The role of parietal cortex in global/local processing of hierarchical stimuli: a transcranial magnetic stimulation study

Jungang Qin[a] and Shihui Han[a,b]

[a]Department of Psychology, Peking University and [b]Learning and Cognition Lab, Capital Normal University, Beijing, PRC

Correspondence to Professor Shihui Han, PhD, Department of Psychology, Peking University, 5 Yiheyuan Road, Beijing 100871, PRC

Materials and methods

Participants

Eighteen healthy, right-handed adults (11 men, seven women, aged between 19 and 23 years, mean=20.7) participated in this study as paid volunteers. All were naive to the aim of the study. All had normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. Written informed consent was obtained from all participants before participation. This study was approved by the local ethical committee at the Department of Psychology, Peking University.

Stimuli and procedures

The stimuli were compound letters made up of white lines (74.5 cd/m^2) on a grey background (15.7 cd/m^2) and were presented on a computer-controlled monitor placed at 125 cm from the participant's eyes. Each global letter ($2.8 \times 1.8°$) was composed of local letters ($0.36 \times 0.23°$) in a 5×5 matrix (see Fig. 1). The letters 'H' and 'S' served as targets and the letters 'A' and 'E' as distractors. Each stimulus contained a target letter at one level and a distrator letter at another level, resulting in eight stimuli. According to Lamb and Robertson [10], 'A' was more similar to 'H' than to 'S' because 'A' and 'H' were identical, apart from the addition of the top horizontal segment in 'A'. Similarly, 'E' was more similar to 'S' than to 'H'. The authors found that reaction times to 'H' targets were shorter with 'A' than with 'E' as the distractor. Thus the interference between the processing of global and local information was measured as the interaction between target and distractor letters.

Each trial began with a 500-ms tone followed by a fixation cross ($0.23 \times 0.23°$) at the centre of the screen for 500 ms. A compound letter was then displayed for 100 ms. Participants were asked to identify target letters shown at either the global or local level of compound stimuli by pressing one of the two buttons on a joystick using the left or right index finger. The intervals between two successive trials were 1000 ms. On each day of test, after one block of 48 trials for practice and rTMS session, each participant performed two blocks of 160 trials. Instruction emphasized both response accuracy and speed. The assignment of global and local targets to the left and right hand response was counterbalanced across participants.

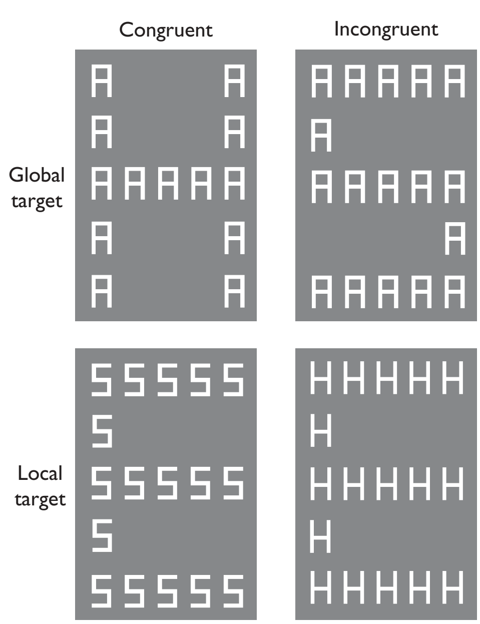


Fig. 1 Illustrations of compound stimuli used in the current experiment.

Transcranial magnetic stimulation protocol

A standard rapid stimulator (MagStim, Whitland, UK) with a 70-mm figure-eight coil was used in the current work. The output strength of the TMS was the same as the motor threshold (between 43 and 70% of the maximum output), defined as the minimum intensity of stimulation capable of inducing visible twitch of the left thumb. rTMS was performed on three different sites on the scalp: the precentral gyrus (at electrode CZ position (according to 10/20 electroencephalogram system), the left (P3) and right (P4) posterior parietal cortex. Each participant received three sessions with rTMS over CZ, P3, or P4, respectively. Each session was performed on a different day. Participants were seated comfortably on a chair with their heads fixed using a chinrest. During rTMS procedure, participants were given rTMS consisting of a train of TMS impulses applied at 1 Hz for 420 s. The order of TMS over the P3, P4, and CZ was counterbalanced across participants.

