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Exploring facial emotion perception in schizophrenia using transcranial magnetic stimulation and spatial filtering

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ABSTRACT

Schizophrenia patients have difficulty extracting emotional information from facial expressions. Perception of facial emotion can be examined by systematically altering the spatial frequency of stimuli and suppressing visual processing with temporal precision using transcranial magnetic stimulation (TMS). In the present study, we compared 25 schizophrenia patients and 27 healthy controls using a facial emotion identification task. Spatial processing was examined by presenting facial photographs that contained either high (HSF), low (LSF), or broadband/unfiltered (BSF) spatial frequencies. Temporal processing was manipulated using a single-pulse TMS delivered to the visual cortex either before (forward masking) or after (backward masking) photograph presentation. Consistent with previous studies, schizophrenia patients performed significantly below controls across all three spatial frequencies. A spatial frequency by forward/backward masking interaction effect demonstrated reduced performance in the forward masking component in the BSF condition and a reversed performance pattern in the HSF condition, with no significant differences between forward and backward masking in the LSF condition. However, the group by spatial frequency interaction was not significant. These findings indicate that manipulating visual suppression of emotional information at the level of the primary visual cortex results in comparable effects on both groups. This suggests that patients' deficits in facial emotion identification are not explained by low-level processes in the retino-geniculo-striate projection, but may rather depend on deficits of affect perception occurring at later integrative processing stages.

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1. Introduction

Impairment in social functioning has been extensively documented in schizophrenia and recognized as one of the hallmarks of the disorder (American Psychiatric Association, 1994). Over the last decade, considerable research has focused on social cognition, which is the ability to construct mental representations about others, oneself, and relations between others and oneself. Social cognition is thought to facilitate skillful social interactions and is, therefore, considered a potential determinant of social dysfunction

among people with schizophrenia. An important aspect of social cognition is the ability to perceive emotions. Numerous studies have shown that individuals with schizophrenia are less accurate than healthy controls in their ability to perceive emotions (Addington and Addington, 1998; Gold et al., 2012; Penn et al., 2002; Sergi et al., 2006). Although emotion perception deficits in schizophrenia have been reported across various modalities of expression, most research has focused on affect perception, due to its essential role in adaptive functioning (Butler et al., 2008b; Williams et al., 2009).

An experimental paradigm that has been employed to examine the underlying mechanism of affect perception deficits in schizophrenia, involves a systematic alteration of the spatial frequency of facial stimuli (Pourtois et al., 2005). The effectiveness of this

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manipulation is based on the distinct properties of two neuro-anatomically defined visual pathways, magnocellular and parvocellular (also called M and P), which convey visual information from the retina to the relevant brain areas (Breitmeyer, 1984; Ogmen, 1993). The M pathway is composed of large, rapidly conducting neurons that are specialized for processing quickly changing stimuli and are strongly activated by stimuli that are relatively large (low spatial frequency; LSF), providing initial detection and segregation of objects from the background (Bar et al., 2006). The P pathway, on the other hand, is composed of smaller, more slowly conducting neurons that are specialized for processing slowly changing, clearly defined patterns and are activated by relatively small (high spatial frequency; HSF) stimuli, coding the details of objects (Butler et al., 2001; Merigan and Maunsell, 1993). Thus, when extracting emotional information from faces, the M-pathway quickly processes coarse emotional LSF information through relatively direct projections to subcortical regions, such as the amygdala and ventral striatum, whereas the P-pathway processes the slower, fine-grained HSF visual information about faces in general, subserved by the fusiform cortex (Vuilleumier et al., 2003).

Spatial frequency of stimuli can be manipulated using various filtering techniques. Typically, normal, unfiltered faces that have the entire broadband spatial frequency (BSF) are compared with filtered HSF faces, which contain mainly HSF information, and filtered LSF faces, which contain mainly LSF information. Studies that examined affect perception deficits in schizophrenia by manipulating the spatial frequency of simple visual and facial stimuli suggested M pathway-driven deficit (Butler et al., 2001; Clark et al., 2013; Lee et al., 2011). For example, several studies found that when spatial frequency of stimuli was manipulated, schizophrenia patients performed differentially worse in the LSF condition (Butler et al., 2001, 2008b). Other studies reported that for schizophrenia patients perceived emotions in HSF faces differ from those in LSF faces (McBain et al., 2010). Patients may even ignore information entirely when the faces obtain only very low spatial frequencies (Clark et al., 2013).

