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Facial decoding in schizophrenia is underpinned by basic visual processing impairments

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ABSTRACT

Schizophrenia is associated with a strong deficit in the decoding of emotional facial expression (EFE). Nevertheless, it is still unclear whether this deficit is specific for emotions or due to a more general impairment for any type of facial processing. This study was designed to clarify this issue. Thirty patients suffering from schizophrenia and 30 matched healthy controls performed several tasks evaluating the recognition of both changeable (i.e. eyes orientation and emotions) and stable (i.e. gender, age) facial characteristics. Accuracy and reaction times were recorded. Schizophrenic patients presented a performance deficit (accuracy and reaction times) in the perception of both changeable and stable aspects of faces, without any specific deficit for emotional decoding. Our results demonstrate a generalized face recognition deficit in schizophrenic patients, probably caused by a perceptual deficit in basic visual processing. It seems that the deficit in the decoding of emotional facial expression (EFE) is not a specific deficit of emotion processing, but is at least partly related to a generalized perceptual deficit in lower-level perceptual processing, occurring before the stage of emotion processing, and underlying more complex cognitive dysfunctions. These findings should encourage future investigations to explore the neurophysiologic background of these generalized perceptual deficits, and stimulate a clinical approach focusing on more basic visual processing.

1. Introduction

Impaired emotional facial expression (EFE) decoding abilities have been repeatedly documented in schizophrenia and play a role in the more globally altered social cognition (Javitt and Freedman, 2015), interpersonal misunderstandings, and inadequate social behaviours (Pinkham and Penn, 2006) related to this pathology (Couture et al., 2006). However, earlier results suggested that schizophrenic patients (SP) are impaired in the recognition of emotional but also non-emotional facial stimuli (Comparelli et al., 2013; Constant et al., 2011; Kucharska et al., 2005; Sachs et al., 2004), raising the question of whether EFE decoding deficits are confined to emotion identification, reflecting a specific dysfunction in high-level emotion-processing regions such as the amygdala (Javitt and Friedmann, 2015), or are part of a broader impairment in other types of facial processing as well, such as identity, age, or gender (Javitt, 2009b; Sehatpour et al., 2010).

The classical tendency in the schizophrenia literature has been to attribute cognitive dysfunction to deficits in higher-level cognitive processes and to view more low-level forms of cognitive dysfunction as being driven by top-down influences from higher cortical regions. Recent research argues against such hypothesis, by showing deficits within the perceptual systems in schizophrenia that cannot be attributed to top-down dysregulation (Uhlhaas and Mishara, 2007). Furthermore, deficits in lower-level perceptual processing may, by a bottom-up mechanism, undermine the ability to perform more complex cognitive operations (Silverstein and Keane, 2011). Neurobiological findings support these bottom-up hypotheses, notably by documenting specific deficits in the functioning of the magnocellular visual pathway among SP, this pathway affecting early global processing of visual stimuli (Butler et al., 2009, 2001; Javitt, 2009a, 2009b). This magnocellular system's impairments will lead SP to lose this 'global advantage' of holistic perceptual organisation, resulting in a fragmented perception of

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reality (Butler, 2013; Hooker and Park, 2002; Sehatpour et al., 2010) but also to higher-order deficits in complex processes (e.g. perceptual closure, object recognition, reading) and even potentially in social cognition (Sergi and Green, 2003).

To our best knowledge the few studies which used psychometrically matched emotional and non-emotional tasks lead to mixed results: early works (Edwards et al., 2002; Kerr and Neale, 1993) concluded that emotion deficits reflect a generalized impairment in face processing rather than a specific emotion-recognition deficit, but more recent ones (Schneider et al., 2006) found stronger impairment in SP for emotion discrimination performance than for the processing of non-emotional features of face, specifically age. Recent reviews on this topic (Bortolon et al., 2015; Darke et al., 2013) have proposed that the deficits observed among SP for face processing tasks are unlikely to be limited to emotion processing, but could rather be associated with a more general deficit in early visual processing which would impact every type of face processing, or even every task involving visual stimuli. However, these reviews concluded that further evidence are necessary, notably based on studies directly comparing different face processing tasks with a control of interfering variables. Indeed, studies investigating non-emotional face processing have used different tasks which did not use comparable stimuli and hampers valid comparison across tasks (Bortolon et al., 2015; Chen and Ekstrom, 2015).

