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Neurophysiological substrates of configural face perception in schizotypy

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ABSTRACT

Face perception is a highly developed function of the human visual system. Previous studies of event-related potentials (ERPs) have identified a face-selective ERP component (negative peak at about 170 ms after stimulus onset, N170) in healthy participants. In contrast, patients with schizophrenia exhibit reduced amplitude of the N170, which may represent a pathological deficit in the neurophysiology of face perception. Interestingly, healthy humans with schizophrenia-like experiences (schizotypy) also exhibit abnormal processing of face perception. Yet, it has remained unknown how schizotypy in healthy humans is associated with the neurophysiological substrates of face perception. Here, we recruited 35 healthy participants and assessed their schizotypy by the magical ideation rating scale. We used high-density electroencephalography to obtain ERPs elicited by a set of Mooney faces (face and non-face visual stimuli). We investigated median and mean reaction times and visual ERP components in response to the stimuli. We observed a significant difference in N170 amplitude between the two face-stimulus conditions and found that the measured schizotypy scores were significantly correlated with both reaction times and N170 amplitude in response to the face stimuli across all participants. Our results thus support the model of schizotypy as a manifestation of a continuum between healthy individuals and patients with schizophrenia, where the N170 impairment serves as a biomarker for the degree of pathology along this continuum.

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1. Introduction

Face perception is a highly developed function of the human visual system (Haxby et al., 2000). Face perception develops at a very early age; faces are the first distinguishable object for infants (Morton and Johnson, 1991). Previous functional brain imaging studies have observed that several brain regions are involved in face perception including the fusiform face area (Kanwisher et al., 1997), right lateral occipital area (Gauthier et al., 2000), and superior temporal sulcus (Hoffman and Haxby, 2000). Complementing the high spatial resolution of imaging, electrophysiological recordings with high temporal resolution provide insights into the brain network dynamics of face perception (Rossion, 2014). In particular, event-related potentials (ERPs), which represent electrical potentials elicited by time-locked external stimuli, can be measured with electroencephalography (EEG) and have been widely investigated in the study of the neural basis of face perception. The N170, which is a negative peak potential at approximately 170 ms from the stimulus onset, is considered a face-selective ERP component (Bentin et al., 1996; Jeffreys, 1996; Rossion and Jacques, 2011). A larger N170 amplitude was observed for face stimuli when compared to other objects in healthy participants (Rossion and Caharel, 2011). Interestingly, in contrast, patients with schizophrenia exhibit impaired processing

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of face perception (Kohler et al., 2010; McCleery et al., 2015; Whittaker et al., 2001). For example, patients with schizophrenia showed reduced amplitude (Herrmann et al., 2004; Ibáñez et al., 2012; Lynn and Salisbury, 2008; Turetsky et al., 2007) and delayed latency (Caharel et al., 2007) of the N170 in response to face stimuli along with structural deficits in bilateral anterior and posterior fusiform gyrus gray matter volumes (Onitsuka et al., 2006). Importantly, these deficits may relate to symptom severity of schizophrenia (Akbarfahimi et al., 2013; Campanella et al., 2006; Kim et al., 2013; Maher et al., 2016; Zheng et al., 2016).

Schizotypy refers to a latent personality trait, which is prone to schizophrenia, and is described by a multidimensional model (positive, negative, and disorganized) (Lenzenweger, 2010). Schizotypy includes not only clinical symptoms such as paranoia but also subtle phenomenology such as magical ideation (Lenzenweger, 2018a). People with schizotypy may exhibit various clinical features including schizotypal personality disorder (Lenzenweger, 2018b, 2015). Interestingly, previous studies have shown that individuals with schizotypy appear to share schizophrenia risk genes (Baron and Risch, 1987; Cadenhead and Braff, 2002; Vollema et al., 2002). In addition, several neuroimaging studies found structural (Moorhead et al., 2009; Peters et al., 2010) and functional (Lagioia et al., 2010; Volpe et al., 2008) impairment in participants with schizotypy, which are also found in patients with schizophrenia. These phenomena can be explained by a theory of a continuum between patients with schizophrenia and healthy participants (Cochrane et al., 2012; van Os et al., 2009). Importantly, participants with schizotypy exhibit impaired processing of face perception in behaviors (Dickey et al., 2011; Mikhailova et al., 1996; Platek and Gallup, 2002). Yet, the neurophysiological substrate of configural face perception, which refers to the ability to recognize whether a stimulus is a face or not, has remained unknown. Here, we recruited healthy participants and assessed their magical ideation. Magical ideation is one of the schizotypy subscales, considered a positive symptom of schizotypy (Raine, 1991). We chose magical ideation as an indicator of schizotypy (Eckblad and Chapman, 1983) since it is considered a prominent symptom of schizotypy (Karcher and Shean, 2012; Kwapil et al., 1997; Thalbourne, 1994). We hypothesized that participants with more magical ideation (positive schizotypy) exhibit more impaired processing of faces in terms of both behavioral performance and neurophysiological substrates. We investigated reaction times and visual ERP components in response to face and non-face stimuli and its relationship with the magical ideation scores. We found significant correlations in both reaction times and the N170 with the magical ideation scores. Thus, our findings suggest that deficits of configural face perception in healthy participants with high schizotypy represent a continuum with schizophrenia and the neurophysiological substrate may represent the degree of this continuum.

