Right Temporoparietal Junction and Attentional Reorienting

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Abstract: The interaction between goal-directed and stimulus-driven attentional control allows humans to rapidly reorient to relevant objects outside the focus of attention—a phenomenon termed contingent reorienting. Neuroimaging studies have observed activation of the ventral and dorsal attentional networks, but specific involvement of each network remains unclear. The present study aimed to determine whether both networks are critical to the processes of top-down contingent reorienting. To this end, we combined the contingent attentional capture paradigm with the use of transcranial magnetic stimulation (TMS) to interfere with temporoparietal junction (TPJ; ventral network) and frontal eye field (dorsal network) activity. The results showed that only right TPJ (rTPJ) TMS modulated contingent orienting. Furthermore, this modulation was highly dependent on visual fields: rTPJ TMS increased contingent capture in the left visual field and decreased the effect in the right visual field. These results demonstrate a critical involvement of the ventral network in attentional reorienting and reveal the spatial selectivity within such network. *Hum Brain Mapp* 34:869–877, 2013. © 2012 Wiley Periodicals, Inc.

Key words: attentional reorienting; temporoparietal junction; TMS; ventral attentional network

INTRODUCTION

Imagine looking for a friend wearing a red coat in a crowd. One can efficiently filter out people without the same feature, but may occasionally get distracted by someone with a red hat. This phenomenon is an example of contingent orienting, where the focus of attention is shifted to other objects that possibly match the current goal of the observer. Contingent orienting has been characterized as a dynamic interaction between top-down and stimulus-driven control. Evidence has suggested that attention can be captured by highly salient bottom-up stimuli [e.g., Hickey et al., 2006; Theeuwes, 1991] or reoriented based on the integration between such stimuli and the current top-down control settings [Folk et al., 1992; Lamy et al., 2004]. The latter phenomenon suggests that attentional orienting is contingent on the current attentional set of the observer,

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which is an important aspect to successful interaction with the visual environment as one usually has an idea of target features, but would not necessarily know when or where the targets of interest would appear. Thus, the visual system's ability to rapidly reorient to any object with a target-defining feature is, although sometimes error-prone, an essential and advantageous aspect of visual cognition.

Neuroimaging studies have suggested two discrete attentional networks [Corbetta and Shulman, 2002; Corbetta et al., 2008] that show increased activation when people attempt to reorient attention to a peripheral relevant stimulus: namely the dorsal frontoparietal network and the ventral network [Corbetta et al., 2000; Downar et al., 2001; Indovina and Macaluso, 2007; Serences et al., 2005; Shulman et al., 2009]. The dorsal frontoparietal network, consisting of the intraparietal sulcus and frontal eye field (FEF), maintains the attentional priority map and executes voluntary attentional control such as orienting to a location, feature, or object [Hopfinger et al., 2000; Nobre, 2001; Nobre et al., 2004; Rushworth et al., 2001]. This network is often activated by exogenous stimuli [Kincade et al., 2005], showing that the dorsal network is highly related to any type of attentional orienting. Thus, the activation of the dorsal network has been considered as a consequence of shifts in attention in contingent reorienting.

In contrast, the ventral attentional network includes the temporoparietal junction (TPJ) and ventral frontal cortex and has been suggested to serve as a circuit-breaker by sending interrupting signals to the dorsal network to modulate ongoing selection. Depending on behavioral relevance, this network also plays a complimentary role in stimulus-driven attentional orienting and is responsible for detecting salient events outside the current focus of attention [Corbetta et al., 2000; Downar et al., 2000, 2001]. For example, observers are often instructed to follow an endogenous cue and shift attention to the cued location or reorient attention to other uncued locations if a target appears elsewhere [Doricchi et al., 2009; Indovina and Macaluso, 2007]. In another example, participants were required to detect a red square in a peripheral picture stream, which would indicate where the following target would appear [Shulman et al., 2009, 2010]. Within the ventral network, the right TPJ (rTPJ) is of particular interest to attentional reorienting as its activation is often observed when attention is oriented to an unattended stimulus that contains a target-defining or task-relevant feature across multiple scenarios, such as a target in an invalid location, a target-colored distractor [Serences et al., 2005], or a highly valid exogenous cue. Together, these studies suggest that rTPJ activation is sensitive to stimuli that share a target-defining or task-relevant feature in some way. Indeed, exogenous cues with no predictive validity [Kincade et al., 2005], or salient but irrelevant distractors [de Fockert et al., 2004], do not activate the ventral network.

