Clinical Neurophysiology 130 (2019) 986–996

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

# EEG correlates of face recognition in patients with schizophrenia spectrum disorders: A systematic review

Alexey A. Murashko *, Alexander Shmukler

*Moscow Research Institute of Psychiatry – the Branch of V. Serbsky National Medical Research Centre for Psychiatry and Narcology, Moscow, Russian Federation*

ARTICLE INFO

*Article history:*
Accepted 11 March 2019
Available online 10 April 2019

*Keywords:*
EEG
ERP
Schizophrenia
Face recognition

HIGHLIGHTS

- Schizophrenia patients exhibit an impaired face processing outside an emotional context.
- Specific conditions of tasks make the differences between patient and control groups more prominent.
- The N170 may have a role as a diagnostic and treatment monitoring biomarker.

ABSTRACT

*Objective:* To systematically assess EEG studies and evaluate neuropsychological changes of face recognition in the context of neutral face stimuli in individuals with schizophrenia spectrum disorders.
*Methods:* A literature search was conducted using the PubMed database from inception to March 2018. Studies included in the review measured any event-related potentials, neural oscillations, or phase synchrony.
*Results:* A total of 113 articles were identified. Twenty-nine studies were included for the review. The majority of the studies focused on the N170 component. Smaller N170 amplitudes were consistently reported in schizophrenia patients compared to the healthy control group. Significant correlations between N170 amplitudes and social functioning scales were reported. Other results were quite inconsistent; however, group differences were more prominent for tasks with specific conditions.
*Conclusions:* Older patients with longer disease duration show more consistent neuropsychological correlations. Alterations of event-related potentials are likely to be linked to higher severity of symptoms. The N170 component seems to be the most promising event-related potential to be used for evaluation of present status and for dynamic control of cognitive impairments, social functioning, and rehabilitation effectiveness.
*Significance:* This systematic review provides evidence of (1) neuropsychological alterations of face processing outside an emotional context, and (2) a potential role of N170 as a diagnostic and treatment monitoring biomarker.


## 1. Introduction

Schizophrenia is a chronic psychiatric disorder characterized by a wide variety of clinical symptoms, including positive symptoms, negative symptoms, cognitive impairments, and social dysfunction. The latter is mostly due to a deficit in social cognition, which means an impaired ability to perceive the intentions and disposition of others and to maintain social interactions (Brothers, 1990). Face processing is a key component of this deficit (Marwick and Hall, 2008).

The dominant theory by Bruce and Young divides face processing into two independent processes: facial recognition and facial emotion processing (Bruce and Young, 1986). Regarding individuals with schizophrenia, research has been conducted in both directions; however, most studies have focused on emotion perception (Kohler et al., 2010) and relatively few have systematically assessed non-emotional aspects of face processing (Darke et al., 2013). Still, debate continues regarding the relationship between face perception and facial emotion recognition deficit in patients with schizophrenia (Rocca et al., 2009). Some authors hypothesize

* Corresponding author at: Moscow Research Institute of Psychiatry – the Branch of V. Serbsky NMRCPN, Poteshnaya 3, 107076 Moscow, Russian Federation.
*E-mail address:* murashko.a@serbsky.ru (A.A. Murashko).

https://doi.org/10.1016/j.clinph.2019.03.027
1388-2457/

a "generalized deficit" based on the observations of impaired recognition of both emotional and non-emotional stimuli (Kohler et al., 2003; Kucharska-Pietura et al., 2005). Other authors found intact facial recognition with impaired facial emotion recognition, and support the hypothesis of a specific deficit of emotion perception (Poole et al., 2000; Kosmidis et al., 2007). The third point of view is that each kind of facial information affects the processing of the others (e.g., participants could not selectively pay attention to emotions regardless of the identity) (Bediou et al., 2005; Martin et al., 2005).

The literature on face perception and facial emotion recognition can be divided into behavioural and neuroimaging studies (typically two types of studies: functional magnetic resonance imaging (fMRI) and electroencephalography (EEG)). Darke et al. (2013) noted that neuroimaging studies can explore the underlying face perception abnormalities that may go undetected through commonly used behavioural measures. The millisecond-level temporal resolution of event-related potentials (ERPs), which are waveforms measured by means of EEG, are well-suited to investigate the processes of face perception.

McCleery et al. (2015) used meta-analysis to show that the N170 and N250 ERP amplitudes in reaction to face stimuli among schizophrenia patients were smaller than in controls. However, the majority of studies included both neutral and emotional faces, so reduced amplitudes of these ERPs might reflect impairments in face processing as well as in facial affect processing. Likewise, Feuerriegel et al. (2015) in their systematic review reported reduced N170 amplitudes among schizophrenia patients. Studies included in their review also involved both emotional and non-emotional face stimuli. The authors noted that revealed abnormalities were specific to facial expressions, but there was also some evidence for impaired configural processing of faces in patients with schizophrenia, such as N170 insensitivity in response to face inversion. Moreover, some psychopathological symptoms contribute to the impairment of various cognitive functions, which can bias the results of testing emotional and non-emotional face processing (Kontaxaki et al., 2014; Gur et al., 2017).

It is worth noting that abnormalities in facial identity and expression recognition are also documented in other psychiatric and neurological disorders, including Autism Spectrum Disorder (ASD). Feuerriegel et al. (2015) supposed that N170 differences in ASD were specific to certain types of facial information, as there were no consistent abnormalities in response to upright faces. Recently Kang et al. (2018) conducted meta-analysis and reported delayed N170 latencies in response to face stimuli in ASD. The authors assumed that attenuation of N170 amplitude and relative lag in N170 latency may also increase with age.

Findings from research on other disorders (alcohol dependence, bipolar disorder, attention deficit hyperactivity disorder, bulimia nervosa, mild cognitive decline, Huntington's disease) showed that people suffering from these disorders almost always had smaller amplitudes or slower latencies in reaction to emotional faces compared to controls, regardless of diagnosis (Feuerriegel et al., 2015).

The aim of our review was to systematically assess EEG studies of face perception outside an emotional context in individuals with schizophrenia spectrum disorders.

## 2. Methods

### 2.1. Search strategy

We conducted an electronic search of the Pubmed/Medline database from inception to March 27, 2018. The search string used was "(eeg[Title/Abstract] OR electroencephalography[Title/Abstract] OR erp[Title/Abstract] OR N170[Title/Abstract] OR P100[Title/Abstract] OR erp[Title/Abstract] OR event-related[Title/Abstract] OR (evoked[Title/Abstract] AND potential[Title/Abstract]) OR evoked-response[Title/Abstract]) AND (psychosis[Title/Abstract] OR schizophrenia[Title/Abstract] OR schizoaffective[Title/Abstract]) AND (face[Title/Abstract] OR facial[Title/Abstract])".

### 2.2. Eligibility criteria

Only English-language articles were included. Articles were retained if they measured any ERPs or other EEG data in response to visual presentation of photographs or schematic face stimuli with neutral face expression, in the context of various conditions, in patients with schizophrenia spectrum disorders. Studies were excluded if there was no data analysis about neutral face expression, or if these data were not presented, or if they contained only data based on emotional faces.

All titles and abstracts identified in the search were screened to exclude obviously irrelevant articles. Full-text versions of all remaining articles were read and assessed for eligibility. The remaining articles were included in the review. The reference lists of all included studies were hand-searched for additional relevant reports.

### 2.3. Data extraction

The following data were extracted onto a customized sheet: participants (sample size, mean age, gender distribution, diagnosis, mean illness duration, scales used and inclusion/exclusion criteria), task (description of experimental task, stimuli used), and results regarding neutral face stimuli (ERPs and reported correlations between ERP measures and behavioural performance, scores of scales for ERP studies, and event-related changes reported for EEG studies). Furthermore, the Newcastle-Ottawa Scale (NOS) was applied to assess the quality of all included studies (Wells et al., 2000). Studies were evaluated by selection with a maximum of four points and comparability with a maximum of two points.

## 3. Results

A total of 113 articles were identified. After screening titles and abstracts 82 articles remained, of which 29 met the eligibility criteria. The article inclusion/exclusion process is shown in Fig. 1. Characteristics of patient samples, study characteristics and results are shown in Tables 1 and 2, respectively.