2. Methods

2.1. Study design

This study was performed at the University of North Carolina at Chapel Hill (UNC–CH) and approved by the Biomedical Institutional Review Board of UNC-CH. Participants were recruited from the UNC-CH community. All participants were males, right-handed, and free of any neurologic or sleep disorders (age: 21.8 ± 3.5 years, mean ± std). We excluded female participants to control sex differences in schizotypal traits (Miettunen and Jaaskelainen, 2010). None of the participants reported any personal or family history of neurological or psychiatric disorders. A urine drug screen was performed to exclude participants who tested positive for drugs of abuse. Eligibility of participants was determined by a telephone screening. All participants provided written informed consent form before participation. Thirty-six participants were enrolled in the study. Participants completed questionnaires for inclusion/exclusion criteria, handedness, and schizotypal traits (magical ideation scale). The Edinburgh handedness inventory was used and a laterality index was obtained from each participant. Data from 35 participants were analyzed since one participant did not complete the schizotypy questionnaire.

2.2. Schizotypy

We used an adapted version of the magical ideation scale (Eckblad and Chapman, 1983) as an indicator of schizotypy. This assessment originally consisted of 30 true/false questions and we had previously adjusted the questions to a six-point rating scale (0: strongly disagree, 5: strongly agree) for a more fine-tuned assessment of schizotypal traits (Lustenberger et al., 2015). Summation of the scores for the 30 questions were used as a schizotypy score (0–150).

2.3. Stimuli and task

We used 80 Mooney faces, which refer to two-tone pictures of faces, that have the highest face-like ratings from a validated set consisting of 144 Mooney faces (Verhallen and Mollon, 2016). We inverted and scrambled the 80 Mooney faces to make another set of 80 non-face stimuli (Uhlhaas et al., 2006). All non-face stimuli had same contrast (white/black) with the face stimuli. The size of all stimuli was 6.8 × 10 cm (width x height). Participants performed a face perception task consisting of the 80 face and 80 non-face stimuli. Before the main task, participants performed 8 practice trials (4 face and 4 non-face trials) to accommodate to the task. Note that these trials were not used in the main task. First, written task instructions were displayed for 60 s and randomized face stimuli were presented for 200 ms each. A total of 160 trials were presented (80 for face and 80 for non-face stimuli) with an inter-trial interval of 3.5–4.5 s. Participants were randomized to one of two task forms (task A and task B) in an equal distribution. In task A, participants were asked to press the left-arrow key for face stimuli and right-arrow key for non-face stimuli as precisely and quickly as possible. In task B, the assignment of the two response keys was reversed (Fig. 1). All instructions and experimental tasks were implemented in Presentation (Neurobehavioral Systems Inc., Berkeley, CA). After the task, participants completed a task load questionnaire, which assessed how difficult the task was. EEG data were recorded by a high-density EEG system (128 channels, EGI Inc., Eugene, OR) at a sampling rate of 1 kHz. Channel Cz and one channel between Cz and Pz were used as the reference and ground, respectively.

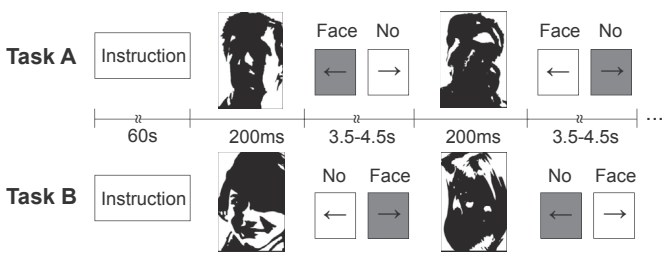

Fig. 1. Experimental paradigm for configural face perception using a set of Mooney faces. Instructions were displayed for 60 s and then face or non-face stimuli were presented for 200 ms. Participants were asked to press the left or right arrow key according to the type of task as quickly and precisely as possible. Inter-trial interval was 3.5–4.5 s. The type of key press was randomized and counter-balanced across participants (task A and task B). A total of 160 trials (80 for each stimulus condition) was obtained.

