authors noted that people with schizophrenia, compared to people without psychiatric disorders, needed longer presentation times to consciously detect the stimulus. Moreover, the clinical group failed to activate the anterior cingulate cortex during the transition to visual awareness, and other brain regions (e.g., cuneus, visual cortex) during unconscious and conscious perception (Lefebvre et al., 2021). Based on the Global Neuronal Workspace (Dehaene & Changeux, 2011; Dehaene et al., 1998; Mashour et al., 2020), Lefebvre et al. (2021) concluded that this elevated threshold for visual awareness was due to impairments in the interplay between sensory pathways and higher-level deficits (as shown by alterations in the anterior cingulate). Although we cannot debate on the role of higher-level deficits, our results might in part be a reflection of sensory impairments in schizophrenia-spectrum disorders (Javitt, 2009). Therefore, people with schizophrenia might need an increased sensory salience (i.e., stimulus contrast) for the stimuli to be consciously detected. This is supported by evidence for an abnormal early visual perception in schizophrenia (Butler et al., 2003; Green et al., 2011, 2012; Herzog & Brand, 2015; Mathis et al., 2012; McCleery et al., 2020; Pitts et al., 2012). Nevertheless, the main effect of group should be interpreted with caution. It is possible that not only CFS-specific factors (i.e., differential processing that occurs specially under CFS) are at play, and future studies should attempt to control for non-CFS specific factors (Stein, 2019), which were not considered in the present study. The inclusion of a binocular control condition might be particularly relevant to rule out these non CFS-specific factors (Stein & Sterzer, 2014).

In line with neurocognitive deficits in schizophrenia (Green, Horan, & Lee, 2019; Laere et al., 2018), the clinical group performed significantly worse in the TMT than the control group. Yet, we found that adding the TMT performance did not significantly improve the model. Groups did not statistically differ in sociodemographic characteristics (e.g., age, gender, education) and anxiety levels, and individual variations were taken into consideration in the model as random effects. Our findings therefore seem not to be modulated by these factors, but a more profound assessment is needed to examine the influence of factors other than the psychiatric diagnosis, such as IQ. There is also a current debate on whether post-perceptual factors, such as motor preparation, have an impact on suppression duration in b-CFS (Stein, 2019; Yang et al., 2014). This is particularly relevant because of the psychomotor slowing observed in schizophrenia-spectrum disorders (Morrens, Hulstijn, & Sabbe, 2007). Indeed, people with schizophrenia perform consistently slower in a variety of neurocognitive tasks, which is associated with alterations in the basal circuitry and peripheral inflammatory markers (Goldsmith et al., 2020). As such, the slower b-CFS (and TMT) performance in the clinical group might at least partly be linked to a delay in planning, programming, and executing the movements to complete the task. Future studies should attempt to separate the relative contribution of psychomotor slowing. A possible way to proceed is to conduct a simpler detection task, in which participants are instructed to indicate whether a stimulus (presented to both eyes in one of the four quadrants) appeared on the left or right side of the screen, by pressing the designated key on the keyboard, as rapidly and accurately as possible. This would allow to quantify the psychomotor slowing in a similar setting as the b-CFS task.

The access to visual awareness by biologically relevant stimuli, such as human faces, was only recently explored in schizophrenia. By using b-CFS, Zhou et al. (2020) found that people with schizophrenia needed longer time to detect the presence of a face than people without psychiatric disorders, similar to the present study. Interestingly, the authors reported that in controls, but not in patients, self-face stimuli broke suppression significantly faster than famous faces, which may be related to bottom-up impairments in self-perception in schizophrenia (Zhou et al., 2020). However, others have reported an intact visual awareness for upright/inverted faces (Caruana et al., 2019), averted/direct eye gaze (Seymour et al., 2016), and angry/fearful faces with direct/averted eye gaze (Caruana & Seymour, 2021) in schizophrenia-spectrum disorders. Seymour et al. (2016) showed a similar b-CFS performance by people with schizophrenia and people without psychiatric disorders, with direct eye gaze breaking suppression significantly faster than averted gaze in both groups. Similarly, Caruana et al. (2019) reported a preserved perceptual prioritization of upright faces, compared to inverted faces, in schizophrenia-spectrum disorders. These mixed findings in the literature may be related to the use of distinct stimuli and methodology, namely suppressors, opacity manipulation, stimulus location, and low-level features (Pournaghdali & Schwartz, 2020). For instance, in the three studies showing similar suppression times (Caruana & Seymour, 2021; Caruana et al., 2019; Seymour et al., 2016), stimuli were viewed through a mirror stereoscope, while anaglyph glasses were used in our and Zhou et al. (2020) study. Anaglyph glasses are associated with some crosstalk between eyes because parts of the suppressed stimuli might bleed through the lenses (Baker, Kaestner, & Gouws, 2016; Carmel, Arcaro, Kastner, & Hasson, 2010). In our study, the elevated suppressor opacity presented to one eye would still overlay this effect during much of the trial. Thus, it seems unlikely that this potential crosstalk would increase the performance discrepancy between groups. Nevertheless, researchers should explore the use of distinct methods for inducing binocular rivalry in schizophrenia-spectrum disorders; see Hesselmann, Darcy, Rothkirch, and Sterzer (2018) for a detailed discussion.