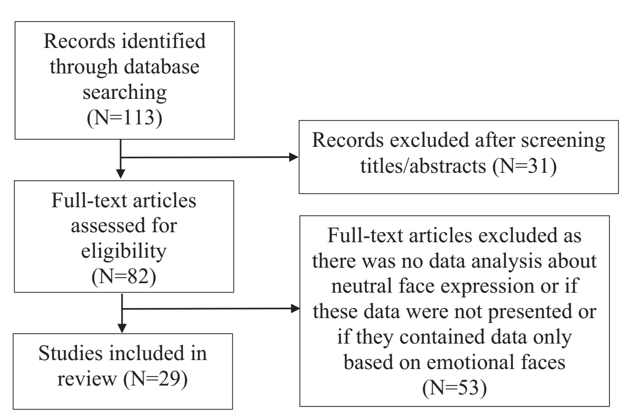


**Fig. 1.** Article screening and selection process.

**Table 1**
Characteristics of patient samples.

| Study | Patient sample | | | | |
|---|---|---|---|---|---|
| | N; gender | Mean age (years (SD)) | Diagnosis | Mean illness duration (years (SD)) | Symptom and social functioning scales |
| Batty et al. (2014) | "Low" group: 13 (f = 7)<br>"High" group: 14 (f = 6) | "Low" group: 30.16 (9.69)<br>"High" group: 24.45 (3.54) | Schizotypy | NR | O-LIFE scales<br>*Groups were divided according to the O-LIFE Cognitive Disorganization dimension |
| Bediou et al. (2007) | 10 (f = 4) | 27.8 (8.4) | Schizophrenia | 5.6 (6.4) | PANSS |
| Brennan et al. (2014) | 108 (f = 38) | 20.71 (2.91) | First onset psychosis: schizophrenia, schizophreniform disorder, psychosis not otherwise specified, schizoaffective disorder, bipolar disorder with psychosis, substance induced psychosis, major depressive disorder with psychosis, delusional disorder | NR | PANSS, CDSS |
| Caharel et al. (2007) | 18 (f = 8) | 37.7 (8.29) | Schizophrenia | 13.6 (9.97) | NR |
| Campanella et al. (2006) | 14 (f = 5) | 47.7 (11.9) | Schizophrenia | NR | PANSS, Beck depression inventory<br>*Groups were divided into 2 subgroups by total PANSS score |
| Csukly et al. (2014) | 24 (f = 11) | 34.2 (10.3) | Schizophrenia | 9.7 (7) | PANSS, Symptom checklist 90 |
| Dima et al. (2011) | 20 (f = 4) | 33.45 (10.2) | Schizophrenia | NR | PANSS |
| Guillaume et al. (2012) | 20 (f = 3) | 27.9 (6.5) | Schizophrenia | 6.4 (4.9) | SAPS, SANS, STAI |
| Guillem et al. (2003) | RD + group: 17 (f = 6); RD– group: 21 (f = 5) | RD + group: 36.0 (11.7); RD– group: 40.4 (7.8) | Schizophrenia | RD + group: 9.3 (6.4); RD– group: 12.9 (7.6) | SAPS, SANS, BPRS<br>*Groups were divided by their reality distortion score (hallucination and delusion SAPS subscales) |
| Herrmann et al. (2004) | 24 (f = 5) | 32.2 (10.0) | Schizophrenia | NR | PANSS |
| Johnston et al. (2005) | 11 (f = 2) | 30.4 (8.3) | Schizophrenia | NR | NR |
| Jung et al. (2012) | 23 (f = 11) | 32.2 (10.1) | Schizophrenia | 5.2 (4.9) | PANSS |
| Kim et al. (2013) | 23 (f = 11) | 32.2 (10.1) | Schizophrenia | 5.2 (4.9) | PANSS |
| Kim et al. (2015) | 21 (f = 10) | 37.57 (11.37) | Schizophrenia | NR | PANSS |
| Kirihara et al. (2012) | 15 | 34.5 (6.8) | Schizophrenia | 12.5 (5.6) | PANSS, NEO-FFI, GAF scale |
| Lee et al. (2010a) | 25 (f = 13) | 34.6 (12.6) | Schizophrenia | 6.1 (5.6) | PANSS |
| Lee et al. (2016) | 24 (f = 14) | 34.67 (12.72) | Schizophrenia | 8.7 (8.15) | PANSS |
| Liu et al. (2016) | 17 (f = 1) | 46.9 (9.66) | Schizophrenia | 16.7 (9.19) | PANSS |
| Liu et al. (2018) | 21 (f = 21) | 34.48 (10.15) | Schizophrenia | 8.47 (4.93) | PANSS |
| Maher et al. (2016) | 20 (f = 9) | 47.75 (12.38) | Schizophrenia, schizoaffective disorder | 23.9 (8.5) | PANSS |
| Obayashi et al. (2009) | 16 (f = 0) | 32.9 (10) | Schizophrenia | 9.9 (7.3) | SAPS, SANS, GAF scale |
| Onitsuka et al. (2006) | 20 (f = 0) | Range: 20–55 | Schizophrenia | NR | PANSS |
| Onitsuka et al. (2009) | 17 (f = 0) | 42.4 (10.8) | Schizophrenia | 20.2 (11.8) | PANSS |
| Ramos-Loyo et al. (2009) | 10 (f = 0) | 30.2 (7.27) | Schizophrenia | NR | PANSS, BPRS |
| Tso et al. (2015) | 28 | Range: 18–60 | Schizophrenia, schizoaffective disorder | NR | SAPS, SANS, BACS, WRAT3-R |
| Tsunoda et al. (2012) | 15 (f = 7) | 30.4 (3.2) | Schizophrenia | 0.53 (0.3) | SAPS, SANS, SFS |

**Table 1** (*continued*)

| Study | Patient sample | | | | |
|---|---|---|---|---|---|
| | N; gender | Mean age (years (SD)) | Diagnosis | Mean illness duration (years (SD)) | Symptom and social functioning scales |
| Turetsky et al. (2007) | 16 (f = 4) | 30.5 (6.0) | Schizophrenia | Male: 7.5 (5.5); female: 10.5 (8.3) | SAPS, SANS, BPRS |
| Yan et al. (2017) | 25 (f = 10) | 31.1 (10.8) | Schizophrenia | NR | PANSS, PSP |
| Zheng et al. (2016) | 24 (f = 12) | 32.3 (11.2) | Schizophrenia | 8.7 (6.3) | PANSS |

Comment: NR - not reported, SD - standard deviation, RD - reality distortion. PANSS - Positive and Negative Syndrome Scale, SAPS - Scale for the Assessment of Positive Symptoms, SANS - Scale for the Assessment of Negative Symptoms, BPRS - Brief Psychiatric Rating Scale, O-LIFE - Oxford-Liverpool Inventory of Feelings and Experiences, CDSS - Calgary Depression Scale for Schizophrenia, STAI - State-Trait Anxiety Inventory, WRAT3 - Wide Range Achievement Test 3, BACS - Brief Assessment of Cognition for Schizophrenia, NEO-FFI - NEO Five-Factor Inventory, GAF - Global Assessment of Functioning, PSP - Personal and Social Performance Scale, SFS - Social Functioning Scale.

### *3.1. Study characteristics*

Twenty-seven studies compared one or more clinical groups against a control group, one compared two schizotypy groups (high vs. low, measured by O-Life scores) (Batty et al., 2014), and one assessed only a clinical group (Kim et al., 2013). All control groups were age- and sex-matched to clinical groups. The size of clinical groups varied between 10 and 25 participants, except one study which had 108 participants in control group and which had taken data from the Brain Resource International Database (Brennan et al., 2014). Mean age varied from 20.71 to 47.75 years. As for the diagnoses, 26 studies assessed only schizophrenia, others included schizophrenia and schizoaffective disorder (Tso et al., 2015; Maher et al., 2016), schizotypy (Batty et al., 2014) and first onset psychosis (Brennan et al., 2014). The main exclusion criteria were any history of neurological disease and substance abuse.

A variety of rating scales were used to assess symptoms and social functioning. The most widely used scale was the Positive and Negative Syndrome Scale (PANSS) (Kay et al., 1987) (21 studies). Other assessment tools included the Scale for the Assessment of Positive Symptoms (SAPS) (Andreasen, 1984) and the Scale for the Assessment of Negative Symptoms (SANS) (Andreasen, 1983) (n = 6), the Brief Psychiatric Rating Scale (BPRS) (Overall and Gorham, 1962) (n = 3), the Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE) (Mason et al., 1995) (n = 1), the Calgary Depression Scale for Schizophrenia (CDSS) (Addington et al., 1990) (n = 1), the State-Trait Anxiety Inventory (STAI) (Spielberger and Sydeman, 1994) (n = 1), the Wide Range Achievement Test 3 (WRAT3-R) (Wilkinson, 1993) (n = 1), Brief Assessment of Cognition for Schizophrenia (BACS) (Keefe et al., 2004) (n = 1), NEO Five-Factor Inventory (NEO-FFI) (Costa and McCrae, 1992) (n = 1), the Global Assessment of Functioning (GAF) (American Psychiatric Association, 1994) (n = 2), the Personal and Social Performance Scale (PSP) (Morosini et al., 2000) (n = 1), and the Social Functioning Scale (SFS) (Birchwood et al., 1990) (n = 1).