Another related aspect of affect perception, which did not receive much attention, is the temporal processing of facial emotion. An experimental manipulation of temporal processing of emotion perception can be achieved through visual suppression with a single-pulse transcranial magnetic stimulation (TMS; Amassian et al., 1989; Corthout et al., 2002; Pascual-Leone and Walsh, 2001). In TMS, a bank of capacitors is rapidly discharged into an electric coil to produce a magnetic field pulse. When the coil is placed near the head, the magnetic field induces an electric field in the underlying region of the brain, which, when sufficiently intense, depolarizes cortical neurons, generating action potentials (Barker and Jalinous, 1985). Such stimulation is a safe way to temporarily alter cortical function and can be employed to effectively suppress visual perception with temporal precision (Amassian et al., 1989; Antal et al., 2002).

In a recent study, we examined the processes underlying emotion perception in healthy individuals by employing both spatial frequency alteration through spatial filtering and visual suppression through TMS (Rassovsky et al., 2013). The integration of these procedures into a single experimental paradigm enabled us to systematically investigate the interactive effects of spatial and temporal properties on affect perception. Specifically, we employed an emotion identification task with standard spatial frequency filtering techniques (Butler et al., 2001; Pourtois et al., 2005; Vuilleumier et al., 2003), while also systematically manipulating the temporal processing of visual stimuli by administering a single-pulse TMS to the visual cortex.

Results indicated that LSF information might play a greater role than HSF information in emotional processing. However, the

quickest perceptual processing of facial emotion information was afforded only when the broadband of spatial frequencies was intact. These findings were interpreted within the basic vision framework of the dual-channel model of retino-cortical dynamics (Breitmeyer, 1984; Ogmen, 1993; Ogmen et al., 2003). A current formulation of this model suggests that conscious visual processing requires not only a fast feedforward sweep of information from the retina to and through the visual cortex, but also an iterative feedforward-feedback reentrant exchanges of neural signals among the different brain levels (Di Lollo et al., 2000; Pascual-Leone and Walsh, 2001). Studies examining visual suppression through single-pulse TMS suggest that forward masking reflects the suppression of the early responses in V1 activating the cortical feedforward sweep, whereas backward masking reflects mostly the later V1 responses due to reentrant activation from post-V1 levels (Breitmeyer et al., 2004; Corthout et al., 1999; Lamme and Roelfsema, 2000). It appears then that in the aforementioned study (Rassovsky et al., 2013), BSF face stimuli were suppressed more with forward than backward TMS masking, suggesting greater reliance on the feedforward process, whereas the filtered HSF faces were most strongly suppressed in the backward masking components, demonstrating the increasing involvement of reentrant activation from post-V1 levels.

In the present study, we examined whether the speed of processing advantage of unfiltered faces seen in healthy individuals would also be found in schizophrenia patients. Additionally, if, as suggested previously, schizophrenia patients have a differential impairment in the M pathway, we would expect significant group by spatial frequency interactions. Finally, we sought to examine whether patients would also demonstrate enhanced susceptibility to TMS masking given their well-documented evidence of visual masking deficits (Braff et al., 1991; Rassovsky et al., 2004; Rund, 1993).

2. Method

2.1. Participants

Participants included schizophrenia patients and healthy controls. Patients were recruited through outpatient clinics at the UCLA and the VA Greater Los Angeles Healthcare System and through presentations in the community. All patients were administered the Structured Clinical Interview for DSM-IV (SCID-P) (First et al., 1997) and met the DSM-IV diagnostic criteria for Schizophrenia (American Psychiatric Association, 1994). All interviewers were trained to administer the SCID by the Diagnostic Core of the Mental Illness Research, Education, and Clinical Center (MIRECC) Treatment Unit, and were required to obtain a Kappa of 0.75 for key psychotic and mood items before proceeding to interview participants independently. Patients were excluded if they had an identifiable neurological condition, IQ < 70 based on medical records, or met criteria for substance dependence in the last six months.

The healthy control group was recruited through online advertisements. They were administered the SCID, as well as selected sections of the Structured Clinical Interview for DSM-IV Axis II Disorders. Exclusion criteria were the same for controls as for patients, with the additional exclusion of histories of any psychotic disorders (including family history in first-degree relatives), any diagnosis in the schizophrenia spectrum, recurrent major depression, bipolar disorder, history of substance dependence, or substance abuse in the past month. The data for the control group were published previously (Rassovsky et al., 2013) and used in the present study as comparison for the new and unpublished data of the schizophrenia patients.