Data analysis

Reaction times and response accuracies were subjected to repeated-measure analysis of variance (ANOVA) with globality (targets are global or local level), interference (targets are congruent or incongruent with distractors), and TMS (over P3 vs. CZ, or P4 vs. CZ) as within-participant independent variables to examine the effect of rTMS on performances differentiating global and local targets. Reaction times and response accuracies were also subjected to ANOVA with globality (targets are global or local level), repetition (targets in two successive trials appeared at the same or different levels), and TMS (over P3 vs. CZ, or P4 vs. CZ) as within-participant independent variables to examine the effect of rTMS on the level-repetition effect.

Results

Response accuracies were high (above 95%) in all stimulus conditions. ANOVAs showed only a significant main effect of interference [$F(1,17)=9.61$, $P<0.01$], indicating that response accuracies were lower when targets were incongruent than congruent with the disctractors (97.1 vs. 98.7%). Comparisons between reaction times and accuracies indicated no speed–accuracy trade-off.

Reaction times to global and local targets in the congruent (the target and the distractor in a compound stimulus were similar) and incongruent (the target and the distractor in a compound stimulus were disimilar) conditions are calculated separately (Fig. 2). The analysis comparing rTMS over P3 vs. CZ showed a significant main effect of interference [$F(1,17)=171.93$, $P<0.001$], reaction times to targets were shorter in the congruent than the incongruent conditions. A reliable interaction effect of globality $\times$ interference [$F(1,17)=21.21$, $P<0.001$] was observed, suggesting a stronger global-to-local interference than local-to-global interference. Interestingly, we found a significant interaction of globality $\times$ TMS [$F(1,17)=5.19$, $P<0.05$], reflecting the fact that global and local responses were equally fast when rTMS was applied to CZ whereas global responses tended

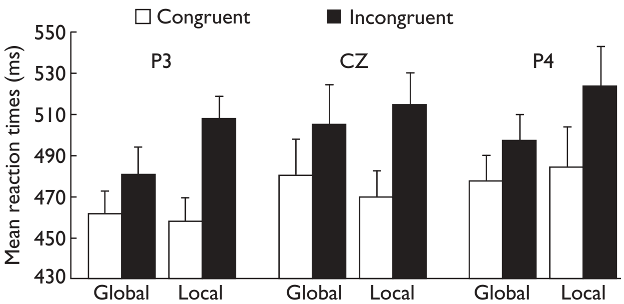
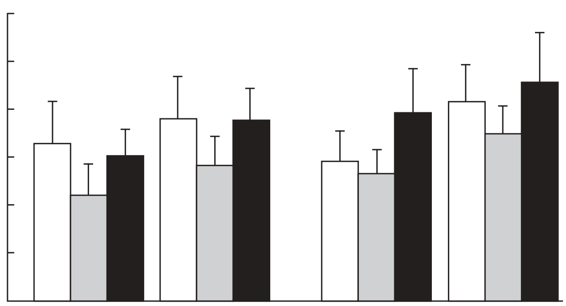


Fig. 2 Mean reaction time for global and local targets in congruent and incongruent conditions with rTMS over P3, CZ and P4. Error bars represent standard errors.



to be faster than local responses when rTMS was applied to P3. The analysis comparing rTMS over P4 vs. CZ showed only a significant main effect of interference [$F(1,17)=191.67$, $P<0.001$] and the interaction of globality × interference [$F(1,17)=9.26$, $P<0.01$], suggesting shorter reaction times in the congruent than the incongruent conditions and greater global-to-local interference than local-to-global interference. Neither the main effect of TMS nor its interaction with other factors, however, was significant.