In order to overcome these limitations, we used a controlled design based on Haxby et al. (2000) face perception model, to examine the recognition of both changeable (eyes orientation, emotion) and stable (age, gender) face characteristics in schizophrenia. As our main aim was to offer a direct comparison between emotional and non-emotional facial judgments, our experimental design was based on binary judgments (e.g. male-female for gender, positive-negative for emotion), leading to the fact that we did not evaluate emotional decoding *per se* (i.e. the identification of the emotion presented by the face), on the basis of a wide-range of emotional faciel expressions, but rather emotional valence (i.e. the ability to distinguish positive and negative emotions) using two contrasted emotions (happiness and disgust). A central strength of this procedure is that the sub-task related to the four facial aspects investigated were based on the exact same stimuli, ensuring an ideal control of perceptive aspects across conditions and allowing to clearly determine whether SP confronted with complex facial decoding have a generalized impairment in face processing rather than a specific emotion-recognition deficit.

2. Materials and methods

2.1. Participants

Thirty inpatients[1] (13 women), diagnosed with paranoid schizophrenia according to DSM-IV criteria and based on the clinical diagnosis by trained psychiatrists, were recruited through the Departments of Psychiatry of the Saint Luc University Hospital (Brussels, Belgium), the Beau Vallon Psychiatric Hospital (Namur, Belgium), and the Psychiatric Hospital Sanatia (Brussels, Belgium). All SP had been in a stable phase for at least 6 months, under atypical or mixed (typical and atypical) antipsychotics. Psychopathology was assessed with the Positive and Negative Syndrome Scale PANSS (Kay et al., 1987). SP were individually matched for age, gender and education with 30 control participants (CP, 13 women) who were free of any history of psychiatric disorder or drug/substance abuse. Education level was assessed according to the number of years of education completed since starting primary school. Exclusion criteria for both groups included current or past neurological disease (e.g., epilepsy, dementia, vascular cerebral accident), substance dependence, and age above 60. SP and CP were assessed using several psychological measures, to evaluate the presence of subclinical comorbid psychopathologies and deficits. The following variables were evaluated using validated self-completion questionnaires: State and trait anxiety (State and Trait Anxiety Inventory, form A and B, Spielberger et al., 1983), depression (Beck Depression Inventory, short version, Beck and Steer, 1987), interpersonal problems (Inventory of Interpersonal Problems, Horowitz et al., 1988), and alexithymia (20-item Toronto Alexithymia Scale, Bagby et al., 1994). Twenty-four SP were receiving second generation antipsychotic drugs ($M = 246.57$ mg; $SD = 457.26$) and 14 were taking first generation drugs ($M = 30.05$ mg; $SD = 40.58$), but no significant Spearman's correlation was found between medication and experimental measures ($p > 0.05$). CP were free of psychotropic medication. Participants were provided with full details regarding the aims of the study and the procedure to be followed, and then gave their informed consent. The study was approved by The Ethical Committee of the Medical Faculty of the Université catholique de Louvain and conducted according to the Declaration of Helsinki.

2.2. Procedure and measures

The experimental task consisted in binary decisions regarding the identification of specific features in human faces. Four experimental tasks were chosen, respectively related to gender, age, eyes orientation and emotion judgments. Each task contained 2 conditions, respectively based on the distinction between male and female (Gender task), child and adult (Age task), left and right (Eyes orientation task), positive and negative (Emotion task). 64 stimuli were selected from the Radboud Face battery (Langner et al., 2010), each being based on a unique combination of the four attributes (e.g. adult female face with negative emotion and left oriented eyes). Positive and negative emotions were respectively depicted by happiness and disgust stimuli. This experimental choice is justified by the fact that, as our experimental design was based on binary decisions, we had to select only one positive and one negative emotions. Happiness is by far the most widely used positive emotion in emotion-recognition studies and its processing has been found to be impaired in SP (e.g. Yang et al., 2015). Disgust processing has been repeatedly shown to be strongly reduced in SP (see Barkl et al., 2014; Comparelli et al., 2013) and its strong interpersonal value (Davey, 2011) is of particular interest when exploring psychopathological states characterized by massive social impairments. These stimuli are illustrated in Fig. 1. All stimuli were then standardized using Photoshop 9.0 (Adobe Systems, Inc., San Jose, CA). They were placed on a black background, resized to a 6.5X5.5 cm format (stimuli subtended a visual angle of 3X4°), and the contrast-luminosity was controlled for. Each task was divided into 3 blocks containing 64 trials. Participants were thus confronted with a total of 12 blocks of 64 stimuli, so that the study consisted in 768 stimuli (96 per condition). Each block contained 32 faces per condition (e.g., 32 child and 32 adult faces for the age task), each face appearing one time by block, and the stimuli were randomly distributed among the block. Each face was thus presented 12 times in the experiment. Importantly, the 64 same stimuli were used in each block to uniformize the perceptive aspects across conditions, but the task to perform varied across blocks. An identical procedure was used in the different experimental tasks: for each face, participants had to perform a binary task as quickly as possible, i.e. judging whether, according to the condition, the face was male-female (gender task), adult-child (age task), left-right (orientation task), or positive-negative (emotion task) by pressing the corresponding button with their right forefinger. Response laterality (e.g., left for adult and right for child) was counterbalanced, and the order of the blocks and