The present study included 25 individuals with schizophrenia (68% males) and 27 healthy controls (78% male). Mean age for patients was 45.2 ($SD = 9.32$; range = 20–55) and for controls 41.8 ($SD = 7.93$; range = 23–55). Mean education for patients was 12.8 ($SD = 1.80$; range = 8–16) and for controls was 14.3 ($SD = 1.79$; range = 10–16). All participants showed corrected visual acuity of at least 20/30 and gave written informed consent after receiving a full explanation of the research according to procedures approved by the Institutional Review Board of UCLA.

2.2. Equipment

TMS was delivered by a Magstim Rapid magnetic stimulator (Magstim, Inc), which produces biphasic pulses using a circular coil with a diameter of 9 cm. The coil was always held at a 90° angle, perpendicular to the meridian along the sagittal plane of the subject's skull (Antal et al., 2002; Corthout et al., 1999). The bottom of the coil was placed tangential to the curve of the skull on the spot of interest along the grid. TMS intensity was held constant at 70% of the maximum stimulator output.

2.3. Procedures

Two TMS procedures were conducted: a “Hotspot” procedure and an emotion identification procedure. The Hotspot procedure is described in more detail elsewhere (Rassovsky et al., 2013). Briefly, it was designed to empirically determine the optimal positioning of the TMS coil to identify the location of maximal visual suppression. Once the optimal positioning of the coil was determined, we maintained the TMS coil at that location for collecting data throughout the second procedure, involving affect perception (see Fig. 1). It should be noted that most studies determine coil positioning using phosphene time (Antal et al., 2002; Corthout et al., 1999; Kammer, 1999; Pascual-Leone and Walsh, 2001). Phosphenes are inherently subjective and require a great deal of preparation even in healthy volunteers (Deblieck et al., 2008; Kammer et al., 2001; Rassovsky et al., 2013), and it was even more difficult to implement this procedure in our schizophrenia sample. Therefore, in the present study, we have implemented the hotspot procedure and no longer inquired about phosphenes. Based on our previous studies, 70% of the maximum stimulator output was substantially below the mean for subjects to reliably detect phosphenes.

The stimuli for the emotion identification procedure consisted of black and white still photographs (2 cm × 3 cm) displaying faces with four basic facial emotions (happy, sad, angry, and afraid), derived from the Karolinska Directed Emotional Faces set (KDEF, Lundqvist, D., Flykt, A., and Ohman, A.; Dept. of Neurosciences,

Karolinska Hospital, Stockholm, Sweden, 1998). We randomly selected 10 actors (5 males and 5 females) displaying the four different emotions (happy, sad, angry, and afraid) from the KDEF set, resulting in a total of 40 different face stimuli. The face pictures were trimmed to exclude the hair and non-facial contours. This task was programmed and run using e-prime software (Psychology Software Tools Inc., USA) and was administered on a Dell Pentium computer with a 17 inch (43 cm) Sony Multiscan 200 PS monitor, driven at 160 Hz. Stimuli were centrally presented as dark on a light background. Participants were asked to identify the emotional expression of face stimuli by pressing one of four labeled keys on the keyboard, such that chance level performance was 25%.

For the HSF faces stimuli, BSF stimuli were filtered using a high-pass filter (≥ 10 cycles/degree), attenuating lower spatial frequencies. Conversely, for the LSF face stimuli, a low-pass filter (≤ 6 cycles/degree) attenuated higher spatial frequencies (see Fig. 1). Filtering was performed in Matlab (The Mathworks, Natick, MA) using second order Butterworth filters. HSF stimuli bias the system toward P pathways, whereas LSF faces bias the system toward M pathways.

The temporal characteristics of affect perception were examined by manipulating the timing of a single-pulse TMS. Intervals between target and TMS pulse were measured by stimulus onset asynchronies (SOAs), spaced in 50 ms increments from –150 to +150 ms (negative SOAs indicate forward masking, and positive SOAs indicate backward masking). Prior to target presentation, a fixation symbol (a small cross) was presented for 200 ms. The target was presented for 200 ms, followed by an inter-trial interval of 5000 ms, during which participants made their response. This interval was sufficiently long to preclude repetitive TMS suppression, which typically relies on TMS pulses presented one every second (see Fig. 1). These parameters were similar to those used in prior studies of affect perception (Holmes et al., 2005; Pourtois et al., 2005; Vuilleumier et al., 2003). Participants were seated 1 m away from the computer monitor, and the TMS coil was positioned at the hotspot. To establish a baseline performance, a block of 96 trials without a TMS pulse was administered at the beginning of the procedure. The order of stimuli administration was fully randomized across the 10 actors, four emotions, three spatial frequencies, and six SOAs (3 forward and 3 backward), with a total of 96 trials per SOA. In all, there were 7 blocks (no-TMS, 3 forward, and 3 backward), and subjects were instructed to take breaks after each block.