Most of the studies focused on the ERP component N170 (n = 20). Other ERPs assessed in the studies were P100 (n = 12), N100 (n = 3), P200 (n = 3), N250 (n = 4), P300 (n = 8), P400 (n = 2), N400 (n = 3). Alterations in EEG bands were studied in 7 articles. Many studies probed more than one component; that explains why the sum of the number of studies is larger than the total number of papers reviewed.

Most of the studies did not find any significant correlations between medication dose and ERP amplitudes and latencies. Some studies did not analyse these correlations (Johnston et al., 2005; Bediou et al., 2007; Ramos-Loyo et al., 2009; Lee et al., 2010a; Dima et al., 2011; Brennan et al., 2014; Zheng et al., 2016; Yan et al., 2017; Liu et al., 2018).

The NOS scores of the included studies are presented in Table 3. Selection scores ranged from 0 to 3, and most of the studies were controlled at least for the most important factor.

We first grouped studies together by each component and reported the differences. Then we separated these studies by features. Data reported once were not included as incomparable.

### *3.2. Electrophysiological data*

#### *3.2.1. P100*

Twelve studies assessed the P100 component (Herrmann et al., 2004; Johnston et al., 2005; Campanella et al., 2006; Bediou et al., 2007; Caharel et al., 2007; Turetsky et al., 2007; Obayashi et al., 2009; Jung et al., 2012; Kim et al., 2013, 2015; Batty et al., 2014; Liu et al., 2016). Regarding amplitudes, 9 studies revealed no differences (mainly measured at occipital electrodes) (Herrmann et al., 2004; Johnston et al., 2005; Bediou et al., 2007; Turetsky et al.,

**Table 2**
Study characteristics and results.

| Study | Behavioural task | Stimuli | Results (patient group vs. healthy controls measured in response to neutral face stimuli unless otherwise specified) |
|---|---|---|---|
| Batty et al. (2014) | Button press to either an intact or disorganized face. | Mooney faces and neutral photographic faces (upright, inverted, upright disorganized, and inverted disorganized) | No significant differences between groups in P100 amplitudes and latencies and N170 latencies to upright faces. Significantly reduced N170 amplitudes to inverted photographic faces in "high" vs. "low" schizotypy groups. Attenuated face inversion effect both to photographic and Mooney faces in "high" group. |
| Bediou et al. (2007) | Count either male or female faces | Emotional and neutral faces | No significant differences in P100 and N170 amplitudes. |
| Brennan et al. (2014) | Passive viewing task | Emotional and neutral faces | Reduced N100 amplitude. Greater absolute magnitude of P300 amplitude. |
| Caharel et al. (2007) | Button press to either familiar on not face | Photographs of the subject's own face, a face personally known to the subject, totally unknown faces (neutral and emotional) | Reduced P100 amplitudes and increased latencies. N170 amplitude reduction. Delayed N170 latencies. |
| Campanella et al. (2006) | Button press to target image (deviant face) | Emotional and neutral faces | Reduced P100, N170, P300 and N400 amplitudes in "high" vs. "low" group or HC. No significant differences in P100 and N170 latencies between groups. |
| Csukly et al. (2014) | Button press to categorize emotional expression on face | Neutral and fearful faces | No difference in N170 amplitudes and latencies. |
| Dima et al. (2011) | Make a decision whether the current stimulus was concave or convex | Ordinary objects (e.g. a chair), a mask, and faces of men and women | The decreased amplitude of P300 for 3D inverted faces compared to 3D normal faces in the patient group, while there was no difference in P300 amplitudes in HC. |
| Guillaume et al. (2012) | Indicate whether any face had been previously presented (old) or not (new) | Neutral faces against natural landscape | Weaker old-new effect modulation during the FN400 time window in the patient group. |
| Guillem et al. (2003) | Indicate whether any face had been previously presented (old) or not (new) | Unfamiliar faces | Less positive fronto-polar component of N300 in both patient groups; increased posterior lateral component in RD+, but reduced in RD− group. Reduced old-new effect modulation during the N400 time window in both clinical groups compared to controls. |
| Herrmann et al. (2004) | Silently classify images as a face or a building | Faces and buildings | No difference in P100 amplitudes. N170 amplitude reduction to faces, but not to buildings. Higher amplitudes of P200 regardless of used stimuli. |
| Johnston et al. (2005) | Count either male or female faces | Emotional and neutral faces | No significant differences in P100 and P300 amplitudes and latencies. |
| Jung et al. (2012) | Button press to an emotional face | Emotional and neutral faces | No significant differences in P100, N170, N250 and P300 amplitudes and latencies. No significant differences in source activation of these components using sLORETA. |
| Kim et al. (2013) | Button press to target image (happy or fearful face) | Emotional and neutral faces | Source localization using sLORETA: PANSS positive scores were negatively correlated with P100 source activation in the left temporo-parietal regions and with N170 and N250 source clusters in the middle or medial frontal gyrus for neutral face stimuli. The left fusiform gyrus showed negative correlation with PANSS negative scores in the P100 components regardless of emotion type. |
| Kim et al. (2015) | Button press to target image (chair) | BSF, LSF, and HSF pictures of fearful and neutral faces and chairs | No difference between groups in P100, N170, N250 and P300 amplitudes and latencies. Reduced P100 amplitude for HSF faces compared to BSF and LSF.Source localization using sLORETA: enhanced P100 activation of the medial frontal gyrus in the HSF neutral condition in the patient group. Significantly enhanced N170 activation for LSF faces compared to HSF faces in the right hemisphere in the patient group, while HC did not show these differences. |
| Kirihara et al. (2012) | Button press to target image (butterflies) | Emotional faces, neutral faces, cars, and butterflies | Not significant reduction of the N170 amplitude. |
| Lee et al. (2010a) | Button press to an emotional face | Emotional and neutral faces | Significantly lower gamma band activity in the 700 to 800 ms time window. Weak patterns of significant synchrony lines in schizophrenia patients. |
| Lee et al. (2016) | Button press to target image (butterflies) | Faces, chairs, nature scenes, and butterflies | Absence of the early-stage GBA preferential pattern for facial stimuli vs. non-facial stimuli and aberrantly increased early-stage GBA for all types of stimuli in the patient group. No significant intergroup differences in phase synchrony for either face or non-face stimuli. |
| Liu et al. (2016) | Button press to target image (monkey face) | Neutral human and primate faces | No difference between groups in P100 and P200 amplitudes and latencies. Reduced N170 amplitudes to face stimuli. Reduced P400 amplitudes. |
| Liu et al. (2018) | Mental count of the number of flowers | Faces (upright and inverted), tables (upright and inverted), flowers | No difference in the evoked power of the low-frequency $\beta$ wave and the induced power of the $\gamma$ wave under face and non-face conditions. |
| Maher et al. (2016) | Indicate on which side of the display the line drawing was present | Faces and trees line drawings of 0% contrast, perceptual threshold, two times perceptual threshold, and 100% contrast | N170 amplitude reduction. |