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2.4. Data analysis and statistical testing

Reaction times were calculated from the key press in response to the face and non-face stimuli. Outliers (>2 s) and missed trials were removed and mean and median reaction times were obtained from each participant. For EEG data, offline processing was performed by EEGLAB (Delorme and Makeig, 2004), FieldTrip (Oostenveld et al., 2010), and custom-built scripts in MATLAB R2015b (Mathworks, Natick, MA). First, all data were band-pass filtered from 1 to 50 Hz and then downsampled to 500 Hz. Second, the data were preprocessed by an artifact subspace reconstruction algorithm (Mullen et al., 2013) to remove high-variance signals at each channel and identify noisy channels. Third, noisy channels that were found in the previous step were interpolated and Cz referencing was kept since the orientation of the N170 aligns with a projected dipole from Cz to posterior regions. Lastly, infomax independent component analysis (ICA) (Jung et al., 2000) was performed to remove eye blinking, eye movement, muscle activity, and heartbeats artifact. All ICA components were visually inspected and components were manually selected for rejection. After these preprocessing steps, data were epoched from −100 ms to 600 ms according to the stimuli onset. A total of 160 trials (80 for face and 80 for non-face stimuli) were obtained for each participant. Each trial was visually inspected in the time domain and noisy and missed trials were removed. Then, the remaining trials were averaged at each channel for each participant to obtain ERPs. To test the continuum between the schizotypy scores and reaction times, we performed correlation analyses using the Spearman's rho since the schizotypy scores are ordinal. Mean and median reaction times were calculated. We used the same correlation analysis approach for ERPs.

To calculate statistical significance for ERPs, we adopted a non-parametric cluster-based permutation test (Maris and Oostenveld, 2007) to deal with the multiple comparison problem of high-density EEG data. First, t-tests were conducted for each channel and time point across participants between conditions (e.g. face vs. non-face). We then constructed clusters from obtained spatio-temporal significant t-value map ($p < 0.05$) and summed all the positive or negative t-values within the clusters separately. The significant t-values were clustered based on spatio-temporal adjacency. The minimum size of a cluster was set to two points. A neighboring channel was defined as spatial adjacency within 4 cm (Maris and Oostenveld, 2007). For the permutation test, we shuffled all trials and divided it into two datasets. We then conducted t-tests for the two datasets to obtain a t-value map. We repeated this procedure by the Monte Carlo simulation with 1000 iterations. To compare with the original dataset, we extracted the largest cluster from each permutation test. Lastly, we constructed a histogram of the 1000 values of the cluster-level statistics and calculated a probability density function (PDF) to estimate cluster-level p-values. The input for the PDF was the cluster-level statistics from the original dataset, while the output was a p-value for each cluster-level statistic. The cluster-level p-values were corrected and approximated by this cluster-based permutation test.

2.5. Inter-stimulus perceptual variance

The N170 has been considered a face-selective ERP component in healthy humans (Bentin et al., 1996; Rossion, 2014). However, one study claimed that this phenomenon reflects an artifact of uncontrolled inter-stimulus perceptual variance (ISPV) (Thierry et al., 2007). According to this study, a larger physical variance between stimuli caused an increased inter-trial jitter in the N170 for non-face stimuli and thus a reduced ERP amplitude. To investigate ISPV in stimulus images used in our study, we first chose images (N = 1, 10, 20, 40, and 80) randomly from the image set for each stimulus condition (face and non-face) and computed pixel-by-pixel averaging across the stimulus images. We then computed histogram of pixel-by-pixel correlations between the stimulus images for each condition to quantify ISPV. Non-parametric kernel-smoothing was used to estimate the probability density function of the histogram.

3. Results

3.1. Behavioral response

To investigate the relationship between behavioral responses in the configural face perception task and the schizotypy scores, we performed correlation analyses using the Spearman's rho. We computed mean and median reaction times in response to the button press for the face and non-face stimuli. We found significant positive correlations in both median ($rho = 0.48$, $p = 0.003$) and mean ($rho = 0.47$, $p = 0.004$) reaction times for the face stimuli, which indicate that button responses were slower as participants had higher schizotypy scores (Fig. 2A and B). Each dot represents a participant and the magenta line indicates the least-squares fit line to the scatter plot. In contrast, we did not find such correlations in either median ($rho = 0.17$, $p = 0.30$) or mean reaction times ($rho = 0.16$, $p = 0.34$) for the non-face stimuli. These findings suggest that more pronounced schizotypy impairs behavioral performance in configural face perception. In an additional, exploratory analysis, we divided the participants into two groups (high and low schizotypy) by a median split of the schizotypy scores and performed statistical tests in bot reaction times (see details in Supplementary Material). We found significant differences between the groups for the face stimuli and this finding further supports that schizotypy is associated with impaired configural face perception (Supplementary Fig. 1).