2.4. Data analysis

Analyses of variance (ANOVA) with repeated measures were conducted to examine the effects of TMS, spatial frequency, and

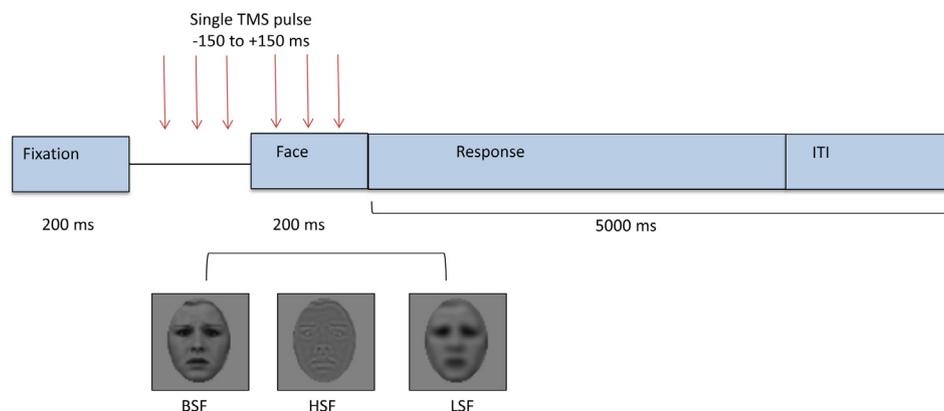


Fig. 1. Schematic representation of the study protocol. BSF = Broadband spatial frequency; HSF = High spatial frequency; LSF = Low spatial frequency.

SOAs. Diagnosis (schizophrenia vs. control) was the between-subjects factor. The within-subjects design was structured as a 3 (spatial frequency: high vs. low vs. broad) by 3 (SOAs: forward masking vs. backward masking vs. no-TMS) ANOVA. The primary interest was in the spatial frequency by group and SOA by group interactions. For all non-significant findings, the results of post-hoc power analyses are presented as the critical N, i.e., the sample size required for 80% power to detect an effect of this size. In cases where the estimated non centrality parameter is negative the critical N is reported as NA and observed power as < 0.05 , as in this case the pattern of results will never yield a significant result. Given the lack of significant differences within the forward and backward masking components, we averaged these components separately across SOAs. Analyses of the full experimental designs including all SOAs (3 spatial frequencies by 7 SOAs by 2 groups), as well as the separate emotions (3 spatial frequencies by 7 SOAs by 4 emotions by 2 groups), are provided as a [Supplementary material](#).

3. Results

3.1. Hotspot procedure validation

To validate our hotspot positioning, we compared performance on letter identification with TMS (at 100 ms SOA) against a no-TMS condition, with the coil held over the determined hotspot. The magnitude of the difference between the means was very large for both patients (Cohen's $d = 3.84$) and controls (Cohen's $d = 3.04$), demonstrating the effect of visual suppression through TMS at the hotspot by both groups. Pairwise t -test analyses indicated that schizophrenia patients performed significantly worse in the TMS vs. no-TMS conditions ($M = 11.9$, $SD = 4.11$ vs. $M = 24.5$, $SD = 2.16$), $t(24) = 17.8$, $p < 0.001$. Similarly, healthy controls performed significantly worse in the TMS vs. no-TMS conditions ($M = 14.3$, $SD = 4.44$ vs. $M = 25.3$, $SD = 2.53$), $t(26) = 12.3$, $p < 0.001$.

3.2. Group comparison on facial emotion identification task

Repeated measures ANOVA revealed a significant between-subjects main effect, such that schizophrenia patients ($M = 0.50$, $SD = 0.12$) performed significantly worse than controls ($M = 0.58$, $SD = 0.12$) across all conditions ($F(1,50) = 5.15$, $p = 0.028$, $f^2 = 0.10$).