In contrast to our hypothesis, suppression times for fearful faces were not slower in people with schizophrenia-spectrum disorders and faster in people without psychiatric disorders, as reflected by the lack of a significant interaction between group and emotion. Instead, all participants, regardless of their group, were significantly faster at detecting happy faces than neutral and fearful ones. This suggests that the implicit perception of emotional faces is relatively intact in schizophrenia-spectrum disorders. Although these results do not support our hypothesis, similar findings are described in the literature (Aichert et al., 2013; Kring et al., 2014; Linden et al., 2010; Shasteen et al., 2016; van't Wout, Aleman, et al., 2007). A previous study showed no differences between people with schizophrenia-spectrum disorders and people without psychiatric disorders in the interference of fearful faces during a gender identification task, suggesting a preserved automatic allocation of attention towards fearful faces (van't Wout, Aleman, et al., 2007). Likewise, Linden et al. (2010) reported that, although people with schizophrenia performed worse than people without psychiatric disorders, they showed a similar interference of angry faces in face identification during a working memory task. Kring et al. (2014) observed that angry and happy faces suppressed from awareness affected the processing of non-suppressed neutral faces in people with schizophrenia and healthy individuals. The authors concluded that people with schizophrenia were able to perceive emotional cues from unseen faces, and that deficits in explicit emotional face perception may arise from the integration of a semantic context (i.e., affective label) with the perceptual information about the face (Kring et al., 2014).

Our findings do not support the reports of an abnormal implicit perception of emotional faces in schizophrenia (Derntl & Habel, 2017; Liu et al., 2016; Park et al., 2011; Rauch et al., 2010; Suslow et al., 2013). Liu et al. (2016) showed that fearful faces presented for 100 ms failed to draw patients' attention in an exogenous and automatic fashion – an attentional bias seen in healthy individuals. The authors concluded that fear processing is impaired by bottom-up factors in early visual perception in schizophrenia (Liu et al., 2016). Nevertheless, it is possible that these tasks do not solely reflect perceptual abnormalities because they require complex cognitive functions. Implicit emotional recognition speed (as assessed via RT) is linked to several cognitive factors: processing speed, impulsivity/inhibition, working-memory capacity, sensorimotor function, and sustained attention/vigilance (Mathersul et al., 2009). Along this line, Meyer and Lieberman (2012) reviewed that cognitive working memory load reduces the activation of brain areas involved in social cognitive processing (i.e., mentalizing network) in working memory for social information. An increased cognitive load may amplify the difference between people with schizophrenia and controls in social cognitive tasks. Therefore, by using a paradigm that minimizes the influence of high-level cognitive domains, we propose that the implicit perception of emotional faces is overall intact in schizophrenia-spectrum disorders, but that deficits arise when tasks become more demanding (Caruana & Seymour, 2021).

Additionally, difficulties in recognizing and discriminating threat-related faces, namely fearful ones, are consistently reported in the schizophrenia literature (Kohler et al., 2003; Kuharic et al., 2019; Lee et al., 2010; Norton et al., 2009; Premkumar et al., 2008; Romero-Ferreiro et al., 2016; Won et al., 2019). These are observed irrespective of the antipsychotic treatment and illness severity (Kohler et al., 2010). Our outcomes suggest that these deficits, however, are most likely explained by top-down cognitive biases related to the judgment of faces, instead of bottom-up abnormalities at early perceptual stages (Caruana & Seymour, 2021; Caruana, Inkley, & El Zein, 2020; Kring et al., 2014; Shasteen et al., 2016). In a recent study by Caruana and Seymour (2021), angry and fearful faces with direct and averted gaze were presented using a b-CFS paradigm. The authors reported that, in the clinical and control groups, fearful faces were faster at breaking visual suppression than angry faces. Moreover, people with schizophrenia or schizoaffective disorder, compared to people without psychiatric disorders, performed significantly worse in a verbal comprehension task to evaluate first-order Theory of Mind inferences about the mental state of a character. Similar to our interpretation, these results point to a preserved implicit perception of fearful (and angry) faces in schizophrenia-spectrum disorders in early visual stages (Caruana & Seymour, 2021). Accordingly, a meta-analysis showed a more pronounced hypo-activation of the limbic system, with compensatory hyper-activation of the medial prefrontal cortex during explicit perception of fearful faces, compared to implicit perception, which might represent an inability to contextualize salient fearful faces (Dong et al., 2018). This is congruent with an increased tendency for paranoid patients to attribute anger to neutral faces (Pinkham, Brensinger, Kohler, Gur, & Gur, 2011), which stresses the role of prior knowledges, expectations, and goals in emotional face recognition in schizophrenia-spectrum disorders.