3.2. ERPs for configural face perception

We investigated the ERPs elicited by the face and non-face stimuli for all participants. We averaged ERPs across correct trials at each channel for each participant and then averaged these across participants to obtain grand-averaged ERPs. Grand-averaged ERPs were obtained for both face and non-face stimuli. This approach resulted in a total of 128 averaged ERPs matching the number of EEG channels (upper panels in Fig. 3A and B). Topographical distributions for two ERP components (P100 and N170) were calculated (lower parts in Fig. 3A and B). We found positive potentials at 100 ms over the occipital region (P100) and negative potentials at 170 ms over the bi-occipito-temporal region (N170). Differences in ERPs averaged over the occipito-temporal region indicate that the N170 was larger for the face stimuli (Fig. 3C, upper panel, shaded gray bar indicates the statistically significant time period determined by the cluster-based non-parametric test). We obtained topographical distributions for averaged differences (Face − Non-Face) in P100 and N170 and found statistically significant channels over the occipito-temporal region in the N170 ($p < 0.05$, non-parametric cluster-based permutation test, significant channels marked by asterisks, 11 channels). These findings demonstrate that the face-selective N170 components over the occipito-temporal region were elicited by the configural face perception task using a set of Mooney faces.

3.3. ERPs and schizotypy

To investigate if the ERP amplitude was correlated with the schizotypy scores, we performed correlation analyses using the Spearman's rho. We computed averaged P100 and N170 ERP amplitude over the corresponding channels (selected from

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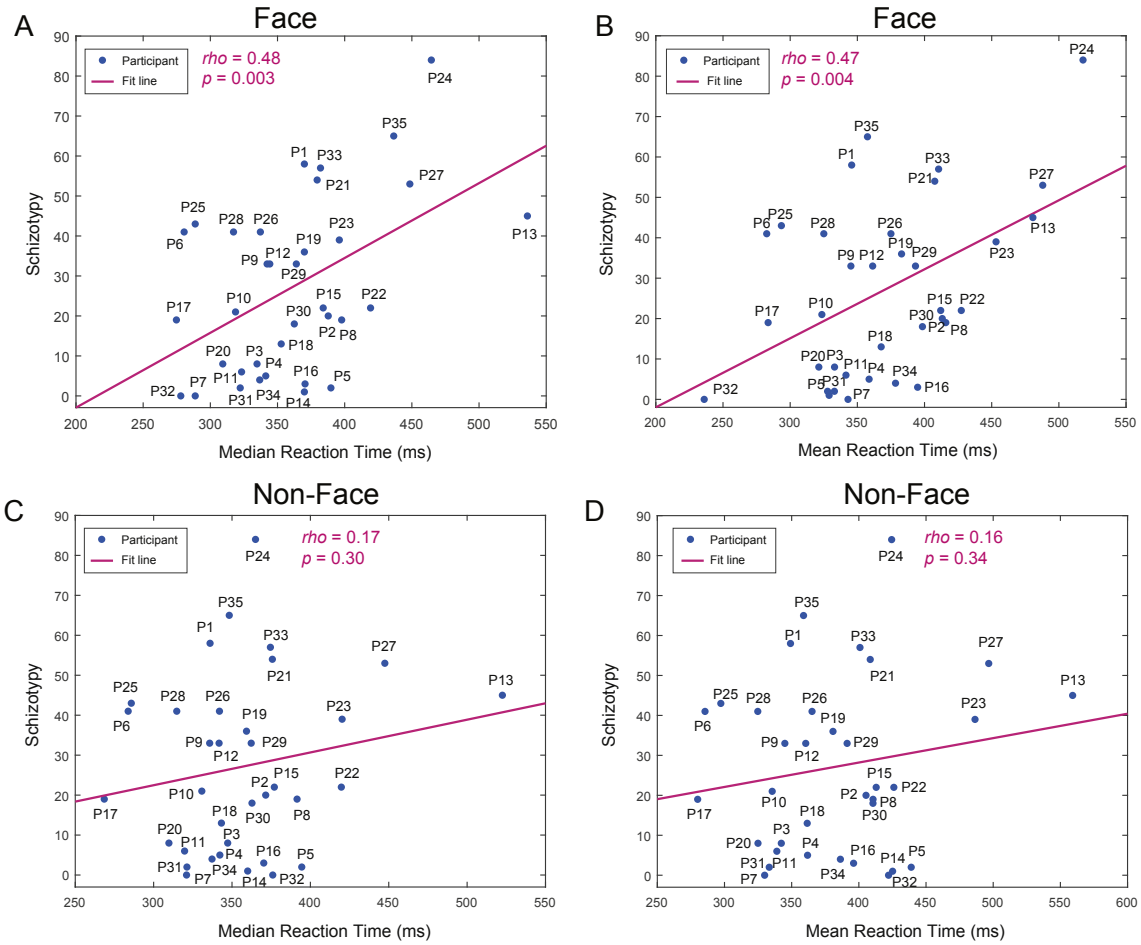