There were also significant main effects of spatial frequency ($F(2,100) = 99.5$, $p = 2.04E-17$ 0.01, $f^2 = 1.9$) and SOA ($F(2,100) = 41.7$, $p = 1.25E-9$, $f^2 = 0.84$). Pairwise comparisons of the main effect of spatial frequency indicated that performance in the BSF condition was significantly better than in either the LSF condition ($p = 2.31E-6$) or the HSF condition ($p = 2.04E-17$). Additionally, participants performed significantly better in the LSF than in the HSF condition ($p = 9.78E-17$). Pairwise comparisons of the main effect of SOA revealed that participants performed significantly better in the no-TMS condition than in the two TMS conditions ($p = 2.01E-7$ and $p = 1.25E-9$, respectively), confirming that TMS had a pronounced masking effect, but no significant differences were detected between the forward and backward TMS masking components ($p = 0.154$).

Consistent with our previous study (Rassovsky et al., 2013), we found a significant spatial frequency by SOA interaction ($F(4,200) = 4.17$, $p = 0.003$, $f^2 = 0.08$). However, contrary to expectations, the spatial frequency by group interaction was not significant ($F(2,100) = 1.60$, $p = 0.206$, $f^2 = 0.03$, observed power = 0.16, Critical N: 187), indicating that the pattern of performance across the three spatial frequencies was similar for both groups. The SOA by group interaction was also not significant ($F(2,100) = 0.58$, $p = 0.559$, $f^2 = 0.01$, observed power < 0.05 , Critical N: NA), indicating that the masking effect of TMS was similar across SOAs for both groups. Finally, the three-way, spatial frequency by SOA by group interaction was also not significant ($F(4,200) = 0.16$, $p = 0.956$, $f^2 < 0.01$, observed power < 0.05 , Critical N: NA). These results are shown separately for patients (left panel) and controls (right panel) in Fig. 2.

Given the lack of significant interactions by group, we further examined the significant spatial frequency by SOA interaction by merging the schizophrenia and control samples. A 3×3 repeated measures (spatial frequency by SOA) ANOVA revealed significant main effects of spatial frequency ($F(2,102) = 98.7$, $p = 1.40E-24$, $f^2 = 1.9$) and SOA ($F(2,102) = 42.4$, $p = 4.02E-14$, $f^2 = 0.83$), as well as a significant spatial frequency by SOA interaction, ($F(4,204) = 4.26$, $p = 0.002$, $f^2 = 0.08$). Pairwise comparisons of the main effects of spatial frequency and SOA revealed a pattern identical to that described above. Pairwise comparisons of the interaction effect revealed a differential performance pattern across the three spatial frequencies. Specifically, in the BSF condition, participants