In addition, RTs in the present study were significantly shorter for happy faces than neutral and fearful ones. Our findings are not consistent with the faster conscious detection of fearful faces in b-CFS (Capit˜ao et al., 2014; Gray et al., 2013; Stein et al., 2014; Tsuchiya et al., 2009; Yang et al., 2007) – as reviewed by Hedger et al. (2016) – and with an overall preferential threat detection in healthy individuals (Öhman, Flykt, & Esteves, 2001; Öhman, Soares, Juth, Lindstörm, & Esteves, 2012; Soares, Lindström, Esteves, Öhman, & Nishijo, 2014). One possible explanation arises from stimuli preparation. For instance, Yang et al. (2007) normalized the stimuli's RMS contrast – linked to the enhancement of high spatial frequencies (Ramanoel et al., 2014), which seems to play a role in fear recognition (Menzel, Redies, & Hayn-Leichsenring, 2018; Smith & Schyns, 2009) – and this might have inadvertently emphasized aspects relevant for detection. Concomitantly, Webb, Hibbard, and O'Gorman (2020) recommended caution when applying RMS contrast normalization since it seems to boost the salience of fearful faces, which may contribute to the fear advantage in b-CFS (Webb & Hibbard, 2020). Moreover, Yang et al. (2007) reported a similar fear advantage with inverted faces, thus highlighting the potential role of low-level properties (unaffected by inversion). Similar to our findings, other b-CFS studies have demonstrated that happy faces are significantly faster at breaking visual suppression than neutral and fearful faces (Yang et al., 2018) or angry faces (Hong, Yoon, & Peaco, 2015; Korb et al., 2017). As reviewed (Pool, Brosch, Delplanque, & Sander, 2016), a happy advantage is reported in paradigms such as dot-probe (Wirth & Wentura, 2020), letter-discrimination (Gupta, Young-Jin, & Lavia, 2016), inattentional blindness (Gupta & Srinivasan, 2015), and visual search (Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Calvo & Nummenmaa, 2008). It has been postulated that salient facial features (particularly in the mouth region) attract attention and facilitate the detection of happy faces (Calvo & Nummenmaa, 2008). This happy advantage is not merely explained by high local luminance in the teeth area – leading to high local contrast in the area around the mouth –, but by a combination of all features that characterize happy faces (Becker et al., 2011; Becker & Srinivasan, 2014; Calvo & Nummenmaa, 2008; Wirth & Wentura, 2020). Moreover, there is a consistent superior recognition of happy faces in the general population (Calvo & Nummenmaa, 2015), even outside of overt visual attention (Calvo, Nummenmaa, & Avero, 2010), and an intact recognition of happy faces in people with schizophrenia or schizoaffective disorder (Kring et al., 2014; Lee et al., 2010; Premkumar et al., 2008; Romero-Ferreiro et al., 2016). Taken together, happy faces are sometimes prioritized by the visual system, with evidence for a faster access to visual awareness in b-CFS, but further studies are needed to confirm this effect, not in the scope of the current work.

Before drawing final conclusions, potential limitations need to be considered. First, it is possible that low-level features, such as the ones related to the teeth in happy faces (Yang et al., 2018), have played a role in suppression times (Gray et al., 2013; Jiang et al., 2007). To control for this effect, only happy and fearful faces with teeth exposure were selected. Stimuli were carefully prepared to avoid variations in size, colour, and luminance and, by including a random intercept for actor, random variations related to the selected faces were statistically controlled. Nevertheless, future studies should include a condition (e.g., inverted/upright faces) to control for the emotional content while keeping constant the low-level properties. Additionally, as previously stated, we did not add a binocular control task because of already extensive task duration. The lack of a control task does not allow to rule out the non CFS-specific factors and, therefore, we cannot assure that our findings reflect differential processing that occurred specially under CFS (Stein & Sterzer, 2014). We thus encourage researchers to include a control task whenever possible.

Second, authors have argued that conscious experience should not be evaluated by dichotomous responses because stimuli that are only partially visible might not yet elicit a “yes” response (Pournaghdali & Schwartz, 2020; Stein, 2019). To account for this, we asked participants to answer as soon as the face or *any part* of the face become visible. However, it would be useful to include objective measures, such as eye-tracking (Vetter, Badde, Phelps, & Carrasco, 2019). Furthermore, the assumption that differences in detection speed in b-CFS reflect distinct unconscious processing has been recently challenged (Stein & Peelen, 2021). The authors proposed that the use of detection-discrimination paradigms would help to unravel the conscious and unconscious influences in visual perception by showing if stimuli that are more rapidly detected are consciously discriminated – supporting conscious processes – or not – supporting unconscious processes.

Third, only male faces were used. Despite evidence that female faces break suppression significantly faster than male faces in healthy individuals (Wang, Tong, Shang, & Chen, 2019), this female advantage is not modulated by the facial expression (Hong et al., 2015). The explicit perception of face gender is relatively intact in schizophrenia (Bortolon et al., 2015), with no evidence for an abnormal implicit perception. Therefore, it is unlikely that our findings are limited to the use of male faces, but we advise researchers to use male and female faces in future studies to avoid this potential limitation.