Mean reaction times to global and local targets in the repeated-level (targets appeared on the same level in two successive trials) and changed-level (targets appeared on different levels in two successive trials) conditions were also calculated (Fig. 3). ANOVAs showed only a significant main effect of repetition [$F(1,17)=32.03$, $P<0.001$ comparing P3 vs. CZ conditions; $F(1,17)=35.07$, $P<0.001$ comparing P4 vs. CZ conditions], indicating that responses were faster when targets appeared at the same level than at different levels in two successive trials. No interaction of repetition with other factors, however, was significant ($P>0.05$), suggesting comparable level-repetition effect when rTMS was applied to P3, P4, and CZ.

Discussion

To examine whether the same neural structure of the posterior parietal lobe contributes both to focus attention on one level and to switch attention between two levels of compound letters across trials, we recorded response speeds to global and local targets after applying rTMS to the left and right posterior parietal cortex. Relative to the control condition where rTMS was applied to the precentral gyrus, rTMS effect on reaction times to global and local targets reflected the effect of temporal disruption of neural activities in the posterior parietal cortices on global/local processing of compound stimuli. Our reaction time results showed evidence for stronger global-to-local interference than local-to-global interference, consistent with previous studies using the paradigm requiring divided attention to both levels of compound stimuli [10]. In addition, we found evidence for the level-repetition effect, reinforcing the previous work [8,9,16] and indicating attention switch between global and local levels across successive trials.

We also found that rTMS applied to P3 over the left hemisphere resulted in faster responses to global than local targets in the condition that global and local responses tended to be equally fast when rTMS was applied to CZ. rTMS to P4 over the right hemisphere did not, however, modulate response speeds to global/local targets. The differential influence of rTMS over the parietal lobe on global/local processing indicate that the low frequency rTMS effects observed in our study could not reflect general impairment of low-level sensory processing (such as changes in threshold sensitivity) or the processing of shape identification and recognition [17] because both global and local perception had to undergo these processes before behavioral responses were made. The effect of rTMS over P3 is consistent with Mevorach *et al.*'s [13] observation that rTMS over P3 increased global-to-local interference in right-handed individuals, both suggesting that inhibition of the left posterior parietal lobe results in difficulty of focusing attention at the local level of compound stimuli and of ignoring the global properties. In addition, these rTMS effects are in line with the functional MRI evidence that the superior parietal cortex is involved when attention was focused to the local level compared with attention to the global level of compound stimuli [12]. The rTMS effect observed here is also in accordance with previous brain imaging studies [1,3,18,19], which showed evidence that the left and right occipital cortex, respectively, dominates the initial local and global processing of compound stimuli. It appears that the parietal activity is also characterized with hemisphere asymmetry in that the left parietal cortex dominates focusing attention to the local aspect of compound stimuli.

Of particular interests about the current study is that, although we found robust level-repetition effect in reaction times, such effect was not influenced by rTMS applied to the posterior parietal cortices under the condition that rTMS led to difficulty of focusing attention to the local level. As Homan *et al.* [20] showed that the electrodes P3 and P4 are located above the intraparietal sulcus, our results implies that these areas in the left parietal cortex may be involved in focusing attention on the local level of a current compound letters but are not necessarily involved in switching attention between local and global levels of two successive trials. As rTMS over P4 did not modulate the level-repetition effect either, it may be proposed that the homologous posterior parietal lobe area in the right hemisphere does not contribute to attentional switch between global and local levels in two successive trials. As the event-related potential study showed evidence for modulation of the left parietal activity by target level switch [14], it is likely that other parietal areas might play a role of switching attention between global and local levels. Patient studies have shown that the left dorsal parietal lesions disrupted shifts of attention between global and local elements of hierarchical displays [21,22]. A positron emission tomography study also found that attention switch between global and local level of compound stimuli was characterized with enhanced activity in the right temporal–parietal junction [1]. On the basis of these observations, it may be proposed that the left dorsal parietal cortex or the temporal–parietal junction is associated with attentional shifts between global and local levels of compound stimuli. Alternatively, the level-repetition effect might be linked to the spatial frequency differences between global and local forms in hierarchical patterns [9] or reflect a level-specific priming mechanism [16] rather than attention switch between local