

Repetitive transcranial magnetic stimulation over right intraparietal sulcus enhances emotional face processing in the left visual field

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The frontoparietal network is largely involved in the process of emotional face perception and attention. However, how the right intraparietal sulcus (rIPS) may guide this process is not yet established. The effect of repetitive transcranial magnetic stimulation (rTMS) over the intraparietal sulcus in the perception of emotional faces is still unclear. To address that, we applied a modified Posner attention task where participants discriminated backward-masked emotional faces at the valid side and delivered 10-Hz rTMS over rIPS and vertex. Behavioral results demonstrated a processing advantage for emotional faces compared with neutral ones. rTMS over the rIPS caused a significant emotional difference (emotional-neutral faces) in the left visual field. This result suggests that rTMS over the rIPS enhances emotional face processing in the left visual field compared with neutral faces. The stimulation of rIPS possibly enhanced the functional connectivity between intraparietal sulcus and superior temporal sulcus, and visual cortex. It helps the emotional faces grab attentional resources and

Introduction

Neurocognitive models have demonstrated an essential role for the frontoparietal network (prefrontal cortex and intraparietal sulcus, IPS) in the perception of emotional stimuli [1,2]. Meta-analysis confirms enhanced neural activation of the frontoparietal attention network when responding to emotional relative to neutral stimuli [3]. Early processing of emotional information may interfere with visual processing through emotion-attention hubs that functionally connect with prefrontal and parietal cortices [4]. Some guidance effects, mediated by the frontoparietal attention network, may occur in parallel to this early processing [5]. Recent research has focused on understanding how brain regions (amygdala and fusiform gyrus) that encode emotional and facial information interact with the prefrontal cortex [6]. Some previous research showed the activation of right intraparietal sulcus (rIPS) during both emotional face perception tasks [7,8] and attention tasks [9] and suggest an essential role for this region in directing spatial attention and emotion perception [2]. However, the guidance effect of rIPS on emotional face processing has been studied relatively less. We aimed to understand the role of rIPS in the interaction between these in this study using repetitive transcranial magnetic stimulation (rTMS).

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Applying rTMS over the parietal cortex in healthy individuals normally disrupts the interhemispheric balance in visuospatial attention [10,11]. In TMS-EEG studies, 20-Hz rTMS was applied for 150 ms at the same time as the presentation of spatial cues in a Posner task [12–14]. The results indicated that rTMS over rIPS before visual target presentation disrupts the allocation of attention in endogenous spatial orienting, especially in the hemisphere contralateral to the locus of attention. However, the whether rTMS over the IPS would influence emotional face perception is still unclear.

The motivation for this study was to investigate the role of the rIPS in emotional face perception. We chose the endogenous attention Posner task in which participants are cued to covertly direct their attention to the peripheral location by an arrow and to discriminate the masked emotional faces. We hypothesized that rTMS over the rIPS would produce an imbalance between the left visual field (VF) and right VF, as the right hemisphere demonstrates dominance for attention and emotion in humans across both lesion and imaging evidence [15]. This interference of one side might cause a hemispheric neglect effect for its inability to orient attention towards the contralateral side. Moreover, there has been evidence to suggest that the recognition of emotional faces is

significantly better than that of neutral faces owing to potential emotion bias [16]. We hypothesized that a similar emotional effect would appear in the rIPS-TMS stimulation.

Participants and methods

Participants

Twenty-five healthy right-handed participants (13 females, aged 21 ± 2.35 , mean \pm SD) with normal or corrected-to-normal vision participated in the study. All participants had no history of neurological and psychiatric diseases. All participants filled out the Edinburgh Handedness Inventory before the experiment [17]. All were capable of discriminating between emotion stimuli (fearful, happy, and neutral faces) in this experiment. Nine participants were excluded from the data analysis owing to the threshold of sensitivity during stimulus detection ($d' = 1$). All participants gave written informed consent before the experiment and received monetary rewards after the experiment. The study was approved by the University of Electronic Science and Technology of China Ethics Committee. The methods were carried out in accordance with the approved guidelines, and all experiments conformed to the Declaration of Helsinki.