Fourth, all patients were medicated with antipsychotics, raising a potential effect of medication. Antipsychotics are relatively ineffective in treating social cognition (Kucharska-Pietura & Mortimer, 2013), and that deficits in visual abilities are also reported in unmedicated people with schizophrenia (Kéri, Kiss, Kelemen, Benedek, & Janka, 2005). One study revealed that the performance in a masking paradigm to investigate conscious access was not correlated with pharmacological treatment (Berkovitch et al., 2018). As such, and although we cannot fully exclude the effects of medication, it is possible that pharmacological treatment has little impact in our findings. Moreover, our clinical records included little information, which limited the analysis. Schizophrenia and schizoaffective disorder are very heterogeneous disorders, with patients exhibiting a wide range of symptomatology (American Psychiatric Association, 2013). For instance, one study showed that emotion perception is influenced by the predominance of positive or negative symptoms (van't Wout, van Dijke, et al., 2007). We thus endorse researchers to adopt a more profound and independent clinical evaluation that allows subgroup comparisons. This evaluation would also include structured diagnostic interviews by clinicians other than the treating medical team to ascertain the diagnosis of all patients and the severity of psychotic symptoms.

Fifth, the relatively modest sample size may not have been sufficiently large to reveal emotion-specific differences between groups, particularly considering the heterogeneity that characterizes schizophrenia-spectrum disorders. Yet, statistical power seems sufficient considering a medium effect of $d = 0.45$, based on subsequent power analysis. The inclusion of multiple observations per individual (i. e., three repetitions for each facial expression, stimulus location, and actor) can increase the power of experimental designs and decrease the variance within conditions (Brysbaert, 2019). Nevertheless, our findings should be considered preliminary before being replicated in a larger sample size.

At last, our clinical sample included diagnosis of schizophrenia and schizoaffective disorder, characterized by the presence of affective symptoms together with psychotic symptoms (American Psychiatric Association, 2013). Despite focusing on a single diagnostic category might have improved the robustness of our findings, no categorical differences between schizophrenia and schizoaffective disorder are observed in brain structure and several domains of social/non-social cognition, including Theory of Mind, processing speed, and working memory (Hartman, Heinrichs, & Mashhadi, 2019). This is supported by our study, showing the same pattern of results after the exclusion of the person with schizoaffective disorder. Genome-wide association studies report an overlap of genetic aetiology between schizophrenia, schizoaffective, and bipolar disorder, and proposed a schizophrenia-bipolar continuum (not reflected in the traditional diagnostic categories) (The International Schizophrenia Consortium, 2009). This spectrum is supported by an overlapping of cognitive and perceptual abnormalities in schizophrenia and bipolar disorder (Berkovitch et al., 2021; Tamminga et al., 2014), although usually less severe in bipolar disorder. Future studies would therefore benefit from the inclusion of a clinical control group composed of people with bipolar disorder.

Notwithstanding these limitations, our study is relevant to understand deficits in social domains in schizophrenia-spectrum disorders. An elevated threshold for visual awareness limits the information that reaches consciousness. This may be especially challenging in socioemotional contexts, where individuals are exposed to a wide range of biologically relevant stimuli – often in an implicit manner – that requires a rapid response. Furthermore, due to a slower access to visual awareness, people with schizophrenia-spectrum disorders may be less open to visual information that challenges their inferences, thus reinforcing their misperceptions about the social world (Berkovitch et al., 2017). Along this line, recent studies have stressed the role of remediation strategies that directly target basic visual perception in higher-level cognitive functions and even social cognition (Best & Bowie, 2017; Kurylo et al., 2018; Silverstein et al., 2020). A broader comprehension of the fundamental aspects of visual perception in schizophrenia-spectrum disorders will therefore enable the development of tailored interventions.

5. Conclusion

We investigated implicit emotion perception in people with schizophrenia or schizoaffective disorder, compared to people without psychiatric disorders, by exploring access to visual awareness by emotional faces. People with schizophrenia-spectrum disorders were slower at consciously detecting the presence of a face stimulus than healthy individuals, which is congruent with an elevated threshold for visual awareness, although further evidence is needed to rule out the effects of non CFS-specific factors and psychomotor speed. However, there was no significant interaction between group and emotion. Instead, RTs for fearful faces did not differ from those for neutral faces, and happy faces were significantly faster at breaking visual suppression than neutral and fearful faces in all participants, regardless of the group. Our study suggests that the implicit perception of emotional faces is intact in schizophrenia-spectrum disorders, while the access to visual awareness might not be. Although they should be considered preliminary, our results contribute to the comprehension of visual consciousness in socioemotional contexts in schizophrenia-spectrum disorders.

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7. Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Nuno Madeira has been a consultant or advisory board member to Angelini, AstraZeneca, Ferrer and Janssen. All other authors have no conflicts of interest/competing interests to report.