[1] The initial sample was constituted of 32 schizophrenic patients. However, in order to remove participants performing at chance level in the experimental tasks, the binomial cumulative distribution was used to derive chance level threshold (Combrisson and Jerbi, 2015). With a p-value of 0.01, two classes of answers and a sample size of 64 participants, the performance threshold was set at 64.6%. Two schizophrenic participants (respectively presenting a mean accuracy of 56.75% and 53.25%) were thus removed from the analyses, all participants included in the final sample presenting a global mean performance higher than 70%, ensuring that they performed above chance level.

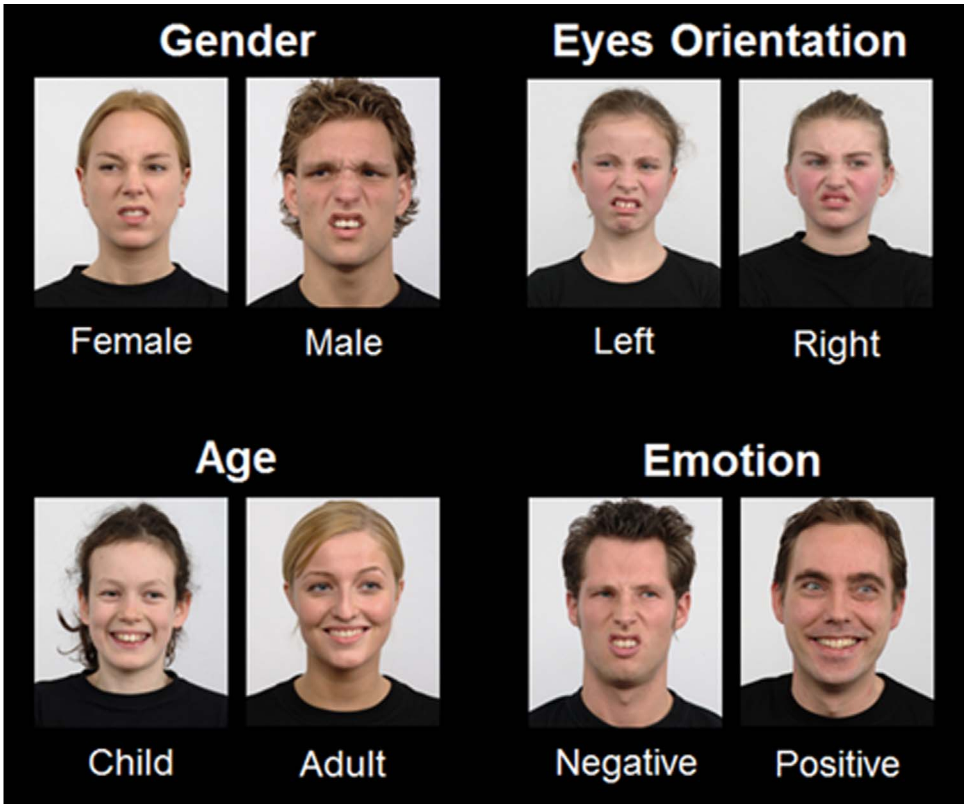

Fig. 1. Illustration of the stimuli used for the gender (male – female), eyes orientation (left – right), age (child – adult) and emotion (negative – positive) binary decision tasks.

tasks were counterbalanced across participants. Participants were reminded of the task instructions before each block. Participants were told that speed was important but not at the cost of accuracy. Response times in milliseconds (ms) and accuracy were recorded. Only correct responses were considered for response times analysis. Each trial presenting a response time lower than 300 ms or higher than 3000 ms was excluded from the analyses (0.81% of the trials), and reaction times more than 2 standard deviations below or above each participant's mean for each experimental task were discarded as outliers at the individual level (0.23% of the trials). Reaction times were log transformed to normalize the distribution.