The aforementioned studies together suggest that both attentional networks are involved in contingent reorienting, but for different processes. That is, the ventral net-

work is a trigger to induce attentional orientation, while the dorsal network executes it [Corbetta and Shulman, 2002; Corbetta et al., 2008]. This hypothesis, however, is mostly restricted to correlational neuroimaging studies. Therefore, it is crucial to establish causal evidence for each of the networks to confirm whether they play a critical role in responding to relevant stimuli. The function of the dorsal network has been investigated with neuroimaging and neurodisruptive techniques, and its function is more clearly understood than that of the ventral network. There are many studies documenting the causal role of the dorsal network in control of covert attention and saccadic eye movements [e.g., Chao et al., 2011; Grosbras and Paus, 2002; Juan et al., 2004, 2008; Kanai et al., 2011; Liu et al., 2011; Muggleton et al., 2003, 2011; Nyffeler et al., 2006; Rushworth and Taylor, 2006; Taylor et al., 2007; Walsh et al., 1999]. The number of studies is relatively less, however, for the ventral network [Ellison et al., 2004; Meister et al., 2006; Schindler et al., 2008], thus making it difficult to systematically compare the ventral and dorsal networks. For this reason, a direct comparison between the dorsal and ventral network within the same contingent reorienting paradigm is much needed.

To this end, we applied theta burst stimulation over the right hemisphere of each attentional network, namely the rTPJ (ventral) and right FEF (rFEF; dorsal) to specifically test the involvement of each network in attentional reorienting. A contingent capture paradigm that requires participants to focus on the central target while distractors of varied levels of relevance would appear on the side [Folk et al., 1992; Serences et al., 2005] was used. This paradigm is known to activate both the dorsal and ventral networks, and the distractors' locations are well controlled to allow further investigation of the transcranial magnetic stimulation (TMS) effect on spatial selectivity. In addition, the location-specific aspect of TMS also provides an added benefit of exploring the possible hemispheric asymmetry within each network. This hemispheric asymmetry has been well documented for the dorsal network. For example, the interfering effect of TMS in many visual tasks is consistently observed in both visual field when applied over the right FEF, but only contralateral visual field for the left FEF [Grosbras and Paus, 2002; Silvanto et al., 2006; Smith et al., 2005]. Therefore, the ventral network is also likely to be right hemispheric dominant [Shulman et al., 2009, 2010], as demonstrated by some TMS studies using visual search tasks [Ellison et al., 2004; Meister et al., 2006; Schindler et al., 2008] and exemplified by the spatial neglect shown by patients with right ventral lesions [Corbetta et al., 2005; Husain and Nachev, 2007; Husain and Rorden, 2003]. This can be tested as we applied TMS over the left TPJ (lTPJ) to compare a possible difference between the left and rTPJ. If the ventral network is indeed right-hemisphere dominant, a difference in magnitude between the two hemispheres should be observed. Thus, the present study set out to (1) provide a direct comparison between the dorsal and ventral network in terms of

causality to contingent reorienting and (2) explore the spatial selectivity of the ventral network by comparing the TMS effects between the two visual fields.

MATERIALS AND METHODS

Participants

Fourteen undergraduate and graduate students from the National Central University (19–26 years old; gender: 8 male; mean age = 21.7) were recruited in Experiment 1. An additional 12 new participants were recruited in Experiment 2 to avoid practice effects on the contingent capture task (18–26 years old; gender: 7 males; mean age = 22). All participants had normal or correct-to-normal visual acuity. Participants gave informed consent before participation and received monetary reward upon the completion of the experiment. In Experiment 1, all participants completed a behavioral experiment session before the magnetic stimulation session. Only participants who demonstrated the expected contingent capture effect in the behavioral session were recruited to participate in the magnetic stimulation session, and two participants were excluded by this criterion. In Experiment 2, the order of the behavioral session and stimulation session was counter-balanced and followed the same criterion of data exclusion; two participants were also excluded in Experiment 2. The experiments were approved by the Institutional Review Board of the Chang-Gung Memorial Hospital, Taoyuan, Taiwan.

Apparatus

Participants sat in a dimly lit room with their heads stabilized by a chinrest. Stimuli were presented on a 19-in. color cathode ray tube monitor (View Sonic Professional Series P95f+), positioned 86 cm in front of the participants. The monitor had a spatial resolution of $1,024 \times 768$ pixels and a refresh rate of 100 Hz. The experiments were generated using E-prime running on a Pentium IV PC, which controlled the presentation of the stimuli and recorded response information.