Fig. 2. Correlations between schizotypy scores and reaction times in response to face and non-face stimuli. Scatter plots of (A) median and (B) mean reaction times in response to face stimuli. Blue dots and magenta lines indicate participants and the least-squares fit to the scatter plot. Rho and p-values for median ($rho = 0.48$, $p = 0.003$) and mean ($rho = 0.47$, $p = 0.004$) reaction times are presented. Scatter plots of (C) median ($rho = 0.17$, $p = 0.30$) and (D) mean ($rho = 0.16$, $p = 0.34$) reaction times are presented in the same manner. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

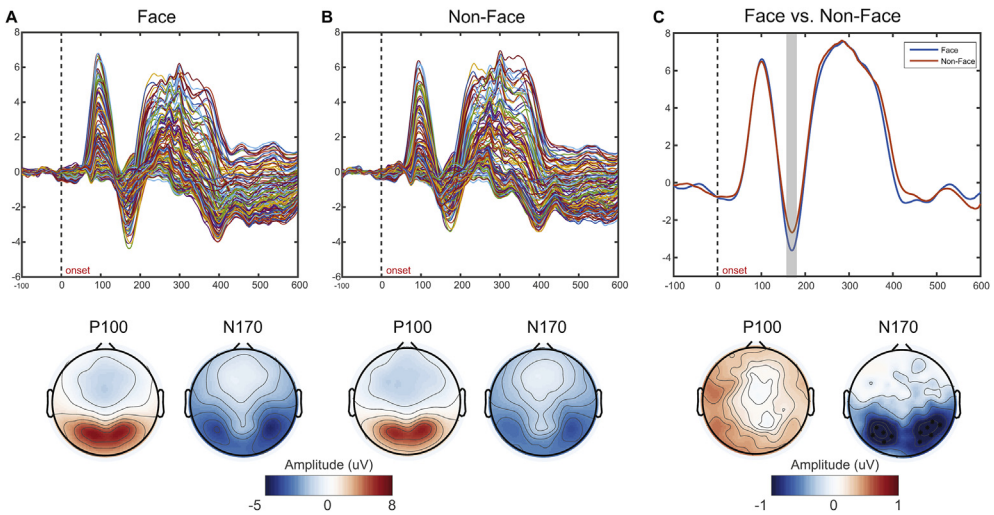

Fig. 3. Grand-averaged ERPs for all channels and topographical distributions of ERP components (P100 and N170) for face and non-face stimuli. ERPs and topographies for (A) face and (B) non-face stimuli. (C) Differences in ERPs averaged over the occipito-temporal region and topographies for P100 and N170. Asterisks in the topography represent statistically significant channels ($p < 0.05$, non-parametric cluster-based permutation test).

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topographical maps in Fig. 3) for each participant in both face and non-face stimuli. We found a significant negative correlation between the absolute N170 amplitudes and schizotypy scores for the face stimuli (Fig. 4A, $rho = -0.56$, $p = 0.0003$), which indicates that a deficit in configural face perception was associated with higher schizotypy scores. Each dot represents a participant and the magenta line indicates the least-squares fit line to the scatter plot. Averaged EEG channels are presented as black dots in the scalp map (inset). In contrast, we found no significant difference (trending effect) for the P100 amplitudes for the face stimuli (Fig. 4B, $rho = -0.29$, $p = 0.0875$). For the non-face stimuli, likewise, we found no significant difference (trending effect) for both N170 and P100 amplitudes (Fig. 4C and D, $rho = -0.31$, $p = 0.0642$ for N170, $rho = -0.29$, $p = 0.0881$ for P100). These findings show that the neurophysiological substrates of configural face perception is significantly associated with the degree of schizotypy. In an additional, exploratory analysis, we performed statistical tests in both ERP components (see details in Supplementary Material) and found a significant difference in N170 in response to face stimuli between the two groups (low and high schizotypy, Supplementary Fig. 2). This finding further support impaired configural face perception in higher risk of schizotypy.