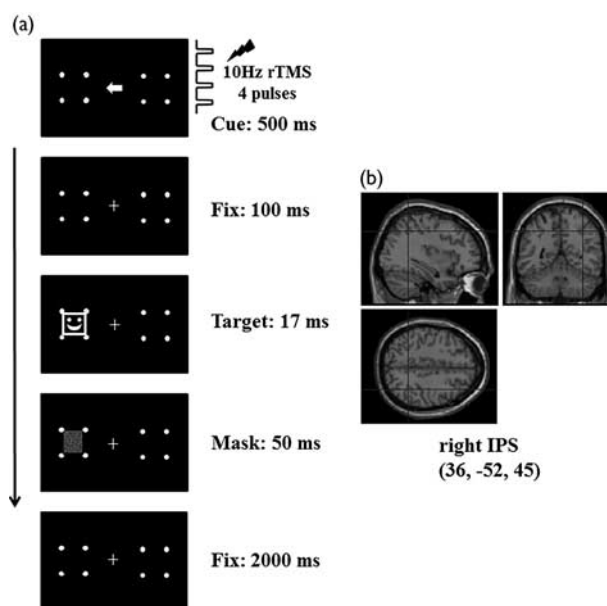
Experiment procedures

Before experimentation, the participants were asked to rate all face stimuli valence from 1 to 5 (1 being the most negative and 5 being the most positive). The participants then completed seven blocks, with the first block being a training block. Each block consisted of 96 trials. Each trial began with the presentation of a visual cue that randomly pointed to either the left or right VF (see illustration in Fig. 1a). After a brief break (100 ms), a target face, with either a fearful, happy, or neutral expression, was presented to the left or right side. The faces appeared at the valid side in 75% of the trials, and at the invalid side in 25% of the trials. Immediately after target presentation, a mask flashed briefly at the same location. Participants were instructed to maintain fixation on a cross-displayed at the center of the screen. They were told to discriminate the facial expressions of the valid targets by clicking the left mouse for a confident judgment of the facial expression, and the right mouse to express uncertainty about the target.

TMS setup

We applied rTMS over the rIPS and the vertex. Stimulation was delivered using an air-cooled, figure-eight coil, connected to a Magstim super rapid magnetic stimulator (Magstim Company Ltd., Whitland, UK). The rTMS train was delivered at the onset of the cue stimulus (see in Fig. 1a) based on the following parameters: 400 ms duration, 10-Hz frequency, and intensity set at 40% of the maximal machine output. Participants completed two separate rTMS sessions (vertex and rIPS), each performed on a different day. TMS stimulation was localized in individual participants using a frameless stereotaxy system. Landmarks on the participants' head were coregistered to participant's own

Fig. 1



Experiment paradigm and transcranial magnetic stimulation. (a) Experiment procedure of a modified Posner task. The participants should press the right mouse if they can confidently discriminate the emotional faces, and the left mouse if they are unsure about the expression of faces. We applied the four rTMS pulses from the onset of cues. (b) rTMS stimulation site and its Montreal Neurological Institute coordinate. IPS, intraparietal sulcus; rTMS, repetitive transcranial magnetic stimulation.

structural MRI (14 participants) or a standard MRI template provided by the TMS system. Stimulation sites were defined using coordinates from a previous spatial attention study [18]: rIPS ($x = 36$, $y = -52$, $z = 45$) (see in Fig. 1b). The location of stimulation was automatically identified on each participant's scalp using the navigation system. The TMS coil was positioned on an individual basis, taking into account participants' scalp shape. An additional control site positioned over the vertex was used to test for any non-specific effects of TMS on task performance.

Data analysis

All behavioral results were normally distributed (Kolmogorov–Smirnov test values > 0.05). We then applied repeated-measures analyses of variance (ANOVAs) to reaction time (RT) and accuracy (ACC) results (Bonferroni's corrected). We performed Mauchly's sphericity test for compound symmetry. When the compound symmetry was not satisfied, we used the Greenhouse–Geisser correction. We also used paired samples *t*-tests (two tailed) for simple contrasts. In all tests, we used an α threshold of 0.05 for assessing statistical significance.