Stimulation site and TMS Protocol

A Magstim Super-Rapid Stimulator with a 55-mm figure-of-eight coil was used to deliver TMS. The sites of theta TMS stimulation were rTPJ (Talairach coordinate: 55, -44, 24), ITPJ (-55, -41, 17), and rFEF (33, 5.1, 65). The talairach coordinates of TPJs were previously reported to be associated with contingent attentional capture in an imaging study [Serences et al., 2005]. The coordinates of rFEF were the average location of rFEF stimulation from a previous study [Muggleton et al., 2003] that demonstrated TMS disruption to conjunction visual search performance.

FSL (FMRIB, Oxford, UK) software was used to transform coordinates for rTPJ, ITPJ, and rFEF for each individual participant. These coordinates were determined by each participant's structural MRI with theBrainsight system (Rogue Research, Montreal, Canada). Participants wore goggles with a tracker attached, enabling them to be co-registered with their structural image using a mounted Polaris infrared tracking system (Northern Digital, Waterloo, Canada).

TMS pulses were applied in a continuous rTMS pattern as specified by a previous study [Hung et al., 2005]: participants received a total of 300 pulses within 20 s, three pulses were given at 50 Hz and were repeated every 200 ms at 40% of maximum intensity. The maximum output of the TMS machine was 2 Telsa. A fixed stimulation level was used, because it has been proven successful and replicable in many studies and over a wide range of tasks [Ashbridge et al., 1997; Chao et al., 2011; Liu et al., 2010; Silvanto et al., 2005, 2007; Stewart et al., 2001] and because motor cortex excitability does not provide a good guide to TMS thresholds in other cortical areas [Stewart et al., 2001].

Stimuli and Task

The behavioral task (Fig. 1) was a modification from Serences et al. [2005]. Participants pressed the space bar to initiate each trial, which began with a 500-ms white fixation cross at the center of the screen, followed by a serial presentation of three letter streams. Each stream consisted of 26 uppercase letters, and each letter was presented for 40 ms, followed by a 10-ms blank interval, yielding a rate of 50 ms/letter. In all letter streams, each letter subtended 1° horizontally and 1.3° vertically. The letters were selected randomly without replacement from the English alphabet. Participants were required to identify the red (Commission International del; Eclairage, $x = 0.60$, $y = 0.34$) letter embedded in the central stream of other colored letters, which were randomly chosen between green ($x = 0.28$, $y = 0.58$), blue ($x = 0.17$, $y = 0.13$), purple ($x = 0.25$, $y = 0.14$), and cyan ($x = 0.20$, $y = 0.15$). Colors in the array were approximately isoluminant (22 cd/m^2). Across trials, the target appeared randomly between the 11th through 14th frames of the letter sequence and was selected equally from first eight and last eight of English alphabet (A to H, S to Z). After the display sequence, participants responded by pressing a button with their right index finger to indicate whether the target belonged to the first eight letters of the alphabet, or another button with their right middle finger if the target belonged to the last eight letters. Accuracy was emphasized and speeded responses were not necessary.

Flanking the target stream was two distractor letter streams located 3° to the left and right of the central stream. On one-third of the trials, the colors of both peripheral distractor streams were gray. On the other two-

Figure 1.

Illustration of the experimental conditions and procedure. Each stream consisted of 26 uppercase letters in serial order, and each letter was presented for 40 ms, followed by a 10-ms blank interval. Participant searched for the unique red letter in the central stream. The peripheral flanker streams were mostly gray letter. On one third of the trials, target-colored distractors were presented in the flanker streams 100 ms before the onset of the central target and lasted for 50 ms after the offset of the target (four frames). On another one-third of the trials, these distractors would be nontarget-colored. The remaining one third of the trials, the distractors were all gray.

thirds of the trials, in either the right or left letter stream, four of the peripheral distractor letters would change color to either red or green (equally likely). The red distractors share the identical color feature with target, which are

categorized as target-colored (TC) distractor, whereas the green distractors are categorized as nontarget-colored (NTC) distractor. The colored distractors were presented 100 ms before the onset of the central target and lasted for 50 ms after the offset of the target (four frames). Participants were instructed to continuously maintain fixation on the central target stream and ignore the peripheral distractor streams. The duration of behavioral task lasted between 10 and 15 min, which varied with subjects' response times.