3.4. Inter-stimulus perceptual variance

Inter-stimulus perceptual variance in two different image sets may affect the N170 amplitude (Thierry et al., 2007). To investigate a statistical difference of ISPV between the face and non-face stimulus conditions used in this study, we computed progressive pixel-by-pixel averaging of the stimulus images in each stimulus condition (Fig. 5A) and histogram of pixel-by-pixel correlations between the stimulus images to quantify ISPV (Fig. 5B). We found no significant difference in mean correlations of the stimulus images between the face and non-face stimulus conditions (two-sample t-test, $p > 0.05$). These findings demonstrate that a potential confound by a difference of ISPV did not exist in our study and that the face perception task using Mooney faces is an appropriate measure to investigate the face-selective N170 components.

4. Discussion

In this study, we asked how the neurophysiological substrates of configural face perception is associated with schizotypy in healthy participants. To answer this question, we adopted a configural face perception task consisting of a set of Mooney faces. We recorded high-density EEG data to obtain ERPs and assessed positive schizotypy by the adjusted magical ideation scale (Eckblad and Chapman, 1983; Lustenberger et al., 2015). We found that reaction times to the face stimuli were significantly correlated with the schizotypy scores. In agreement with previous studies, we also found that the typical face-selective N170 component differed in amplitude between the face and non-face stimuli over the bi-