Results

Stimuli ratings

All participants completed the stimuli valence ratings before the experiment. Ratings of emotional stimuli differed

significantly across valence [$F(2,30)=809.763$, $P<0.001$, $\eta^2=0.982$]. Happy stimuli (mean \pm SD: 4.31 ± 0.33) yielded higher valence ratings relative to neutral stimuli (2.89 ± 0.22) [$t(15)=26.839$, $P<0.001$] and fearful stimuli (1.76 ± 0.25) [$t(15)=31.269$, $P<0.001$]. Neutral stimuli displayed significantly higher valence ratings compared with fearful stimuli [$t(15)=21.977$, $P<0.001$]. The rating results suggest the valid discrimination of emotional face stimuli.

Behavioral results

We examined RT and ACC of the stimuli as a function of Stimulation Site (vertex and rIPS), VF (left and right), and Emotion (happy, fearful and neutral) to perform two $2 \times 2 \times 3$ repeated-measures ANOVAs.

For RT, only a main effect of Emotion [$F(2,30)=43.231$, $P<0.001$, $\eta^2=0.742$] was found. It indicated that the reactions to fearful faces and happy faces were significantly faster than neutral faces [happy < neutral, $t(15)=8.093$, $P<0.001$; fearful < neutral, $t(15)=6.056$, $P<0.001$].

For ACC, there was a significant main effect of VF [$F(1,15)=5.447$, $P=0.034$, $\eta^2=0.266$] and Emotion [$F(1,15)=10.373$, $P=0.003$, $\eta^2=0.409$]. We only found a significant interaction between Stimulation Site, VF, and Emotion [$F(2,30)=4.268$, $P=0.044$, $\eta^2=0.222$]. We separated the Stimulation Site (vertex and rIPS) into two 2×3 ANOVA for a better understanding of the interaction.

Vertex-TMS effect

The 2×3 ANOVA revealed only a main effect of Emotion [$F(2,30)=5.922$, $P=0.022$, $\eta^2=0.284$]. There was no main effect of VF [$F(1,15)=2.071$, $P=0.171$, $\eta^2=0.121$]. This indicated that vertex-TMS stimulation yielded no significant difference between performance in each VF (see in Fig. 2a). Performance towards happy faces was much better than toward the neutral faces [happy > neutral, $t(15)=3.082$, $P=0.008$; fearful > neutral, $t(15)=1.904$, $P=0.076$]. The VF-Emotion interaction was not significant [$F(2,30)=1.979$, $P=0.156$, $\eta^2=0.117$].