**Table 2** (*continued*)

| Study | Behavioural task | Stimuli | Results (patient group vs. healthy controls measured in response to neutral face stimuli unless otherwise specified) |
|---|---|---|---|
| Obayashi et al. (2009) | 1. Button press to target image (shoes)<br>2. Identify emotions using the BSF, HSF, and LSF pictures | BSF, LSF, and HSF pictures of happy, angry, fearful, and neutral faces and houses | No difference between groups in N170 latencies and P100 amplitudes or latencies. Bilateral face-specific N170 amplitude reduction. Lack of P100 and N170 amplitude enhancement in response to face stimuli of different spatial frequency in the patient group. |
| Onitsuka et al. (2006) | Button press to target image (butterflies) | Neutral faces, hands, cars, butterflies | Bilateral N170 amplitude reduction in response to faces, but not to cars. |
| Onitsuka et al. (2009) | Button press to target image (the female face). | Neutral male faces (unrepeated faces), one neutral male face (repeated face), and one neutral female face (target stimulus) | N170 amplitude reduction. No significant correlations between PANSS scores and N170 amplitudes. Reversed pattern of lateralization in schizophrenia patients. |
| Ramos-Loyo et al. (2009) | Button press to target image | Emotional and neutral faces | N100 amplitude reduction in prefrontal and inferior frontal regions. Not significant N170 amplitude increase in occipital regions. Significantly larger P200 component over the occipital areas in all of the tasks performed. Lower P300 amplitude in identity tasks. In the alpha band, the amplitude of oscillations was higher in occipital regions. No difference in the theta band between groups. |
| Tso et al. (2015) | Indicate whether the face was "looking at me" or "looking away from me," and press corresponding button | Neutral and fearful faces with different head orientation (forward, 30° deviated), and gaze direction (direct, averted) | No significant differences in N170 amplitudes and latencies. A reduction of the normal N170 amplitude modulation by head orientation. |
| Tsunoda et al. (2012) | Button press to target image (butterflies) | Neutral faces (upright and inverted), cars, butterfly | Bilateral N170 amplitude reduction to images of faces. A reduced FIE of the N170 amplitude. Trend-level delayed N170 latencies to inverted objects. |
| Turetsky et al. (2007) | Button press to categorize emotional expression on face | Emotional and neutral faces | No difference in P100 amplitudes between groups. N170 and P300 amplitude reduction. Non-significant N250 amplitude reduction. |
| Yan et al. (2017) | Mental count of the number of flowers | Unfamiliar faces (upright and inverted), tables (upright and inverted), flowers | Reduced synchrony patterns in the gamma-frequency range in patients in the 150–300 ms interval during upright face perception. |
| Zheng et al. (2016) | Mental count of the images of flowers | Faces (upright and inverted), tables (upright and inverted), flowers | Reduced N170 amplitudes for all stimuli. Delayed N170 latencies in the patient group only under face-evoked conditions (both upright and inverted). A reduced FIE of the N170 amplitude. |

Comment: LSF - low spatial frequency, HSF - high spatial frequency, BSF - broad spatial frequency, FIE - face inversion effect, RD - reality distortion, GBA - gamma band activity, PANSS - Positive and Negative Syndrome Scale, SAPS - Scale for the Assessment of Positive Symptoms, SANS - Scale for the Assessment of Negative Symptoms, GAF - Global Assessment of Functioning.

2007; Obayashi et al., 2009; Jung et al., 2012; Batty et al., 2014; Kim et al., 2015; Liu et al., 2016), two reported significant reduction (at P7, P8 (Caharel et al., 2007) and at O1, O2 electrodes (Campanella et al., 2006)), and one did not assess P100 amplitudes (Kim et al., 2013). Six studies reported no differences in P100 latencies (Johnston et al., 2005; Campanella et al., 2006; Obayashi et al., 2009; Batty et al., 2014; Kim et al., 2015; Liu et al., 2016), Caharel et al. (2007) reported increased latencies in the clinical group, and four studies did not assess the P100 latencies at all. Two studies assessed the effect of spatial frequency on P100 and found scattered differences in both groups (Obayashi et al., 2009; Kim et al., 2015). Three studies assessed and found no correlations with any social or symptom scales (Obayashi et al., 2009; Caharel et al., 2007; Batty et al., 2014). Three studies used a source localization tool (sLORETA). Among them, Kim et al. (2015) reported enhanced activation of the medial frontal gyrus in clinical groups compared to healthy controls (HC), Kim et al. (2013) found significant correlations between positive and negative PANSS and some source clusters, while Jung et al. (2012) did not find any link between PANSS and ERP sources.

### 3.2.2. N100

Three studies evaluated the N100 component (Ramos-Loyo et al., 2009; Brennan et al., 2014; Liu et al., 2016). Two of them revealed N100 amplitude reduction in frontal (Brennan et al., 2014), prefrontal, inferior frontal regions (Ramos-Loyo et al., 2009), and one study found more negative N100 in frontal than in fronto-central or central regions in patients with schizophrenia, with no difference between regions found in HC (Liu et al., 2016).

### 3.2.3. N170

Nineteen studies measured N170 amplitudes in response to upright faces, of which ten reported significant reduction compared to HC (Herrmann et al., 2004; Onitsuka et al., 2006, 2009; Caharel et al., 2007; Obayashi et al., 2009; Turetsky et al., 2007; Tsunoda et al., 2012; Maher et al., 2016; Liu et al., 2016; Zheng et al., 2016). Campanella et al. (2006) showed significant reduction in high-score vs. low-score schizophrenia patients' group (separated on the basis of their total PANSS score) or control group, two reported non-significant reduction (Kirihara et al., 2012; Batty et al., 2014), five did not reach significant differences between groups (Bediou et al., 2007; Jung et al., 2012; Csukly et al., 2014; Kim et al., 2015; Tso et al., 2015), and one reported a non-significant enhancement of N170 amplitude in patients with schizophrenia vs. HC (Ramos-Loyo et al., 2009). It is worth noting that all studies that included patient groups with mean age ≥37.7 years and with mean illness duration ≥13.6 years found N170 amplitude reduction in the patient group compared to HC (Campanella et al., 2006; Caharel et al., 2007; Onitsuka et al., 2009; Maher et al., 2016; Liu et al., 2016). Other studies included patient groups with mean age ≤37.57 years and with mean illness duration ≤12.5 years, and their results were not entirely consistent.

Nine studies examined correlations between N170 amplitudes and symptom or social scales. Six of these studies did not find any correlations between symptom scales (PANSS (Herrmann et al., 2004; Onitsuka et al., 2009; Kim et al., 2013; Zheng et al., 2016), SAPS/SANS (Kirihara et al., 2012; Tsunoda et al., 2012)). Maher et al. (2016) reported marginal correlation with negative

**Table 3**
Newcastle-Ottawa scale scores for included studies.

| Newcastle-Ottawa scale scores for included studies | Selection | Comparability |
|---|---|---|
| Batty et al. (2014) | – | + (IQ) |
| Bediou et al. (2007) | + | + (age) |
| Brennan et al. (2014) | +++ | ++ (age, gender) |
| Caharel et al. (2007) | ++ | ++ (age, gender) |
| Campanella et al. (2006) | ++ | + (age) |
| Csukly et al. (2014) | ++ | ++ (age, gender, education) |
| Dima et al. (2011) | + | ++ (age, gender) |
| Guillaume et al. (2012) | ++ | ++ (age, gender, SES) |
| Guillem et al. (2003) | ++ | ++ (age, gender, parental SES) |
| Herrmann et al. (2004) | + | + (education) |
| Johnston et al. (2005) | +++ | ++ (age, gender) |
| Jung et al. (2012) | +++ | ++ (age, gender, education) |
| Kim et al. (2013) | – | – |
| Kim et al. (2015) | ++ | ++ (age, gender, education) |
| Kirihara et al. (2012) | ++ | ++ (age, personality traits (NEO-FFI)) |
| Lee et al. (2010a) | +++ | ++ (age, gender, education) |
| Lee et al. (2016) | ++ | ++ (age, gender, education) |
| Liu et al. (2016) | ++ | ++ (age, parental SES) |
| Liu et al. (2018) | +++ | ++ (age, gender, education) |
| Maher et al. (2016) | ++ | ++ (age, gender, verbal IQ) |
| Obayashi et al. (2009) | ++ | ++ (age, parental SES) |
| Onitsuka et al. (2006) | +++ | ++ (age, parental SES) |
| Onitsuka et al. (2009) | +++ | – |
| Ramos-Loyo et al. (2009) | ++ | ++ (age, education) |
| Tso et al. (2015) | + | ++ (age, gender) |
| Tsunoda et al. (2012) | ++ | ++ (age, parental SES) |
| Turetsky et al. (2007) | + | + (age) |
| Yan et al. (2017) | + | – |
| Zheng et al. (2016) | + | + (age) |

Comment: SES - socioeconomic status.

PANSS, Campanella et al. (2006) showed positive correlation with positive PANSS, and Kim et al. (2013) revealed correlation between N170 source clusters and positive PANSS. In addition, three of the nine studies assessed correlations between N170 amplitudes and rating scales of social functioning. Tsunoda et al. (2012), Kirihara et al. (2012), and Obayashi et al. (2009) found negative correlation with SFS scores, NEO scores for extraversion, and GAF scale scores, respectively.

Eight studies assessed N170 latencies, of which six studies reported no significant interactions between groups (Campanella et al., 2006; Obayashi et al., 2009; Tsunoda et al., 2012; Batty et al., 2014; Kim et al., 2015; Tso et al., 2015) and two found delayed latencies (Caharel et al., 2007; Zheng et al., 2016).