3. Results

3.1. Control measures

As shown in Table 1, SP and CP were similar in terms of age [$F(1,58)=0.12$, $p=0.73$, Cohen's $d=0.09$], gender, and education [$F(1,58)=1.81$, $p=0.18$, $d=0.36$], and did not differ for state anxiety [$F(1,58)=2.09$, $p=0.15$, $d=0.37$]. Nevertheless, the 2 groups did differ significantly for interpersonal problems [$F(1,58)=18.54$, $p < 0.001$, $d=1.13$], alexithymia [$F(1,58)=18.31$, $p < 0.001$, $d=1.11$], trait anxiety [$F(1,58)=7.14$, $p=0.01$, $d=0.69$], and depression [$F(1,58)=9.81$, $p < 0.01$, $d=0.81$], showing higher scores for SP compared to CP. However, these differences are unlikely to have influenced the experimental results as: (1) no significant Spearman's correlations were shown between any psychological measure and any behavioral data, on the whole sample and in each group ($p > 0.05$ for every correlation), and (2) a complementary analysis was conducted, including the depression and anxiety scores as covariables in our ANOVA statistical analyses, and showing no significant influence of these factors on the results as all significant effects remained following the inclusion of these co-variables ($p < 0.05$).

Table 1
Demographic and clinical measures for schizophrenic patients (SP) and control participants (CP): Mean (S.D.) [range].

Measure	SP ($n=30$)	CP ($n=30$)
Demographic measures		
Age (in years)	46.8 (10.1) [25–60]	45.9 (10.7) [23–60]
Gender ratio (female/male)	13/17	13/17
Education level (in years)	11.2 (2.9) [5–19]	12.2 (2.6) [6–19]
Clinical measures		
Beck Depression Inventory	11.3 (10.6) [0–39]	4.7 (4.5) [0–13]
STAI state anxiety inventory	42.3 (10.4) [24–70]	37.5 (14.9) [20–62]
STAI trait anxiety inventory	47.4 (10.2) [25–71]	40.0 (11.3) [24–60]
Inventory of Interpersonal Problems	1.77 (0.6) [0.7–2.6]	1.06 (0.7) [0–2.6]
Toronto Alexithymia Scale	58.4 (11.4) [33–80]	46.4 (10.2) [25–68]
Positive and Negative Syndrome Scale - Total	94.3 (29.9) [41–144]	/
Positive and Negative Syndrome Scale - Positive	20.4 (8.5) [7–41]	/
Positive and Negative Syndrome Scale - Negative	23.9 (9.7) [8–47]	/

3.2. Experimental task

3.2.1. Accuracy

A 4 × 2 ANOVA with task (age, gender, emotion, and orientation) as within-factor and group (SP and CP) as between-factor was carried out. A main effect of group [$F(1,58)=17.69$, $p < 0.001$, $d=1.09$] was found, SP presenting reduced accuracy scores for gender [$t(29)=2.33$, $p < 0.05$, $d=0.63$], age [$t(29)=2.46$, $p < 0.05$, $d=0.68$], orientation [$t(29)=2.10$, $p < 0.05$, $d=0.56$] and emotion [$t(29)=2.75$, $p=0.01$, $d=0.74$]. No main effect for task [$F(3174)=1.92$,

$p = 0.13$, $d = 0.36$] and no interaction [$F(3174) = 1.00$, $p = 0.39$, $d = 0.20$] were found.