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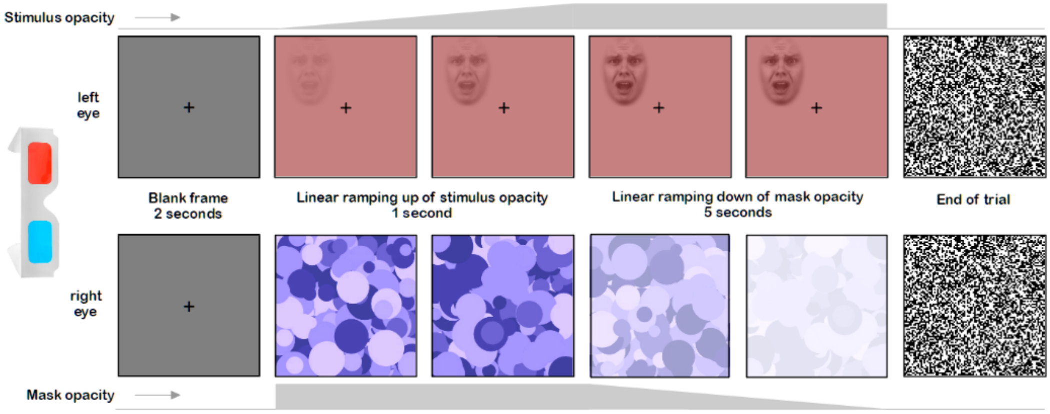

Fig. 1. Illustration of a trial in b-CFS task with fearful faces. Face stimuli were retrieved from the Karolinska Directed Emotional Faces (Lundqvist et al., 1998).

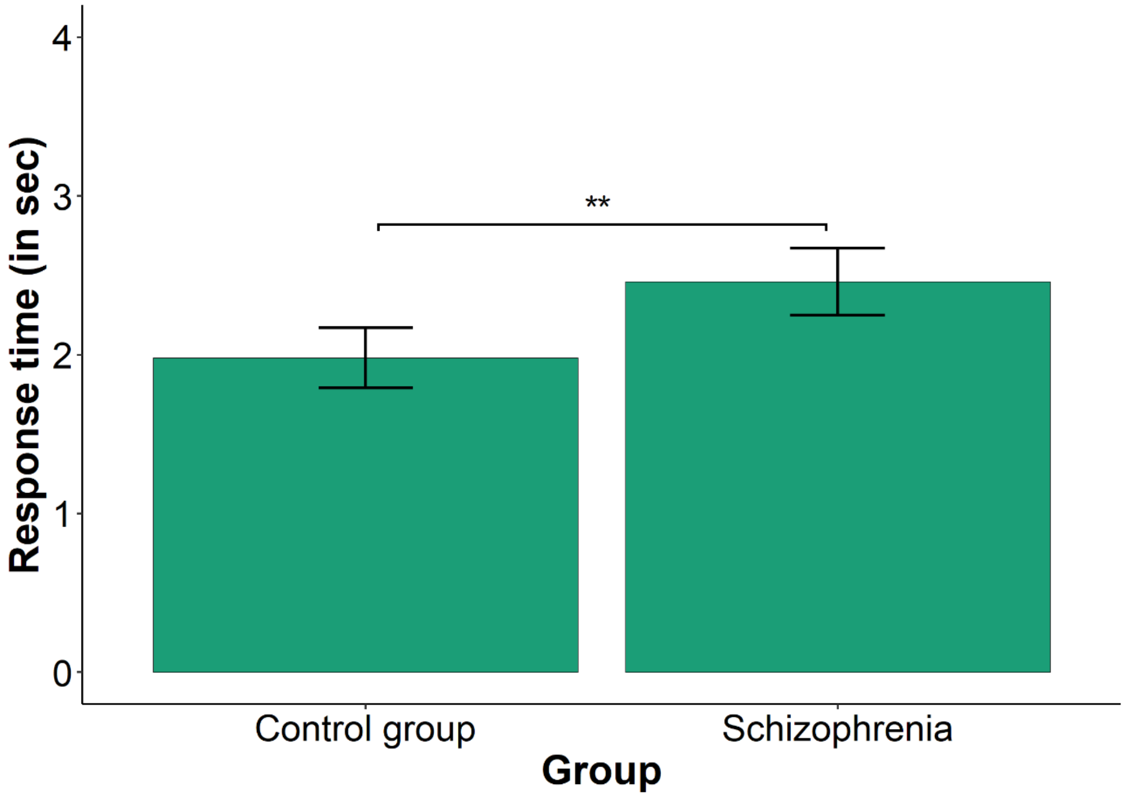

Fig. 2. Means of response time (in sec) by group. Analysis with generalized linear-mixed models showed that response times were significantly longer in the schizophrenia group than the control group (p = .006). Error bars indicate standard error.