Zheng et al. (2016) assessed correlations between N170 latencies and symptom scales and found positive correlations with positive and general PANSS.

Three studies assessed face inversion effect. All of them reported reduced N170 amplitudes in response to inverted faces in the clinical group compared to HC (Tsunoda et al., 2012; Zheng et al., 2016), or in high-score vs. low-score schizotypal group, where low-score schizotypal group showed a classic increase in amplitude to inverted relative to upright photographs (Batty et al., 2014). Zheng et al. (2016) found significantly delayed N170 latencies in response to inverted and upright faces, Tsunoda et al. (2012) revealed trend-level delayed latencies only to inverted faces, and Batty et al. (2014) did not find differences in response to inverted faces. Batty et al. (2014) also assessed the response to upright and inverted Mooney faces in high-score vs. low-score schizotypal groups. The low-score schizotypal group showed an increase in amplitude to upright relative to inverted Mooney faces, whereas high-score patients showed comparable N170 amplitude to Mooney faces in both orientations. Moreover, the authors found negative correlation between O-LIFE scores and the latency of the N170 for inverted Mooney faces.

Two studies assessed N170 abnormalities for spatial frequency (SF)-filtered neutral faces and found diverse significant interactions for both groups (Obayashi et al., 2009; Kim et al., 2015).

Tso et al. (2015) revealed decreased modulation of N170 amplitude by head orientation in patients with schizophrenia compared with HC.

Onitsuka et al. (2009) found a reversed pattern of lateralization of N170 repetition effect in schizophrenia patients (over the left hemisphere in schizophrenia patients and over the right in HC).

### *3.2.4. P200*

Only three studies evaluated the P200 component, two of which found significantly larger amplitudes over occipital electrodes in the clinical group compared to HC (Herrmann et al., 2004; Ramos-Loyo et al., 2009), and Liu et al. (2016) reported no significant differences of P200 amplitudes between groups in visual condition; however, in the latter study P200 was measured over the fronto-central region.

### *3.2.5. N250*

None of the four studies assessing N250 waveform found significant interactions of N250 amplitude or latency with the group types (Jung et al., 2012; Kim et al., 2013, 2015), and only Turetsky et al. (2007) reported a non-significant trend towards patients having reduced N250 amplitudes. However, Kim et al. (2013) found that PANSS positive scores were significantly correlated with source clusters in the middle or medial frontal gyrus.

### *3.2.6. P300*

For the P300 component, two studies found significantly reduced amplitudes in the clinical group compared to controls (Turetsky et al., 2007; Ramos-Loyo et al., 2009) and one study in high-score vs. low-score schizophrenia patients' group/control group (Campanella et al., 2006). Three studies did not find any significant correlations (Johnston et al., 2005; Jung et al., 2012; Kim et al., 2015). Moreover, Brennan et al. (2014) observed greater P300 amplitudes in the first onset psychosis group compared to HC. Dima et al. (2011) investigated hollow mask illusion in patients and reported a decreased amplitude of P300 for the 3D inverted faces compared to 3D normal faces in the patient group, however, in the control group there was no difference between results for the 3D normal faces and 3D inverted faces.

### *3.2.7. P400*

Liu et al. (2016) found reduced P400 amplitude in visual condition in fronto-central region in the clinical group. Guillem et al. (2003) assessed a control group and two clinical groups divided by reality distortion (RD) scores into RD+ and RD−, and found that a fronto-polar component was less positive in both patient groups; and a posterior lateral component was increased in RD+, but reduced in the RD− group. The former study included a patient group with mean age of 46.9 years and mean illness duration of 16.7 years. For the latter study these values were 36.0 and 9.3 for the RD+ group and 40.4 and 12.9 for the RD− group respectively.

### *3.2.8. N400*

Campanella et al. (2006) evaluated the N400 component in their study. The task included one frequently repeated stimulus (face) and a number of deviant faces. The authors reported that low-score patients tended to display decreased N400 (measured at occipito-temporal sites (T5, Oz, T6)) in response to deviant faces as compared to controls, while in high-score patients this decrease was more significant. Guillem et al. (2003) reported a modulation of the old-new effect (i.e., when a subject makes old/new recognition judgements on presented stimuli) over posterior sites during the N400 time window, which was similarly reduced in both RD

+ and RD− groups compared to controls. Guillaume et al. (2012) assessed FN400 and revealed that the mid-frontal FN400 old-new effect was weaker and limited to a small topographic area (fronto-central) among patients as compared to controls, whereas there was no difference between groups at posterior sites (Cz and Pz). Mean age (27.9 years) and mean illness duration (6.4 years) in this study were the lowest among those that assessed N400.

*3.2.9. Neural oscillations and phase synchrony*

Lee et al. (2016) and Liu et al. (2018) found that the power of gamma band in schizophrenia patients was not modulated by the stimulus (i.e. face or non-face stimulus) in early-stage processing, however the "face effect" was still presented in schizophrenia patients in alpha band (Liu et al., 2018). In addition, Lee et al. (2016) reported aberrantly increased early-stage gamma band activity (GBA) either for face or non-face stimuli, significant correlation between negative symptoms and frontal GBA for non-face stimuli, and a lack of deactivation of GBA in the middle stage of visual processing (400–700 ms) in schizophrenia patients. Liu et al. (2018) also found that both control and clinical groups presented an inversion effect in gamma band, but the occipital area was deficient in schizophrenia patients. Lee et al. (2010a) reported significant differences in GBA in the 700 to 800 ms time window only, whereas it was lower in the clinical group. In addition, the gamma band activity measures of frontal, central and parietal areas were negatively correlated with the score for negative symptoms on the PANSS, and the number of hospitalizations in schizophrenia patients.

Yan et al. (2017) and Lee et al. (2010a) revealed that patients with schizophrenia exhibited reduced synchrony patterns in the gamma-frequency range in the early stage processing, while Lee et al. (2016) found no significant intergroup differences in phase synchrony for either face or non-face stimuli.

## 4. Discussion

In the last few decades it was shown that patients with schizophrenia can demonstrate cognitive deficit, in particular impairments in face recognition. In our review we assessed neuropsychological changes in the context of neutral face stimuli in schizophrenia spectrum disorders.

Unfortunately, many studies assess face stimuli of various emotional valence, and thus the results on face perception and emotion recognition cannot always be differentiated. Data are quite nonconclusive; however, results appeared more consistent and the difference between the patient group and HC were more pronounced among the studies that assessed older participants with longer disease duration (mean age >37.7 years old and illness duration >12.9 years) (Guillem et al., 2003; Campanella et al., 2006; Caharel et al., 2007; Onitsuka et al., 2009; Liu et al., 2016; Maher et al., 2016). This conforms with the results of behavioral studies, although the latter assessed emotion recognition. For example, Bortolon et al. (2015) in their review reported deficits in patients with the mean disease duration varying from 11.40 to 18.80 years, while most other studies that included individuals at ultra-high risk for psychosis and early onset schizophrenia patients did not present deficits in face processing at the behavioural level (Kucharska-Pietura et al., 2005). More generally, Silverstein et al. (2014) showed that the group of patients with schizophrenia demonstrated more significant impairments in processing images of different spatial frequency than the first episode psychosis group at discharge from hospital.

A possible mechanism of the relationship between face perception impairments and illness progression could be assumed. Inferior temporal gyrus has been shown to be important in the representation of visual shapes. The fusiform gyrus has been shown to be involved in face recognition. Significant reductions in grey matter density of the fusiform area occur even in patients with first episode schizophrenia (Bangalore et al., 2009). More generally, among treatment-naïve schizophrenia patients temporal and occipitotemporal grey matter volume decrease has been reported (Guo et al., 2013). In addition, grey matter volume atrophy progressed with illness duration, showing more reductions in temporal and occipital areas in later stages of the disorder (van Haren et al., 2007; Jiang et al., 2018). According to source localization studies among healthy individuals, N170 elicited in response to face stimuli reflects activity of the fusiform gyrus and occipital cortex (Herrmann et al., 2005; Deffke et al., 2007). Similarly, correlations of attenuated N170 amplitudes with decreased grey matter volume in the right fusiform gyrus among schizophrenia patients have been shown (Johnston et al., 2005; Onitsuka et al., 2006).

Thus, it can be speculated that increasing impairments in face perception during illness progression are associated with progressive grey matter loss in the relevant brain areas and can be objectively assessed by neuropsychological methods. Future studies should recruit older participants with longer illness duration to clarify the precise changes in the neuropsychological picture.