3.2.2. Reaction times

A 4 × 2 ANOVA with task (age, gender, emotion, and orientation) as within-factor and group (SP and CP) as between-factor was first carried out. As expected, a main effect of group [$F(1,58) = 56.05$, $p < 0.001$, $d = 1.88$] was found: SP were globally slower than CP, for gender [$t(29) = 4.95$, $p < 0.001$, $d = 1.15$], age [$t(29) = 7.41$, $p < 0.001$, $d = 1.59$], orientation [$t(29) = 6.92$, $p < 0.001$, $d = 1.79$] and emotion [$t(29) = 4.98$, $p < 0.001$, $d = 1.27$], showing a generalized deficit for the processing of emotional facial features, beyond emotional facial decoding. Moreover, we found a significant main effect of task [$F(3174) = 6.34$, $p < 0.001$, $d = 0.48$]: Gender task led to faster responses than age [$t(59) = 3.49$, $p = 0.001$, $d = 0.41$], and emotion [$t(59) = 2.46$, $p < 0.05$, $d = 0.33$] tasks, and orientation task led to faster responses than age [$t(59) = 3.63$, $p = 0.001$, $d = 0.35$], and emotion [$t(59) = 2.76$, $p < 0.01$, $d = 0.28$] tasks, the other differences being non-significant. More centrally, an interaction was found [$F(3174) = 5.08$, $p < 0.01$, $d = 0.59$]: In CP, faster reaction times were found for the orientation task compared with gender [$t(29) = 2.92$, $p < 0.01$, $d = 0.70$], age [$t(29) = 4.39$, $p < 0.001$, $d = 0.99$] and emotion [$t(29) = 4.94$, $p < 0.001$, $d = 0.94$] tasks, and for the gender task compared with emotion [$t(29) = 2.48$, $p < 0.05$, $d = 0.35$] and age [$t(29) = 2.77$, $p = 0.01$, $d = 0.39$] tasks. In SP, the only significant results were the faster reaction times in the gender task compared with age [$t(29) = 2.73$, $p < 0.05$, $d = 0.59$] and orientation [$t(29) = 9.46$, $p < 0.001$, $d = 0.39$] tasks. These results are presented in Table 2.

3.3. Complementary analyses

Several complementary analyses were conducted to:

- *Explore the link between experimental measures and Positive and Negative Syndrome Scale (PANSS)*: No significant Spearman's correlations were observed in SP between accuracy and reaction times in the experimental tasks on the one hand and PANSS total ($\rho < 0.34$, $p > 0.05$), positive ($\rho < 0.31$, $p > 0.05$) and negative ($\rho < 0.24$, $p > 0.05$) scores on the other hand.
- *Explore the gender effect*: 4 × 2 ANOVAs with task (age, gender, emotion, and orientation) as within-factor and gender (male and female) as between-factor, were conducted separately for accuracy and reaction times. No significant gender effect was found, either in the whole sample [Accuracy: $F(1,58) = 2.41$, $p = 0.13$; Reaction Times: $F(1,58) = 0.36$, $p = 0.55$] or in each group [For SP: Accuracy: $F(1,28) = 2.21$, $p = 0.15$; Reaction Times: $F(1,28) = 0.24$, $p = 0.63$; for CP: Accuracy: $F(1,28) = 0.92$, $p = 0.35$; Reaction Times: $F(1,28) = 0.62$, $p = 0.44$].
- *Explore the age effect*: No significant Spearman's correlations were observed between experimental tasks (accuracy and reaction times) and age, either in the whole sample ($\rho < 0.19$, $p > 0.05$) or in each group (For SP: $\rho < 0.17$, $p > 0.05$; for CP: $\rho < 0.29$, $p > 0.05$).
- *Explore the inverse efficiency score:* in order to explore the links between accuracy and reaction times and to obtain an aggregated efficiency score, the inverse efficiency score (reaction times/accuracy) was computed for each task, and a 4 × 2 ANOVA with task (age, gender, emotion, and orientation) as within-factor and group (SP and CP) as between-factor was carried out. Results totally replicated those obtained for accuracy and reaction times considered separately, as a main group effect was found [$F(1,58) = 29.19$, $p < 0.001$, $d = 1.41$], SP showing reduced efficiency (i.e. higher inverse efficiency scores) compared to CP for gender [$t(29) = 3.18$, $p < 0.01$, $d = 0.83$], age [$t(29) = 4.09$, $p < 0.001$, $d = 1.15$], orientation [$t(29) = 3.29$, $p < 0.01$, $d = 0.90$] and emotion [$t(29) = 3.44$, $p < 0.01$, $d = 0.94$]. No main effect for task [$F(3174) = 1.24$, $p = 0.29$, $d = 0.29$] and no interaction [$F(3174) = 0.37$, $p = 0.77$, $d = 0.15$] were found.