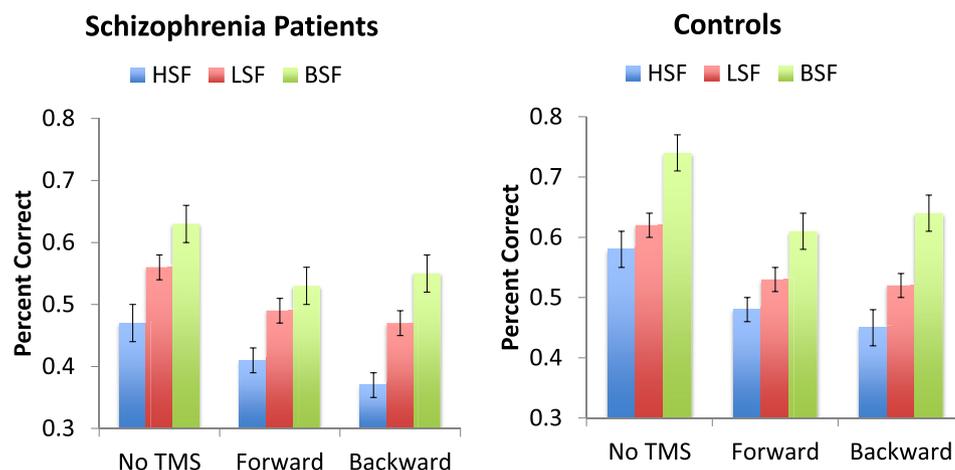


Fig. 2. Schizophrenia patients' (left panel) and controls' (right panel) performance in the different spatial frequency conditions across baseline (no TMS), forward masking, and backward masking. BSF = Broadband spatial frequency; HSF = High spatial frequency; LSF = Low spatial frequency. ANOVA with repeated measures revealed a significant between-subjects effect, such that schizophrenia patients ($M = 0.50$, $SD = 0.12$) performed significantly worse than controls ($M = 0.58$, $SD = 0.12$) across all conditions ($F(1,50) = 5.15$, $p = 0.028$, $f^2 = 0.10$). There were also significant main effects of spatial frequency ($F(2,100) = 99.5$, $p = 2.04E-17$ 0.01, $f^2 = 1.9$), SOA ($F(2,100) = 41.7$, $p = 1.25E-9$, $f^2 = 0.84$), as well as a spatial frequency by SOA interaction ($F(4,200) = 4.17$, $p = 0.003$, $f^2 = 0.08$). None of the interactions by group were significant.

performed significantly better in the no-TMS component than in either the forward TMS masking components ($p = 1.04E-6$) or the backward TMS masking components ($p = 5.81E-5$). Furthermore they performed significantly better in the backward than forward TMS masking components ($p = 0.002$). Conversely, in the HSF condition, although participants still performed in the no-TMS component significantly better than in either the forward ($p = 2.19E-5$) or backward ($p = 1.93E-9$) TMS masking components, they demonstrated a reversed pattern, performing significantly better in the forward than backward TMS masking components ($p = 4.44E-4$). Finally, in the LSF condition, participants again performed in the no-TMS component significantly better than in either the forward ($p = 2.68E-5$) or backward ($p = 2.97E-7$) TMS masking components, but no significant differences were detected between the forward and backward TMS masking components ($p = 0.135$; see Fig. 3). Taken together with the aforementioned results, this suggests that schizophrenia patients demonstrate general deficits in facial emotion perception, compared with controls, and that visual suppression with TMS affects both groups to the same degree.

4. Discussion

In the present study, we examined facial emotion perception in schizophrenia by systematically altering the spatial frequency of stimuli and suppressing visual processing with temporal precision using TMS. Consistent with other studies of emotion perception in schizophrenia (Clark et al., 2013; Lee et al., 2011; McBain et al., 2010), we found that schizophrenia patients performed significantly worse than controls across all three spatial frequency conditions. Importantly, both groups responded to our empirically-based Hotspot technique for TMS coil positioning (Mulleners et al., 2001; Rassovsky et al., 2013), suggesting effective visual suppression with single-pulse TMS. However, in contrast to our hypothesis, no significant group by spatial frequency interaction was found, indicating that the pattern of performance across the three spatial frequencies was similar for both schizophrenia

patients and controls (see Fig. 2). It should be noted that this finding is not necessarily inconsistent with studies suggesting a differential, M pathway-driven, impairment in schizophrenia (Butler et al., 2001, 2008a; Schechter et al., 2005). The present study did not examine early visual processing deficits in schizophrenia or its contribution to later perceptual dysfunction. Instead, the present findings suggest that deficits in facial emotion identification in schizophrenia are not explained by low-level processes in the retino-geniculo-striate projection, but may rather depend on deficits of affect perception occurring beyond the primary visual cortex.

Similar to our previous study (Rassovsky et al., 2013), we found that in the BSF condition both groups performed significantly worse in the forward than backward masking component, whereas the opposite pattern was detected in the HSF condition, with no significant differences between the forward and backward masking components in the LSF condition (see Fig. 3). These findings are consistent with other TMS studies of early visual processing, suggesting that TMS forward masking suppresses retino-cortical feed-forward sweep, whereas backward TMS visual suppression reflects mostly the responses after V1, due to disruption of reentrant processing levels (Corthout et al., 1999). For both groups in the present study, BSF stimuli were suppressed less with backward than forward TMS masking, suggesting that the rapid transmission of BSF stimuli allowed the percepts to escape the masking effects. The filtered HSF faces, which were transmitted more slowly, were more strongly affected by backward masking, presumably because processing was still taking place at the time the TMS pulse was applied (Breitmeyer et al., 2004; Corthout et al., 1999). The lack of temporal advantage for the LSF faces may indicate that coarse LSF information may be necessary, but not sufficient, for efficient affect perception.