Secondly, despite no consistent correlations with symptom scales, the studies that separated patient groups into two subgroups by severity (assessed by symptom scales) showed significant results for groups with more severe schizophrenia symptoms, while patients with mild disease more likely had no differences from HC (Guillem et al., 2003; Campanella et al., 2006; Batty et al., 2014), so it can be suggested that significant correlations appear just in more severe cases. Behavioural studies also show a tendency of the severity of schizophrenia symptoms to be linked to more pronounced face processing impairments (Soria Bauser et al., 2012), for instance, patients with higher severity of symptoms showed a weaker inversion effect (Joshua and Rossell, 2009). Moreover, the review of research on perceptual organization impairment showed a link to disorganized symptoms (Silverstein and Keane, 2011). However, we do have insufficient data to confirm or deny these results in our study. We conclude that future research should recognize this gap and investigate correlations with subscales in two or more patient groups separated by symptom severity.

Current neuropsychological results present within the context of neutral face stimuli, which supports the hypothesis of generalized deficit rather than only emotion recognition deficits. The most convincing data are shown for the N170 component. Our results are consistent with previous reviews (Feuerriegel et al., 2015; McCleery et al., 2015) and confirm the reduction of N170 amplitude in patients. In two cases the N170 amplitude reduction was constantly reported. Reduction was clearly expressed while using tasks that compared responses to face and non-face stimuli (the HCs' response to face stimuli differed from other stimuli, while patients mostly had similar patterns for both kinds of stimuli). Likewise, face inversion effect in HC was characterized by higher amplitudes to inverted face stimuli than to upright (Rossion and Gauthier, 2002), but patients showed smaller amplitudes and delayed latencies. This is also supported by event-related EEG data such as phase synchrony and neural oscillations (Yan et al., 2017; Liu et al., 2018). Accordingly, such tasks can be used in assessing face recognition deficit more effectively than just passive viewing tasks. However, there are still 9 out of 19 tasks that were not reported to correlate with significant reduction of N170 in schizophrenia patients. It can be attributed to the difference between experimental conditions that were not always well reported. For instance, some authors argued that N170 could be modulated by the quality of attention in healthy participants (Jacques and Rossion, 2007; Feng et al., 2012), while Asgharpour et al. (2015) found that schizophrenia patients had decreased visual attention to neutral and emotional face stimuli. It was shown that in autism spectrum disorder N170 was affected by reference electrode location (Joyce and Rossion, 2005). Maurer et al. (2008) showed that N170 was affected by habituation. Moreover, Sel et al. (2015) stated that one's own facial expression of happiness can significantly modulate the N170 in response to neutral faces.

Facial emotions are also supposed to modulate N170 (Blau et al., 2007; Schacht and Sommer, 2009). Turetsky et al. (2007) showed that emotional faces elicited larger responses than the neutral faces. Caharel et al. (2007) reported that N170 amplitudes among schizophrenia patients were smaller for disgusted relative to smiling and neutral expressions, implying inadequate emotional reactions to negative emotions. Lee et al. (2010b) found that the N170 amplitude for happy and fearful emotions was significantly lower among schizophrenia patients than in normal control groups. Hence, the assessment of neutral face stimuli was aimed to exclude this factor.

ERP N170 is usually called "face-specific" potential (Yovel, 2016), while face recognition is one of the basic skills needed for effective social communication (Tsunoda et al., 2012). Thus, a link between N170 and social functioning can be supposed (Kucharska-Pietura et al., 2005; Earls et al., 2016), and this is supported by our results of significant correlations between N170 amplitude and social functioning scales. Therefore, future studies should assess the viability of using N170 as a neuropsychological index of social functioning. Moreover, social cognition training, even if aimed ultimately at teaching higher order social cognitive skills, should begin by addressing facial recognition deficits, modelling the bottom-up nature of social cognition (Ventura et al., 2013). It could be speculated that the N170 component may be tested as a neuropsychological assessment tool for evaluating the effectiveness of social cognition training methods.

The other component, N400 ERP, was originally used in language experiments and refers to "contextual expectancy", where it has increased amplitudes for incongruent endings of sentences in healthy people (Olivares et al., 2015). When N400 ERP was used in the context of face stimuli, it was studied within the old-new effect (participants should decide whether the stimulus was presented before or not). Significant difference between patients and HC was seen in such tasks (Danker et al., 2008), where N400 amplitude was reduced in patients. Taking into account that abnormal N400 ERP component in schizophrenia is reported in language studies that rely on priming paradigms (Mohammad and DeLisi, 2013), this component cannot be interpreted as specific to face abnormality, but rather point to memory associated deficit (Kutas and Federmeier, 2011).

Our data on P100 in response to neutral face stimuli are inconsistent with the results of a recent meta-analysis of P100 in schizophrenia by Earls et al. (2016). These authors concluded that P100 amplitude while viewing neutral faces was greater in healthy controls than in patients. On the one hand, this meta-analysis had strict limitations on inclusion criteria, so fewer studies could be assessed, and such small samples can produce biased results. On the other hand, we cannot affirm the opposite point of view based on our data, therefore this should be studied in the future on larger samples.

Regarding other ERPs, there were too few studies for us to arrive at any definite conclusion on their usefulness; in addition, ERPs did not show consistent associations to neutral face stimuli in various studies. Further research should analyse them in view of other paradigms.

Our review was limited to neutral face stimuli with no limits to experimental tasks. Also, sample sizes in the majority of the included studies were very small. There was a lack of data about the disease: not all the studies provided information about the duration of illness, age at onset, severity of positive, negative and disorganized symptoms, and some studies even had no healthy controls (instead, patient groups with more severe vs. less severe symptoms were compared). Furthermore, antipsychotic medication could influence the amplitude of ERPs (Korostenskaja and Kähkönen, 2009; Su et al., 2012; Du et al., 2015). We cannot exclude this potential influence of medication, even though no significant correlations between medication dose and ERPs' amplitudes and latencies were reported in the included studies. The findings of this systematic review should be interpreted with caution owing to these limitations and to the heterogeneity of the studies' design that could have affected the results of the review. According to NOS scores we cannot exclude selection bias as well as a potential publication bias due to the fact that studies are more likely to be published if they produce positive findings, as well as selective reporting bias, as non-significant differences are less likely to be reported than significant ones.

## 5. Conclusions

The main findings of our review: (1) neuropsychological correlations of face recognition impairments are often revealed in older patients with schizophrenia spectrum disorders with longer disease duration; (2) neuropsychological studies show a tendency for association between ERPs and higher severity of symptoms; (3) among ERPs, N170 seems to be the most significant component with the potential to be used for evaluation of patients' present status, as well as for dynamic control of cognitive impairments, social functioning, and rehabilitation effectiveness.

Future research is needed with respect to age, illness duration, and division by disease type and symptom severity, to assess the neuropsychological changes in dynamics.

## Funding

This research did not receive any specific grants from funding agencies in the public, commercial, or non-for-profit sectors.

## Conflict of interest

None.

## Contributors

Murashko: searching for articles, their primary screening, analysis of abstracts and full-text versions of articles, drafting the article. Shmukler: idea, analysis of the abstracts and full-text versions of articles, article editing.

## References

Addington D, Addington J, Schissel B. A depression rating scale for schizophrenics. Schizophr Res 1990;3:247–51.
American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4th ed. Washington, DC: Am Psychiatr Press; 1994.
Andreasen NC. Scale for the Assessment of Negative Symptoms (SANS) Iowa City. IA: University of Iowa; 1983.
Andreasen NC. Scale for the Assessment of Positive Symptoms (SAPS) Iowa City. IA: University of Iowa; 1984.
Asgharpour M, Tehrani-Doost M, Ahmadi M, Moshki H. Visual attention to emotional face in schizophrenia: an eye tracking study. Iran J Psychiatry 2015;10:13–8.

Bangalore SS, Goradia DD, Nutche J, Diwadkar VA, Prasad KM, Keshavan MS. Untreated illness duration correlates with gray matter loss in first-episode psychoses. NeuroReport 2009;20:729–34.

Batty RA, Francis AJ, Innes-Brown H, Joshua NR, Rossell SL. Neurophysiological correlates of configural face processing in schizotypy. Front Psychiatry 2014;5:101.

Bediou B, Franck N, Saoud M, Baudouin JY, Tiberghien G, Daléry J, d'Amato T. Effects of emotion and identity on facial affect processing in schizophrenia. Psychiatry Res 2005;133:149–57.