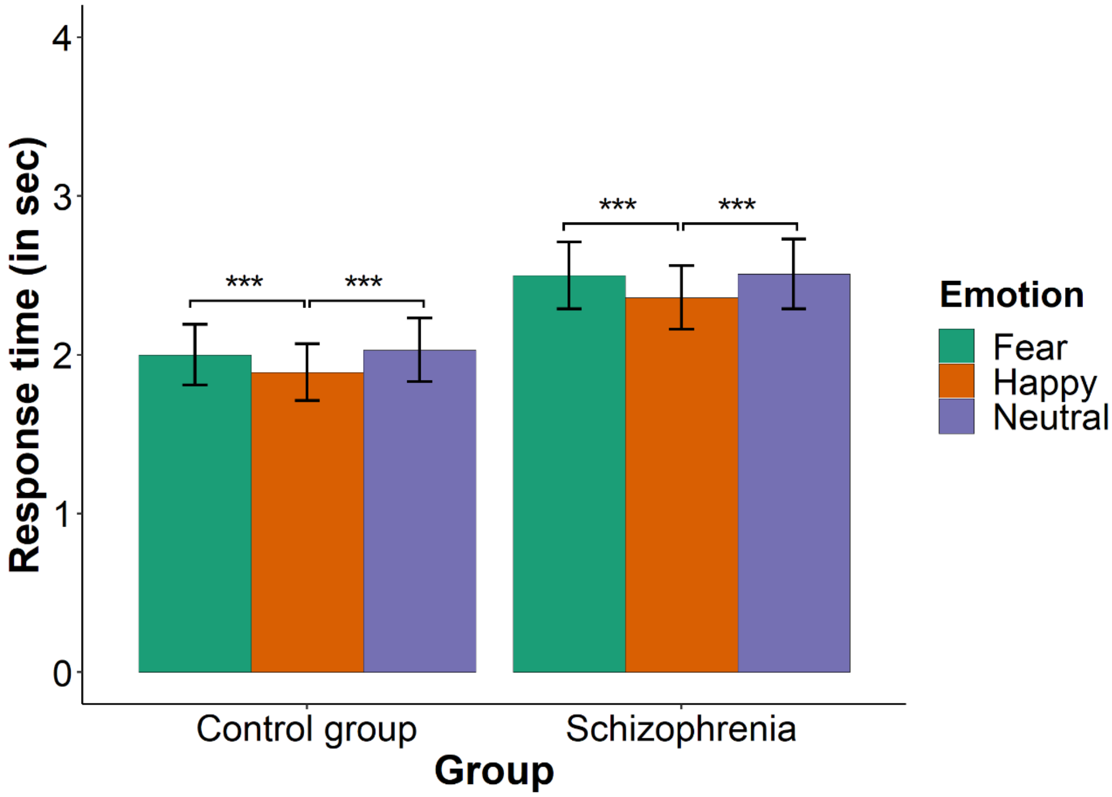

Fig. 3. Means of response time (in sec) by group and emotion. Exploratory analysis with generalized linear-mixed models per group showed that, in the schizophrenia group and in the control group, response times were significantly shorter for happy faces than neutral ($p < .001$) and fearful ones ($p < .001$), with no difference between fearful and neutral faces ($p > .050$). Error bars indicate standard error.

Table 1.

Sociodemographic and clinical characteristics of people with schizophrenia and people without psychiatric disorder

		SZ *n=23*	*CG* *n=22*	*p-value* [1]
Age, *M (SD)*		28 (5.74)	27.81 (5.39)	.913
Gender, *n* (%)	Male	15 (65.22)	15 (68.18)	.833
	Female	8 (34.78)	7 (31.82)	
Education, *n* (%)	First cycle	0 (0)	0 (0)	.440
	Second cycle	1 (4.35)	0 (0)	
	Third cycle	1 (4.35)	3 (13.64)	
	Secondary	15 65.22)	10 (45.45)	
	Graduation	4 (17.39)	5 (22.73)	
	Master or higher	2 (8.70)	4 (18.18)	
Occupation, *n* (%)	Student	4 (17.39)	3 (13.64)	.891
	Employed	11 (47.83)	12 (54.55)	
	Unemployed	8 (34.78)	7 (31.82)	
Handedness, *n* (%)	Right	23 (100)	21 (95.45)	.301
	Left	0 (0)	1 (4.55)	
Ocular dominance, *n* (%)	Right	13 (56.52)	13 (59.09)	.862
	Left	10 (43.48)	9 (40.91)	
First episode psychosis, *n* (%)	Yes	11 (47.83)		
	No	12 (52.18)		
Number of hospitalizations, *M (SD)*		1.39 (1.27)		
Duration of the disorder (years), *M (SD)*		3.39 (2.04)		
Age of onset, *M (SD)*		24.61 (5.69)		

Note: CG, control group; SZ, schizophrenia-spectrum group

[1]The comparisons between groups were performed using Chi-Square, Fisher, or independent sample *t-tests*.

Highlights

- This study explores visual awareness and emotional faces in schizophrenia
- We used a continuous flash suppression task with fearful, happy and neutral faces
- Schizophrenia patients exhibited an overall slower access to visual awareness
- Happy faces broke suppression faster in both schizophrenia and control groups
- The implicit perception of emotional faces is intact in schizophrenia

CRediT authorship contribution statement

Joana Grave: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization. **Nuno Madeira:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Maria João Martins:** Conceptualization, Methodology, Investigation, Resources, Writing – review & editing. **Samuel Silva:** Conceptualization, Methodology, Software, Resources, Writing – review & editing. **Sebastian Korb:** Conceptualization, Methodology, Software, Formal analysis, Resources, Data curation, Writing – review & editing. **Sandra Cristina Soares:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision.