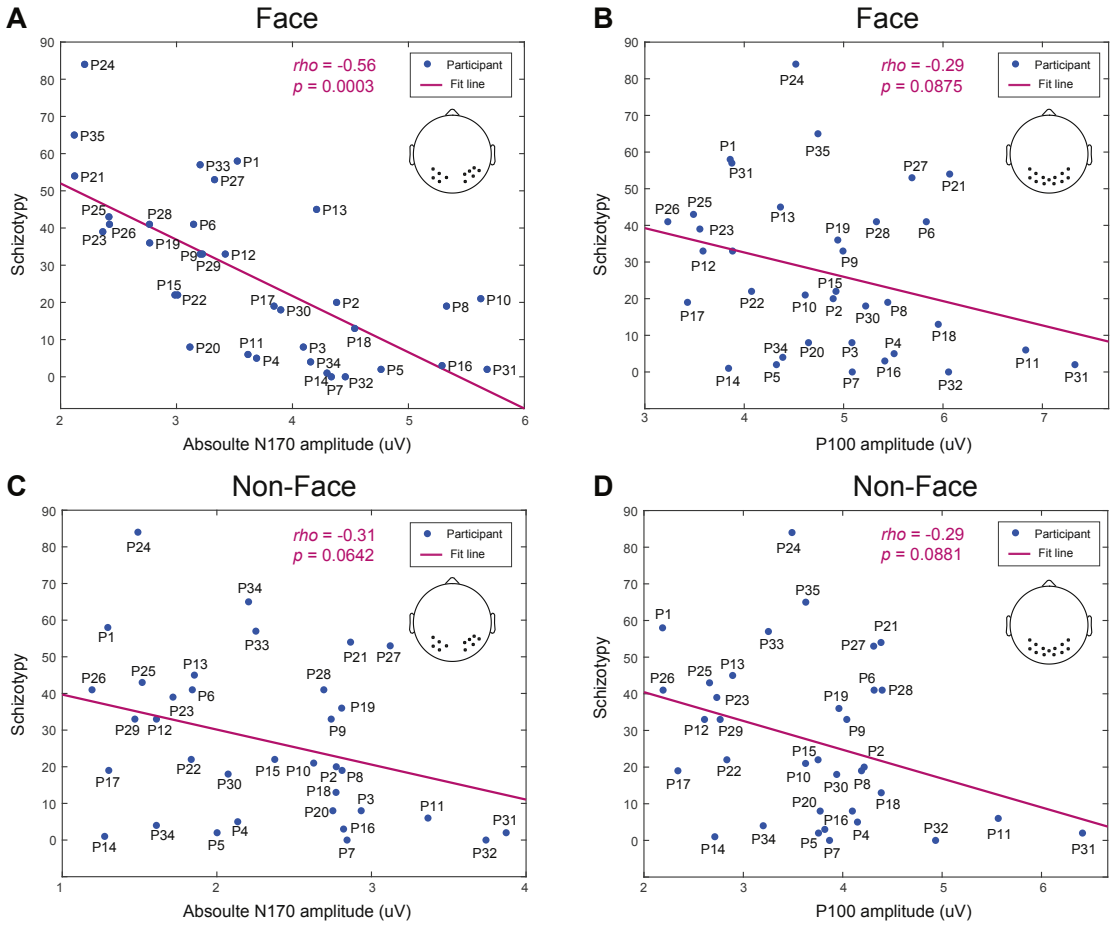

Fig. 4. Correlations between schizotypy scores and ERP components (P100 and N170). Scatter plots of (A) absolute N170 amplitudes averaged over the bi-occipito-temporal regions (B) P100 amplitudes in response to face stimuli averaged over the occipital region. Black dots in topographical maps indicate averaged EEG channels for each ERP component. Blue dots and magenta lines indicate participants and the least-squares fit to the scatter plot. Spearman's rho and p-values are presented for N170 ($rho = -0.56$, $p = 0.0003$) and P100 ($rho = -0.29$, $p = 0.0875$). Scatter plots of (C) absolute N170 amplitude ($rho = -0.31$, $p = 0.0642$) and (D) P100 ($rho = -0.29$, $p = 0.0881$) in response to non-face stimuli are presented in the same manner. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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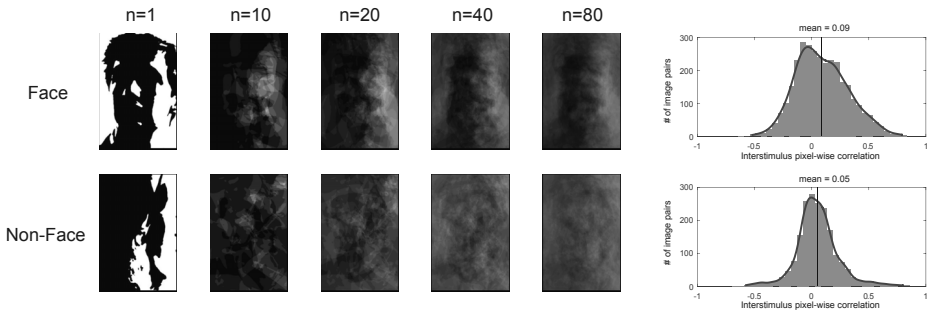

Fig. 5. Inter-stimulus perceptual variance (ISPV) of stimulus images in face and non-face conditions. (A) Progressive pixel-by-pixel averaging of stimulus images in both conditions. The number of stimulus images used in each average is presented (B) Histogram of pixel-by-pixel correlations between stimulus images in each condition (Face: 0.09, Non-Face: 0.05). Red lines indicate fit lines to the histogram using non-parametric kernel-smoothing. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

occipito-temporal regions. Importantly, amplitudes of the N170 components in response to the face stimuli significantly correlated with the schizotypy scores. Thus, our findings support the model that schizotypy is on a continuum with schizophrenia and that the neurophysiological substrate may represent where individuals are located on this continuum.

Other studies of schizotypy have used the schizotypal personality questionnaire (SPQ), a self-report measure to asses schizotypal personality disorder consisting of nine schizotypal traits (74 questions in total); ideas of reference, social anxiety, magical thinking, unusual perceptual experiences, eccentric behavior, no close friends, odd speech, constricted affect, and suspiciousness/paranoid ideation (Raine, 1991). In the SPQ, there are seven questions to assess magical thinking as a positive symptom of schizotypy. In our study, we used the magical ideation scale (Eckblad and Chapman, 1983), which is a detailed measure consisting of 30 questions ("yes" or "no") for magical ideation, since previous studies have shown that the scale is associated with neurocognitive and neurophysiological markers in healthy individuals with schizotypal personality traits (Brugger and Graves, n.d.; Lustenberger et al., 2015; Mohr et al., 2003; Taylor et al., 2002). Moreover, we chose a 6-point rating scale to have a more fine-tuned assessment of magical ideation and to prevent a floor effect. As a result, the chosen scale is difficult to compare with the "yes/no" answer type of the original scale (Eckblad and Chapman, 1983). In an additional analysis, however, to approximate this "yes/no" type of answers, we rated a question as a "yes" if a participant scored>=3 (0,1,2,3,4,5 as possible answers, with 0 for "strongly disagree" and 5 for "strongly agree") and as a "no" if a participant scored < 3. Even though the magical ideation scale represents one positive dimension of schizotypy, Eckblad and Chapman (1983) used it to define participants at higher risk for psychosis. According to this study, participants who scored >2 standard deviations above the mean (4.4% of men in a student population) were considered at higher risk for psychosis. In our study, the participants scored 4.85 questions with "yes" on average (min: 0, max: 19, mean: 4.85, std: 3.65) and five out of 35 participants (14.3%) were considered at higher risk for psychosis (>2 standard deviations above the mean).