Table 2
Performance in the experimental task for schizophrenic patients (SP) and control participants (CP): Mean (S.D.) [range].

Experimental measures	SP (*n* = 30)	CP (*n* = 30)
Accuracy (in % of correct answer)		
Gender	89.0 (14.9) [58–100]	95.9 (3.6) [86–100]
Eyes Orientation	90.6 (13.9) [61–100]	96.4 (4.7) [77–100]
Age	86.9 (9.1) [66–99]	91.9 (5.2) [79–99]
Emotion	84.7 (20.9) [65–100]	95.8 (3.4) [89–100]
Reaction Times (in milliseconds)		
Gender	893.7 (265.2) [382–1634]	659.7 (114.1) [507–1017]
Eyes Orientation	1041.9 (412.5) [521–2338]	581.5 (156.3) [423–1061]
Age	1058.5 (321.7) [623–1902]	706.1 (130.2) [519–1108]
Emotion	1030.5 (359.5) [456–2077]	707.0 (153.4) [534–1221]

4. Discussion

As underlined above, our experimental design capitalized on Haxby et al. (2000) face perception model, centrally distinguishing the representation of invariant and changeable aspects of faces (Haxby et al., 2000), and the results will be discussed following this framework. First, regarding the invariant aspects, SP were slower than CP in both gender and age recognition tasks, but the gender task was the fastest perform in SP. In both tasks, SP presented reduced accuracy scores. While a ceiling effect was observed among CP, the percentage of errors was more than twice higher in SP. However, no main effect for task and no interaction effect were observed. Age recognition has been widely investigated but contradictory results have been reported: some studies reported no deficit (Gur et al., 2002a, 2002b; Schneider et al., 1998), but most studies, in line with our, demonstrated impairments in SP (Delerue et al., 2010; Gessler et al., 1989; Goghari and Sponheim, 2013; Kohler et al., 2000; Schneider et al., 1995, 2006). Yet, it has been suggested that performance in the age discrimination task may depend on whether the task is time-limited or not (Goghari et al., 2011), SP presenting better performance when timing is not constrained. Our study however suggests the opposite; despite the fact that our task time was not limited, SP made significantly more errors than CP. Regarding gender recognition, most studies found no impairment in SP (Bediou et al., 2012, 2007, 2005a, 2005b; Delerue et al., 2010; Michalopoulou et al., 2008) except for two studies (Bigelow et al., 2006; Hall et al., 2008), which found similar results than those observed here.

Second, regarding the changeable aspects of faces which play a crucial role in facilitating social communication (Haxby et al., 2000), SP were also globally slower and performed less efficiently than CP in both emotion and eyes orientation tasks. However, no main effect for task and no interaction effect were observed. Regarding emotion recognition, a deficit in emotion identification of social stimuli in SP (face and voice) had already been documented (Comparelli et al., 2013; Constant et al., 2011; Kucharska-Pietura et al., 2005), but our data do not support the hypothesis that SP have a specific impairment in the ability to recognize the emotional expressions of faces. Rather, they support the idea of a generalized deficit in the identification of emotional and non-emotional complex face features. Concerning orientation recognition, deficits in gaze discrimination had been described in SP. According to Baron-Cohen (1995), gaze discrimination relies on the functioning of a specific cognitive module, the Eye Direction Detector (EDD). It has been proposed (Rosse et al., 1994) that impairment in gaze discrimination is present in SP but gaze direction detection and interpretation of gaze expression had never been completely dissociated in earlier studies. Actually, only one other study used the same experiment attempting to test the SP' skill in a simple gaze direction detection task (Franck, 1998), and found preserved gaze direction detection. The deficit in gaze discrimination in our study illustrates how even the more elementary functions, such as the detection of gaze direction, which needs less high level cognitive processing, are impaired in SP. It should also be noted that, in line with what is classically reported in this population (Buckley et al., 2009), SP presented psychopathological comorbidities, and centrally higher depression, trait anxiety and alexithymia than CP. Nevertheless, our complementary analyses showed that these differences did not influence experimental results, this control of depression-anxiety levels ensuring that the potential cognitive deficits observed among SP are due to schizophrenia itself and not to comorbidities.