Supplementary Material

Slower access to visual awareness but otherwise intact implicit perception of emotional faces in schizophrenia-spectrum disorders

Supplementary Material

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Results

Analysis without the participant diagnosed with schizoaffective disorder

To test whether the inclusion of two diagnostic categories shaped the results, the winning models for the full sample were computed without the one person diagnosed with schizoaffective disorder. Regarding RTs, we found a similar main effect of group, $\chi^2(1) = 4.51$, $p = .034$, main effect of emotion, $\chi^2(2) = 7.74$, $p = .021$, main effect of habituation, $\chi^2(1) = 532.91$, $p < .001$, and no significant interaction between group and emotion, $\chi^2(2) = 0.58$, $p = .749$. Likewise, for accuracy, we found a similar main effect of group, $\chi^2(1) = 9.78$, $p = .002$, main effect of habituation, $\chi^2(1) = 126.44$, $p < .001$, no main effect of emotion, $\chi^2(3) = 4.65$, $p = .098$, and no significant interaction between group and emotion, $\chi^2(2) = 1.061$, $p = .588$.

Table A.1 Comparison of generalized linear mixed models values for the **response time** during a breaking-Continuous Flash Suppression task with fearful, happy, and neutral facial expressions. Models were compared with the simpler model using the same combination of random effects.

Description	*AIC*	*BIC*	logLik	χ^2	*p*
Random effects: (1|Individual) + (1|Actor)					
Group * Emotion	17853	17917	-8917		
Group * Emotion + Habituation	17337	17409	-8659	517.58	< .001 ***
Group * Emotion + Age	17852	17923	-8916	3.00	.083
Group * Emotion + TMT-A	17853	17925	-8917	1.39	.239
Group * Emotion + TMT-B	17855	17926	-8917	0.30	.582
Group * Emotion + Dominant eye	17854	17925	-8917	1.24	.266
Group * Emotion + Handedness	17853	17924	-8916	1.76	.185
Random effects: (1+Emotion|Individual) + (1|Actor)					
Group * Emotion	17775	17875	-8874		
Group * Emotion + Habituation	17259	17466	-8614	518.36	< .001 ***
Group * Emotion + Age	17773	17880	-8872	4.14	.042 *
Group * Emotion + TMT-A	17776	17883	-8873	1.50	.221
Group * Emotion + TMT-B	17777	17884	-8874	0.22	.638
Group* Emotion + Dominant eye	17776	17883	-8873	1.02	.312
Group * Emotion + Handedness	17776	17883	-8873	1.13	.288

AIC Akaike information criterion*; BIC* Bayesian information criterion*; TMT-A* Trial Making Test (Part A); *TMT-B* Trial Making Test (Part B)

The model containing the anxiety scores was not statistically compared with the simpler model because they had different sizes due to the missing responses in the anxiety questionnaire

*** $p < .001$, * $p < .050$

Table A.2 Output of the generalized linear mixed-effects model for **response time** during a breaking-Continuous Flash Suppression task with fearful, happy, and neutral facial expressions. The model contained the intercept for individual and by-individual random slope for the effect of emotion (1 + emotion|individual), and the intercept for actor (1|actor) as random effects; group × emotion as fixed factors; and habituation as covariate.

			95% CI			
Predictors	*Estimate*	*SE*	*Lower*	*Upper*	*t-value*	*p*
(Intercept)	2.10	0.17	1.78	2.43	12.62	< .001***
$Group_{SZ\text{-}CG}$	0.50	0.18	0.14	0.86	2.72	.006**
$Emotion_{H\text{-}F}$	-0.09	0.04	-0.17	-0.01	-2.27	.023*
$Emotion_{N\text{-}F}$	0.03	0.04	-0.05	-0.12	0.74	.458
$Group_{SZ\text{-}CG}$:$Emotion_{H\text{-}F}$	-0.04	0.06	-0.15	-0.08	-0.62	.533
$Group_{SZ\text{-}CG}$:$Emotion_{H\text{-}F}$	-0.04	0.06	-0.16	-0.08	-0.69	.490
Habituation	-0.13	0.01	-0.15	-0.12	-23.08	< .001***
Random effects						
σ^2	0.10					
ICC	0.39					
$N_{individual}$	41					
N_{face}	6					
Observations	9175					
Marginal R^2 / Conditional R^2	0.31 / 0.58					

CG control group; *F* fearful faces; *H* happy faces; *N* neutral faces; *SZ* schizophrenia; *SE* standard error; *95% CI* confidence interval
****p* < .001, ** *p* < .01, * *p* < .05

Table A.3 Output of the generalized linear mixed-effects model for **response time** during a breaking-Continuous Flash Suppression task with fearful, happy, and neutral facial expressions, in the **control group**. The model contained the intercept for individual and the intercept for actor (1|actor) as random effects; group × emotion as fixed factors; and habituation as covariate.