Contrary to our hypothesis, we found that visual suppression with TMS affected both groups to the same degree. This finding indicates that patients did not have differential susceptibility to the TMS pulse than controls, above and beyond their impairment in facial emotion processing. Patients do show increased susceptibility to visual masking (Braff et al., 1991; Green and Walker, 1984; Rassovsky et al., 2004; Rund, 1993). Of course, one potential limitation that might account for the lack of significant interactions by group is the low statistical power due to the relatively small sample size. However, the very small effect sizes, further validated by *post-hoc* power analyses (large Critical Ns), demonstrated that these findings were not due to lack of statistical power. These findings therefore could possibly be accounted for by the differences between TMS masking and visual masking procedures. Visual masking involves rapid sequential presentation of visual stimuli that are difficult for patients to decipher, whereas in TMS masking stimuli are suppressed by temporarily altering cortical function. Furthermore, whereas visual masking studies involve stimulus competition starting at the level of the retina, TMS was administered at the level of the occipital cortex. Thus, in addition to affecting visual processing of M and P neurons at cortical levels, as achieved by TMS (Amassian et al., 1989; Antal et al., 2002; Pascual-Leone and Walsh, 2001), visual masking may also tap emotional processing that is subserved by subcortical activity directly from the retina to the superior colliculus and then through the pulvinar to the amygdala (de Gelder et al., 2011; Dolan, 2002; Tamiotto and de Gelder, 2010; Vuilleumier et al., 2003). Additional studies are needed to examine the masking mechanisms underlying these procedures (e.g., applying TMS pulse higher up along the ventral pathway) and to make direct comparisons between visual and TMS masking.

In summary, this is the first study to directly examine the temporal aspects of affect perception deficits in schizophrenia. The present findings suggest that schizophrenia patients' deficits in facial emotion identification are not explained by low-level processes in the retino-geniculo-striate projection. Instead, they seem

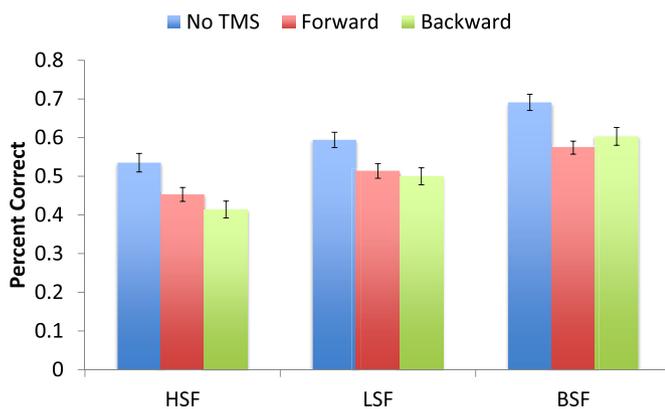


Fig. 3. Evaluation of the spatial frequency by SOA interaction after merging the schizophrenia and control samples. BSF = Broadband spatial frequency; HSF = High spatial frequency; LSF = Low spatial frequency. ANOVA with repeated measures revealed a significant spatial frequency by masking condition interaction, ($F(4,204) = 4.26, p = 0.002, \eta^2 = 0.08$). Pairwise comparisons of the interaction effect indicated that participants performed significantly better in the no-TMS masking condition than in the forward or backward masking conditions, across all three spatial frequencies. However, a differential performance pattern was found for the forward and backward masking components for the three spatial frequency conditions. Specifically, in the BSF condition, participants performed significantly better in the backward than forward TMS masking components ($p = 0.002$). Conversely, in the HSF condition, they performed significantly better in the forward than backward TMS masking components ($p = 4.44E-4$). In the LSF condition, no significant differences were detected between the forward and backward TMS masking components ($p = 0.135$).

to depend on deficits of affect perception, occurring at later integrative processing stages. This conclusion is consistent with recent studies that employed color priming and visible persistence with very simple stimuli, showing that schizophrenia patients appear to have intact processing prior to visual cortex (Green et al., 2011; Hahn et al., 2011; Jahshan et al., 2012). The current paper extended this question to affect perception in schizophrenia and arrived at a similar conclusion that problems in processing occur at later (post primary visual cortex) stages.

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Contributors

Yuri Rassovsky conducted the study and wrote the first draft of the manuscript. Junghee Lee, Allan Wu, Marco Iacoboni, Bruno Breitmeyer, and Michael Green assisted with study conceptualization, data interpretation, and manuscript preparation. Gerhard Hellemann assisted with statistical analysis, and Poorang Nori assisted with data collection, management, and analyses.

Conflict of interest

All authors declare that they have no conflicts of interest arising from this manuscript.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jpsychires.2014.07.017>.

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