Bediou B, Hénaff MA, Bertrand O, Brunelin J, d'Amato T, Saoud M, Krolak-Salmon P. Impaired fronto-temporal processing of emotion in schizophrenia. Neurophysiol Clin 2007;37:77–87.

Birchwood M, Smith J, Cochrane R, Wetton S, Copestake S. The social functioning scale. The development and validation of a new scale of social adjustment for use in family intervention programmes with schizophrenic patients. Br J Psychiatry 1990;157:853–9.

Blau VC, Maurer U, Tottenham N, McCandliss BD. The face-specific N170 component is modulated by emotional facial expression. Behav Brain Funct 2007;3:7.

Bortolon C, Capdevielle D, Raffard S. Face recognition in schizophrenia disorder: A comprehensive review of behavioral, neuroimaging and neurophysiological studies. Neurosci Biobehav Rev 2015;53:79–107.

Brennan AM, Harris AW, Williams LM. Neural processing of facial expressions of emotion in first onset psychosis. Psychiatry Res 2014;219:477–85.

Brothers L. The neural basis of primate social communication. Motiv Emot 1990;14:81–91.

Bruce V, Young A. Understanding face recognition. Br J Psychol 1986;77:305–27.

Caharel S, Bernard C, Thibaut F, Haouzir S, Di Maggio-Clozel C, Allio G, et al. The effects of familiarity and emotional expression on face processing examined by ERPs in patients with schizophrenia. Schizophr Res 2007;95:186–96.

Campanella S, Montedoro C, Streel E, Verbanck P, Rosier V. Early visual components (P100, N170) are disrupted in chronic schizophrenic patients: an event-related potentials study. Neurophysiol Clin 2006;36:71–8.

Costa PT, McCrae RR. Revised NEO Personality Inventory (NEO-PI-R) and NEO FiveFactor Inventory (NEO-FFI): professional manual. Odessa, FL: Psychol Assess Resour; 1992.

Csukly G, Stefanics G, Komlósi S, Czigler I, Czobor P. Event-related theta synchronization predicts deficit in facial affect recognition in schizophrenia. J Abnorm Psychol 2014;123:178–89.

Danker JF, Hwang GM, Gauthier L, Geller A, Kahana MJ, Sekuler R. Characterizing the ERP Old-New effect in a short-term memory task. Psychophysiol 2008;45:784–93.

Darke H, Peterman JS, Park S, Sundram S, Carter O. Are patients with schizophrenia impaired in processing non-emotional features of human faces? Front Psychol 2013;4:529.

Deffke I, Sander T, Heidenreich J, Sommer W, Curio G, Trahms L, Lueschow A. MEG/EEG sources of the 170-ms response to faces are co-localized in the fusiform gyrus. Neuroimage 2007;35:1495–501.

Dima D, Dillo W, Bonnemann C, Emrich HM, Dietrich DE. Reduced P300 and P600 amplitude in the hollow-mask illusion in patients with schizophrenia. Psychiatry Res 2011;191:145–51.

Du XD, Zhang GY, Yang Y, Li Z, Pan W, Yin GZ, et al. Follow-up of N400 in the Rehabilitation of First-episode Schizophrenia. Chin Med J (Engl) 2015;128:2215–9.

Earls HA, Curran T, Mittal V. Deficits in early stages of face processing in schizophrenia: a systematic review of the P100 component. Schizophr Bull 2016;42:519–27.

Feng W, Martinez A, Pitts M, Luo YJ, Hillyard SA. Spatial attention modulates early face processing. Neuropsychol 2012;50:3461–8.

Feuerriegel D, Churches O, Hofmann J, Keage HA. The N170 and face perception in psychiatric and neurological disorders: A systematic review. Clin Neurophysiol 2015;126:1141–58.

Guillaume F, Guillem F, Tiberghien G, Stip E. ERP investigation of study-test background mismatch during face recognition in schizophrenia. Schizophr Res 2012;134:101–9.

Guillem F, Bicu M, Pampoulova T, Hooper R, Bloom D, Wolf MA, et al. The cognitive and anatomo-functional basis of reality distortion in schizophrenia: a view from memory event-related potentials. Psychiatry Res 2003;117:137–58.

Guo X, Li J, Wei Q, Fan X, Kennedy DN, Shen Y, et al. Duration of untreated psychosis is associated with temporal and occipitotemporal gray matter volume decrease in treatment naïve schizophrenia. PLoS One 2013;8:e83679.

Gur RE, Moore TM, Calkins ME, Ruparel K, Gur RC. Face processing measures of social cognition: a dimensional approach to developmental psychopathology. Biol Psychiatry Cogn Neurosci Neuroimaging 2017;2:502–9.

Herrmann MJ, Ellgring H, Fallgatter AJ. Early-stage face processing dysfunction in patients with schizophrenia. Am J Psychiatry 2004;161:915–7.

Herrmann MJ, Ehlis AC, Muehlberger A, Fallgatter AJ. Source localization of early stages of face processing. Brain Topogr 2005;18:77–85.

Jacques C, Rossion B. Electrophysiological evidence for temporal dissociation between spatial attention and sensory competition during human face processing. Cereb Cortex 2007;17:1055–65.

Jiang Y, Luo C, Li X, Duan M, He H, Chen X, et al. Progressive reduction in gray matter in patients with schizophrenia assessed with MR imaging by using causal network analysis. Radiol 2018;287:633–42.

Johnston PJ, Stojanov W, Devir H, Schall U. Functional MRI of facial emotion recognition deficits in schizophrenia and their electrophysiological correlates. Eur J Neurosci 2005;22:1221–32.

Joshua N, Rossell S. Configural face processing in schizophrenia. Schizophr Res 2009;112:99–103.

Joyce C, Rossion B. The face-sensitive N170 and VPP components manifest the same brain processes: the effect of reference electrode site. Clin Neurophysiol 2005;116:2613–31.

Jung HT, Kim DW, Kim S, Im CH, Lee SH. Reduced source activity of event-related potentials for affective facial pictures in schizophrenia patients. Schizophr Res 2012;136:150–9.

Kang E, Keifer CM, Levy EJ, Foss-Feig JH, McPartland JC, Lerner MD. Atypicality of the N170 event-related potential in autism spectrum disorder: a meta-analysis. Biol Psychiatry: Cogn Neurosci Neuroimaging 2018;3:657–66.

Kay SR, Fiszbein A, Opler LA. The positive and negative syndrome scale (PANSS) for schizophrenia. Schizophr Bull 1987;13:261–76.

Keefe RS, Goldberg TE, Harvey PD, Gold JM, Poe MP, Coughenour L. The Brief Assessment of Cognition in Schizophrenia: reliability, sensitivity, and comparison with a standard neurocognitive battery. Schizophr Res 2004;68:283–97.

Kim DW, Kim HS, Lee SH, Im CH. Positive and negative symptom scores are correlated with activation in different brain regions during facial emotion perception in schizophrenia patients: a voxel-based sLORETA source activity study. Schizophr Res 2013;151:165–74.

Kim DW, Shim M, Song MJ, Im CH, Lee SH. Early visual processing deficits in patients with schizophrenia during spatial frequency-dependent facial affect processing. Schizophr Res 2015;161:314–21.

Kirihara K, Kasai K, Tada M, Nagai T, Kawakubo Y, Yamasaki S, et al. Neurophysiological impairment in emotional face processing is associated with low extraversion in schizophrenia. Prog Neuropsychopharmacol Biol Psychiatry 2012;37:270–5.

Kohler CG, Turner TH, Bilker WB, Brensinger CM, Siegel SJ, Kanes SJ, et al. Facial emotion recognition in schizophrenia: intensity effects and error pattern. Am J Psychiatry 2003;160:1768–74.

Kohler CG, Walker JB, Martin EA, Healey KM, Moberg PJ. Facial emotion perception in schizophrenia: a meta-analytic review. Schizophr Bull 2010;36:1009–19.

Kontaxaki MI, Kattoulas E, Smyrnis N, Stefanis NC. Cognitive impairments and psychopathological parameters in patients of the schizophrenic spectrum. Psychiatr 2014;25:27–38.

Korostenskaja M, Kähkönen S. What do ERPs and ERFs reveal about the effect of antipsychotic treatment on cognition in schizophrenia? Curr Pharm Des 2009;15:2573–93.

Kosmidis MH, Bozikas VP, Giannakou M, Anezoulaki D, Fantie BD, Karavatos A. Impaired emotion perception in schizophrenia: a differential deficit. Psychiatry Res 2007;149:279–84.