In summary, SP are impaired in the recognition of both variant and invariant aspects of faces, demonstrating a generalized face recognition deficit in SP potentially related to a perceptual deficit in basic visual processing. This suggests that the well-established emotion decoding impairment in SP, usually interpreted as specific deficits of emotion processing, could be partly explained by generalized perceptual deficits occurring before emotion processing stage. These results are in line with earlier ones (Edwards et al., 2002), but are here obtained in a more controlled design based in a well-established theoretical model (Haxby et al., 2000) and controlled design (the same stimuli being presented in the different tasks). Our interpretation of a generalized deficit probably caused by a perceptual deficit in basic visual processing occurring before the stage of emotion processing is in line with recent electrophysiological findings demonstrating abnormalities in early visual encoding of facial features that precedes the affect-modulated ERP response (Herrmann et al., 2006, 2004; Johnson et al., 2005). Another study demonstrated, using emotional signal strength modulation, that deficient emotion recognition in SP is not determined solely by affective processing but is also linked to the processing of basic visual and facial information (Norton et al., 2009; McBain et al., 2010). This is also coherent with the increasing evidence that SP exhibit visual processing deficits specific to the magnocellular visual system (Butler et al., 2009, 2008a, 2008b, 2001; Javitt and Friedmann, 2015), a fast pathway carrying lower spatial frequencies, associated with the general configuration of the elements of a face to a subcortical route consisting of the superior colliculus, pulvinar and amygdala (Johnson, 2005). Functionally, this manifests an inability to integrate discrete elements of an image into a total gestalt (Doniger et al., 2002), which is particularly required when processing faces.

It is largely established that SP have a generalized emotion decoding impairment, consistent with impairments of emotion identification in self and others. This impairment has also been shown to be associated with clinical consequences, namely social cognition deficits, including potential misattributions of emotions to others, with possible interpersonal difficulties and higher risk of relapse. Our study demonstrates that the generalized emotion decoding impairment in SP, interpreted as specific deficits of emotion processing, could probably be explained by generalized perceptual deficits, which occurs before the specific emotion processing stage. In line with earlier studies (Bortolon et al., 2015; Butler et al., 2005; Maher et al., 2016; Sergi and Green, 2003), we thus propose that deficits in the early stages of visual processing significantly impacts higher cognitive deficits (i.e. emotional processing in the present study). It should be acknowledged that the present study relied on a quite small sample which may limit the statistical power and reliability of our findings. The absence of control for global cognitive functioning (by means of a non-facial task exploring for example object recognition) constitutes another limit. Indeed, our design do not allow excluding an influence of cognitive processes not specific to face processing (e.g., attention or executive control) on the observed deficits, either through very non-specific effects (e.g., lower attention to the task or instructions misunderstandings) or through failures of top-down face processing modulation. Moreover, as underlined above, our experimental design was based on binary judgments and we thus only included one positive (happiness) and one negative (disgust) emotional facial expressions. This leads to the fact that the present experiment cannot be considered as evaluating emotional decoding *per se*, but rather emotional valence. The binary decision task is also based on speeded answers, which could have promoted the emergence of general rather than emotion-specific deficits in comparison with earlier emotion-decoding task not based on processing speed. Future studies should thus use a wider range of emotions and tasks, but also ensure a better matching between tasks (as tasks were not matched regarding reaction times in the present study), to determine whether the present results can be generalized to other emotions and to genuine emotional decoding. Finally, as we primarily compared emotional and non-emotional face processing, the present study did not explore face-based identity recognition, despite the fact that this process has been shown to be impaired compared to object recognition in SP (Megreya et al., 2016), but to a lesser extent than emotional decoding (Silver et al., 2009). A direct comparison between emotional and identity recognition could thus deepen the understanding of the differential deficit across facial processing in SP.

Despite these limitations, the present findings should encourage future investigations to determine the neurophysiologic background of these generalized perceptual deficits, and stimulate a clinical approach focusing on more basic visual processing. Further explorations of the deficits related to basic visual processing could indeed not only help to more fully understand the mechanisms underlying face processing impairment in SP, but could also lead to the emergence more targeted therapeutic approaches to improve face-related perceptual and social functioning among SP.

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