The N170 has been considered a face-selective ERP component in healthy humans (Bentin et al., 1996; Rossion, 2014). However, one study claimed that this phenomenon reflects an artifact of uncontrolled ISPV (Thierry et al., 2007). According to this study, a larger physical variance between stimuli caused an increased inter-trial jitter in the N170 for non-face stimuli thus the increased latency jitter reduced ERP amplitude. This study cast doubts on the well-established findings of face processing in human ERP studies. However, follow-up arguments claimed that there were methodological issues with the experimental images used in the study (Bentin et al., 2007; Rossion and Jacques, 2008). A further study also demonstrated that the N170 component is largely preserved after controlling for ISPV by presenting the same stimulus repeatedly (Ganis et al., 2012). In our study, we used a set of Mooney faces to minimize ISPV differences between the face and non-face conditions (Verhallen and Mollon, 2016) and investigated ISPV across the stimulus images in both face and non-face conditions. We found no significant difference in mean correlations of the stimulus images between the face and non-face conditions. After controlling ISPV between the face and non-face conditions, we found larger amplitude of the N170 components over the occipito-temporal region for face stimuli compared to those for non-face stimuli. Thus, our findings of typical N170 components demonstrate that a face perception task using Mooney faces represents a valid measure to investigate the face-selective N170 components.

Impaired face perception has been reported in patients with schizophrenia (Herrmann et al., 2004; Kim et al., 2010; Shin et al., 2007; Soria Bauser et al., 2012). One study compared the N170 between patients with schizophrenia and healthy controls and found significantly lower differences in the N170 between face and building pictures in patients with schizophrenia (Herrmann et al., 2004). Individuals at "ultra-high risk" for psychosis performed more poorly in face discrimination than healthy control (Kim et al., 2010). In addition to face perception, patients with schizophrenia also exhibit a deficit in early visual processing (Butler, 2009; Butler et al., 2005, 2001; Johnson et al., 2005). Patients responded more slowly and less accurately for body perception than healthy controls (Soria Bauser et al., 2012). Together, patients with schizophrenia exhibit a deficit in both early visual processing and face perception. In our study, however, we found significant correlations of reaction times with the schizotypy scores only in the face stimulus condition (Fig. 2A and B). Likewise, we found a significant correlation of N170 amplitude with the schizotypy scores in the face stimulus condition (Fig. 4A). In contrast, the P100, which represents early visual processing, was not significantly correlated with the schizotypy scores (Fig. 4B and D) but trending effects. Thus, our data demonstrate a continuity with schizophrenia in terms of configural face perception and a discontinuity for early visual processing. To date, few studies have investigated neurophysiological correlates in schizotypy (Aichert et al., 2012; Batty et al., 2014; Corlett and Fletcher, 2012). These investigations including our study are important to understand the continuum of psychosis disorders such as schizophrenia.

Our study has several limitations. First, we did not compare the ERP components in healthy controls with patients with schizophrenia. Although we found significant correlations of behavioral

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and neurophysiological data with schizotypy scores, an age- and sex-controlled comparison is needed to further investigate the proposed continuum of schizophrenia symptoms. A follow-up study should include both healthy controls and patients with schizophrenia for a direct comparison. Second, we only assessed positive schizotypy (magical ideation) in our study. Since schizotypy is described by a multidimensional model (positive, negative, and disorganized) (Lenzenweger, 2010), it is necessary to investigate whether our findings could be generalized to negative and disorganized schizotypy. A follow-up study should include assessments for negative and disorganized schizotypy for this reason. Third, the schizotypy scores were not normally distributed ($p < 0.05$, one-sample Kolmogorov-Smirnov test). However, the scores were well-distributed (i.e. little overlap across participants) thus the deviation from a normal distribution was not considered to be a critical factor for this study. Future studies should consider normality and administer additional measures for schizotypy such as the SPQ (Raine, 1991).

In summary, we report the neurophysiological substrate of configural face perception in a non-clinical population who report schizophrenia-like experiences in terms of magical ideation. We found significant correlations of behavioral and neurophysiological data with schizotypy scores. Our findings are consistent with the theory that psychosis exists on a continuum and suggest that non-clinical populations may represent a useful target to investigate the neurobiological basis of schizophrenia by avoiding the confound of psychotropic drug treatment.

Contributors

C.L. and F.F. designed the study protocol. C.L. collected the data. S.A. analyzed the data. S.A. wrote the first draft of the manuscript. S.A., C.L., L.F.J., and F.F. edited the manuscript. All authors contributed to and have approved the final manuscript.

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Declaration of competing interest

S.A., C.L., L.F.J., and F.F. have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.schres.2019.11.005.

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