Kucharska-Pietura K, David AS, Masiak M, Phillips ML. Perception of facial and vocal affect by people with schizophrenia in early and late stages of illness. Br J Psychiatry: J Mental Sci 2005;187:523–8.

Kutas M, Federmeier KD. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). Annu Rev Psychol 2011;62:621–47.

Lee SH, Kim DW, Kim EY, Kim S, Im CH. Dysfunctional gamma-band activity during face structural processing in schizophrenia patients. Schizophr Res 2010a;119:191–7.

Lee SH, Kim EY, Kim S, Bae SM. Event-related potential patterns and gender effects underlying facial affect processing in schizophrenia patients. Neurosci Res 2010b;67:172–80.

Lee SH, Kim S, Shim MS, Kim DW, Im CH. Dysfunctional patterns of gamma-band activity in response to human faces compared to non-facial stimuli in patients with schizophrenia. Psychiatry Investig 2016;13:349–59.

Liu T, Pinheiro AP, Zhao Z, Nestor PG, McCarley RW, Niznikiewicz M. Simultaneous face and voice processing in schizophrenia. Behav Brain Res 2016;305:76–86.

Liu M, Pei G, Peng Y, Wang C, Yan T, Wu J. Disordered high-frequency oscillation in face processing in schizophrenia patients. Medicine (Baltimore) 2018;97:e9753.

Maher S, Mashhoon Y, Ekstrom T, Lukas S, Chen Y. Deficient cortical face-sensitive N170 responses and basic visual processing in schizophrenia. Schizophr Res 2016;170:87–94.

Martin F, Baudouin JY, Tiberghien G, Franck N. Processing emotional expression and facial identity in schizophrenia. Psychiatry Res 2005;134:43–53.

Marwick K, Hall J. Social cognition in schizophrenia: a review of face processing. Br Med Bull 2008;88:43–58.

Mason O, Claridge GS, Jackson M. New scales for the assessment of schizotypy. Pers Individ Dif 1995;18:7–13.

Maurer U, Rossion B, McCandliss BD. Category specificity in early perception: face and word N170 responses differ in both lateralization and habituation properties. Front Hum Neurosci 2008;2:18.

McCleery A, Lee J, Joshi A, Wynn JK, Hellemann GS, Green MF. Meta-analysis of face processing event-related potentials in schizophrenia. Biol Psychiatry 2015;77:116–26.

Mohammad OM, DeLisi LE. N400 in schizophrenia patients. Curr Opin Psychiatry 2013;26:196–207.

Morosini PL, Magliano L, Brambilla L, Ugolini S, Pioli R. Development, reliability and acceptability of a new version of the DSM-IV Social and Occupational

Functioning Assessment Scale (SOFAS) to assess routine social functioning. Acta Psychiatr Scand 2000;1001:323–9.
Obayashi C, Nakashima T, Onitsuka T, Maekawa T, Hirano Y, Hirano S, et al. Decreased spatial frequency sensitivities for processing faces in male patients with chronic schizophrenia. Clin Neurophysiol 2009;120:1525–33.
Olivares EI, Iglesias J, Saavedra C, Trujillo-Barreto NJ, Valdés-Sosa M. Brain signals of face processing as revealed by event-related potentials. Behav Neurol 2015;2015:514361.
Onitsuka T, Niznikiewicz MA, Spencer KM, Frumin M, Kuroki N, Lucia LC, et al. Functional and structural deficits in brain regions subserving face perception in schizophrenia. Am J Psychiatry 2006;163:455–62.
Onitsuka T, Spencer KM, Lucia LC, Shenton ME, McCarley RW, Niznikiewicz MA. Abnormal asymmetry of the face N170 repetition effect in male patients with chronic schizophrenia. Brain Imaging Behav 2009;3:240–5.
Overall JE, Gorham DR. The brief psychiatric rating scale. Psychol Rep 1962;10:799–812.
Poole JH, Tobias FC, Vinogradov S. The functional relevance of affect recognition errors in schizophrenia. J Int Neuropsychol Soc 2000;6:649–58.
Ramos-Loyo J, González-Garrido AA, Sánchez-Loyo LM, Medina V, Basar-Eroglu C. Event-related potentials and event-related oscillations during identity and facial emotional processing in schizophrenia. Int J Psychophysiol 2009;71:84–90.
Rocca P, Castagna F, Mongini T, Montemagni C, Rasetti R, Rocca G, Bogetto F. Exploring the role of face processing in facial emotion recognition in schizophrenia. Acta Neuropsychiatr 2009;21:292–300.
Rossion B, Gauthier I. How does the brain process upright and inverted faces? Behav Cogn Neurosci Rev 2002;1:63–75.
Schacht A, Sommer W. Emotions in word and face processing: early and late cortical responses. Brain Cogn Sci 2009;69:538–50.
Sel A, Calvo-Merino B, Tuettenberg S, Forster B. When you smile, the world smiles at you: ERP evidence for self-expression effects on face processing. Soc Cogn Affect Neurosci 2015;10:1316–22.
Silverstein SM, Keane BP. Perceptual organization impairment in schizophrenia and associated brain mechanisms: review of research from 2005 to 2010. Schizophr Bull 2011;37:690–9.
Silverstein SM, Keane BP, Papathomas TV, Lathrop KL, Kourtev H, Feigenson K, et al. Processing of spatial-frequency altered faces in schizophrenia: effects of illness phase and duration. PLoS One 2014;9:e114642.
Soria Bauser D, Thoma P, Aizenberg V, Brüne M, Juckel G, Daum I. Face and body perception in schizophrenia: a configural processing deficit? Psychiatry Res 2012;195:9–17.
Spielberger CD, Sydeman SJ. State-trait anxiety inventory and state-trait anger expression inventory. In: Maruish ME, editor. The use of psychological testing for treatment planning and outcome assessment. Hillsdale, NJ: Lawrence Erlbaum Associates; 1994. p. 292–321.
Su L, Cai Y, Shi S, Wang L. Meta-analysis of studies in China about changes in P300 latency and amplitude that occur in patients with schizophrenia during treatment with antipsychotic medication. Shanghai Arch Psychiatry 2012;24:200–7.
Tso IF, Calwas AM, Chun J, Mueller SA, Taylor SF, Deldin PJ. Altered attentional and perceptual processes as indexed by N170 during gaze perception in schizophrenia: Relationship with perceived threat and paranoid delusions. J Abnorm Psychol 2015;124:519–31.
Tsunoda T, Kanba S, Ueno T, Hirano Y, Hirano S, Maekawa T, et al. Altered face inversion effect and association between face N170 reduction and social dysfunction in patients with schizophrenia. Clin Neurophysiol 2012;123:1762–8.
Turetsky BI, Kohler CG, Indersmitten T, Bhati MT, Charbonnier D, Gur RC. Facial emotion recognition in schizophrenia: when and why does it go awry? Schizophr Res 2007;94:253–63.
van Haren NE, Hulshoff Pol HE, Schnack HG, Cahn W, Mandl RC, Collins DL, et al. Focal gray matter changes in schizophrenia across the course of the illness: a 5-year follow-up study. Neuropsychopharmacol 2007;32:2057–66.
Ventura J, Wood RC, Jimenez AM, Hellemann GS. Neurocognition and symptoms identify links between facial recognition and emotion processing in schizophrenia: meta-analytic findings. Schizophr Res 2013;151:78–84.
Wells GA, Shea B, O'Connell D, Robertson J, Peterson J, Welch V, et al. The Newcastle-Ottawa scale (NOS) for assessing the quality of non-randomised studies in meta-analyses. Ottawa Hospital Research Institute; 2000 [accessed 15 February 2019]. Available from: http://www.ohri.ca/programs/clinical_epidemiology/Oxford.asp.
Wilkinson GS. Wide Range Achievement Test 3 (WRAT3) Wilmington. DE: Wide Range Inc; 1993.
Yan T, Wang W, Liu T, Chen D, Wang C, Li Y, et al. Increased local connectivity of brain functional networks during facial processing in schizophrenia: evidence from EEG data. Oncotarget 2017;8:107312–22.
Yovel G. Neural and cognitive face-selective markers: An integrative review. Neuropsychologia 2016;83:5–13.
Zheng Y, Li H, Ning Y, Ren J, Wu Z, Huang R, et al. Sluggishness of early-stage face processing (N170) is correlated with negative and general psychiatric symptoms in schizophrenia. Front Hum Neurosci. 2016;10:615.