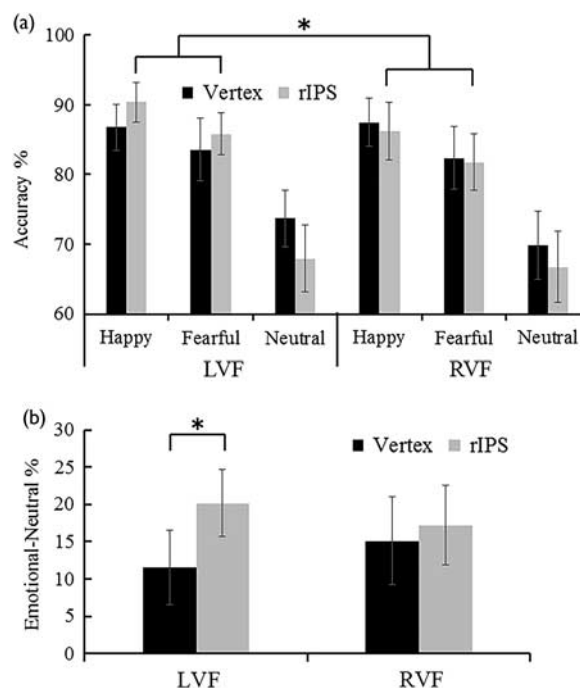
rIPS-TMS effect

The comparison of ACC revealed main effects of VF [$F(1,15)=4.755$, $P=0.046$, $\eta^2=0.241$] and Emotion [$F(2,30)=13.682$, $P=0.001$, $\eta^2=0.477$] (see in Fig. 2a). Similarly, performance on emotional faces was much better than on neutral faces [happy > neutral, $t(15)=4.261$, $P=0.001$; fearful > neutral, $t(15)=3.321$, $P=0.005$]. Importantly, we also observed a significant performance difference between the VFs [left > right, $t(15)=2.181$, $P=0.046$]. The VF-Emotion interaction did not reach the significance level [$F(2,30)=1.286$, $P=0.285$, $\eta^2=0.079$].

Emotion effect

To further investigate the influence of the site of stimulation on the emotion effect, we examined ACC difference (emotional-neutral) as a function of Stimulation Site (vertex and rIPS) and VF (left and right), and performed a 2×2

Fig. 2



Behavioral results. (a) The accuracy of correctly discriminating emotional faces at the valid side. (b) Emotion effect or difference (emotional-neutral) in face perception. LVF, left visual field; rIPS, right intraparietal sulcus; RVF, right visual field. * $P<0.05$.

repeated-measure ANOVA. There was a significant interaction between Stimulation Site and VF [$F(1,15)=4.9$, $P=0.043$, $\eta^2=0.246$]. A paired t -test showed a significant difference between Stimulation Site on the left VF [$t(15)=2.374$, $P=0.031$] (see in Fig. 2b). This indicated that rIPS stimulation enhanced the emotional difference in the left VF.

Discussion

In this study, we examined the influence of the right IPS on emotional face processing. The behavioral results demonstrated a processing advantage over emotional faces compared with neutral ones. rTMS over the rIPS made emotional faces better to discriminate, but only in the left VF. This suggested that interference of the rTMS over the right IPS enhances emotional face processing in the left VF compared with neutral face processing.

Our current results are consistent with anticipation. We found significantly better perception of emotional faces than neutral faces in the Posner attention task. We also reduplicated the interhemispheric imbalance in emotional face perception owing to the use of TMS over rIPS. The possible mechanisms of interhemispheric imbalance are addressed in the following paragraphs.

Previous neuroimaging studies have demonstrated that right-parietal-damage patients normally experience left

VF neglect [19,20]. However, emotional stimuli presented in the left VF had a tendency to be less ignored or even better noticed relative to neutral stimuli [21]. Some patients even show faster detection of emotional than neutral targets in visual search tasks on the contra-neglected side [20]. Consistent with our findings, these suggest that emotional stimuli may still grab attentional resources and compete for conscious awareness even when someone cannot orient attention toward the contralateral side owing to parietal disruption. There is a possibility that emotional information can still interact with the attention network through residual parts of the dorsal frontoparietal cortex or remodeling of the frontoparietal network for functional compensation.

For this influence of IPS in emotional face processing, Haxby *et al.* [9] proposed a potential extended connection between IPS and a well-developed posterior network of cortical regions contributing to facial perception [22]. Materna *et al.* [23] performed a functional MRI study to show that posterior superior temporal sulcus regions are specifically involved in extracting and using detailed directional information to redirect one's own attention. When applying rTMS over the IPS, it might disrupt the main orientation function of the IPS in spatial attention. However, the bottom-up functional connectivity between posterior superior temporal sulcus and IPS might compensate for the orientation lost, as emotional faces still grab attention resources and reach conscious awareness.

Moreover, feedback from the IPS might enhance the activation of the visual cortex and may cause the enhanced perception of emotional faces. Indeed, previous research has shown functional connectivity between IPS and visual cortex. Furthermore, they suggest that the IPS biases the signals observed in visual cortex. There has been evidence to indicate a direct causal role of the IPS on attention-related modulation of visual cortex activity [24]. Interestingly, Fried *et al.* [25] reported that applying TMS to posterior parietal cortex or IPS evoked phosphenes, which emerged through indirect activation of visual areas to solidify the view that the IPS and visual cortex are coupled functionally.

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Conflicts of interest

There are no conflicts of interest.

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