			95% CI			
Predictors	*Estimate*	*SE*	*Lower*	*Upper*	*t-value*	*p*
(Intercept)	2.09	0.17	1.76	2.43	12.26	< .001***
$Emotion_{H-F}$	-0.09	0.02	-0.13	-0.06	-5.22	< .001***
$Emotion_{N-F}$	0.011	0.02	-0.03	0.05	0.61	.544
Habituation	-0.12	0.01	-0.13	-0.11	-17.03	< .001***
Random effects						
σ^2	0.10					
$ICC_{individual}$	0.35					
ICC_{face}	0.03					
$N_{individual}$	22					
N_{face}	6					
Observations	4597					
Marginal R^2 / Conditional R^2	0.09 / 0.44					

F fearful faces; *H* happy faces; *N* neutral faces; *SE* standard error; *95% CI* confidence interval

***$p < .001$

Table A.4 Output of the generalized linear mixed-effects model for **response time** during a breaking-Continuous Flash Suppression task with fearful, happy, and neutral facial expressions, in the **schizophrenia group**. The model contained the intercept for individual and the intercept for actor (1|actor) as random effects; group × emotion as fixed factors; and habituation as covariate.

			95% CI			
Predictors	*Estimate*	*SE*	*Lower*	*Upper*	*t-value*	*p*
(Intercept)	2.62	0.18	2.27	2.98	14.36	< .001***
$\text{Emotion}_{H\text{-}F}$	-0.14	0.02	-0.19	-0.09	-5.63	< .001***
$\text{Emotion}_{N\text{-}F}$	-0.01	0.03	-0.06	0.04	-0.26	.793
Habituation	-0.16	0.01	-0.18	-0.14	-16.27	< .001***
Random effects						
σ^2	0.11					
$\text{ICC}_{individual}$	0.31					
ICC_{face}	0.07					
$\text{N}_{individual}$	23					
N_{face}	6					
Observations	4578					
Marginal R^2 / Conditional R^2	0.15 / 0.47					

F fearful faces; *H* happy faces; *N* neutral faces; *SE* standard error; *95% CI* confidence interval
****p* < .001

Table A.5 Comparison of generalized linear mixed models values for the **accuracy** during a breaking-Continuous Flash Suppression task with fearful, happy, and neutral facial expressions. Models were compared with the simpler model using the same combination of random effects.

Description	*AIC*	*BIC*	logLik	χ^2	*p*
Random effects: (1|Individual) + (1|Actor)					
Group * Emotion	2738	2796	-1361		
Group * Emotion + Habituation	2604	2669	-1293	136.32	< .001 ***
Group * Emotion + Age	2740	2805	-1361	0.00	.958
Group * Emotion + TMT-A	2740	2805	-1361	0.40	.526
Group * Emotion + TMT-B	2740	2805	-1361	0.12	.725
Group * Emotion + Dominant eye	2739	2804	-1360	1.47	.226
Group * Emotion + Handedness	2739	2804	-1360	1.34	.247

AIC Akaike information criterion; *BIC* Bayesian information criterion; *TMT-A* Trial Making Test (Part A); *TMT-B* Trial Making Test (Part B)
Models were compared with the simpler model with the same random effects
The model with the handedness failed to converge
The model containing the anxiety scores was not statistically compared with the simpler model because they had different sizes due to the missing responses in the anxiety questionnaire
*** $p < .001$, * $p < .050$

Table A.6 Output of the generalized linear mixed-effects model for **accuracy** during a breaking-Continuous Flash Suppression task with fearful, happy, and neutral facial expressions. The model contained the intercept for individual (1|individual) and the intercept for actor (1|actor) as random effects; and the group × emotion as fixed factors.

			95% CI			
Predictors	*Log-Odds*	*SE*	*Lower*	*Upper*	*z-value*	*p*
(Intercept)	4.95	0.39	4.17	5.72		<.001***
$Group_{SZ-CG}$	-1.65	0.47	-2.57	-0.73		< .001***
$Emotion_{H-F}$	0.64	0.30	0.04	1.23		0.036*
$Emotion_{N-F}$	0.36	0.28	-0.20	0.91		0.206
$Group_{SZ-CG}$:$Emotion_{H-F}$	-0.06	0.34	-0.73	0.61		0.859
$Group_{SZ-CG}$:$Emotion_{H-F}$	-0.19	0.31	-0.81	0.43		0.542
Habituation	0.67	0.06	0.55	0.79		< .001***
Random effects						
σ^2	3.29					
$ICC_{individual}$	0.34					
ICC_{face}	0.02					
$N_{individual}$	45					
N_{face}	6					
Observations	9720					
Marginal R^2 / Conditional R^2	0.20 / 0.49					

CG control group; *F* fearful faces; *H* happy faces; *N* neutral faces; *SZ* schizophrenia; *SE* standard error; *95% CI* confidence interval
*** $p < .001$, * $p < .050$