Design

The behavioral task consisted of 20 practice trials, followed by 120 formal trials. The 120 formal trials were composed of six different combinations of distractor color and location, and each combination was used 20 times. In Experiment 1, the TMS condition consisted of two separate sessions: rFEF TMS and rTPJ TMS (Fig. 2). All conditions were within-subject designs and were run on two different days. The materials, stimuli, and procedures were identical across all TMS conditions. Thus, the only difference between these two conditions was the TMS site. The orders of the rFEF TMS and rTPJ TMS conditions were counterbalanced between every participant. All participants completed a behavioral experiment before the TMS session for the purpose of evaluating their contingent capture effect. In addition, to balance out the potential practice effect and avoid any confound with the effect of TMS, an additional behavioral block was performed after the TMS experiment on a different day in Experiment 1. The data of these two behavioral blocks were averaged to yield the behavioral results of Experiment 1. In Experiment 2, the behavioral session and ITPJ TMS session were counterbalanced between all participants.

Figure 2.

Example of the TMS-stimulated brain regions in one participant. The stimulation sites were localized using individual MRI scan co-registered to the skull co-ordinates using BrainSight™ software.

Figure 3.

Effect of TMS on accuracy from Experiment 1. The contingent capture effect (lower accuracy of the TC distractor condition, denoted by the red bars) was eliminated in the right visual fields by the rTPJ TMS, and it differed from the left visual field. Error bars represent 95% confidential interval.

RESULTS

Participants were asked to identify the sole red letter in the rapid serial visual presentation (RSVP) task. The aim of Experiment 1 was to investigate whether rTPJ TMS or rFEF TMS would affect the contingent capture effect while the no-TMS condition served as a control. The following ANOVA was performed for accuracy. First, to include all three factors of the experimental design, a $3 \times 3 \times 2$ repeated measures ANOVA was performed with factors of stimulation condition (no-TMS, rFEF, rTPJ), distractor type (absent, NTC, TC), and distractor location (left, right). There was a significant main effect of distractor type [$F_{(2,22)} = 23.077$, $P < 0.001$]. More importantly, the three-way interaction reached significance [$F_{(4,44)} = 3.402$, $P < 0.05$; see Fig. 3]. To investigate whether TMS affected the capture effect, three 3×2 repeated measures ANOVAs were performed separately for each different stimulation condition with the factors of distractor type and distractor location.

Behavioral Session

Accuracy from the no-TMS condition was averaged from the two behavioral sessions. A two-way repeated measures ANOVA revealed a significant main effect of distractor type [$F_{(2,22)} = 18.691$, $P < 0.001$]. Post hoc paired-sample *t*-test comparisons confirmed previous behavioral results: accuracy from the TC distractor condition was lower than the NTC condition [$t(11) = 4.571$, $P < 0.01$] and colored-distractor absent condition [$t(11) = 5.557$, $P < 0.001$]; Folk et al., 1992; Lamy et al., 2004; Serences et al., 2005]. There was no difference between the NTC condition and colored-distractor absent condition [$t(11) = 0.923$, $P = 0.376$]. The main effect of distractor location and the interaction with distractor type were not statistically significant [$F_{(1,11)} = 0.078$, $P = 0.785$; $F_{(2,22)} = 0.324$, $P = 0.727$].

Capture Effects in the Right Attentional Network

rFEF TMS Session

A two-way repeated measures ANOVA revealed a significant main effect of distractor type [$F_{(2,22)} = 13.826$, $P < 0.001$]. Accuracy of the TC-distractor condition was lower than the colored-distractor absent condition ($P < 0.001$) and NTC distractor condition ($P < 0.01$). The main effect of distractor's location and the interaction with distractor type were not significant [$F_{(1,11)} = 0.322$, $P = 0.582$; $F_{(2,22)} = 0.439$, $P = 0.650$]. The pattern of the capture effect was similar for the no-TMS session, and the contingent attentional capture was not affected by rFEF-TMS (Fig. 3).

rTPJ TMS Session

Consistent with the behavioral session, the main effect of distractor type was significant [$F_{(2,22)} = 6.946$, $P < 0.01$], and there was an additional significant interaction between distractor type and distractor location [$F_{(2,22)} = 6.695$, $P < 0.01$]. Simple effects were analyzed for each distractor location separately with paired least significant difference measures. In the left visual field, the accuracy of target-colored distractor condition was lower than the other two distractor types [$F_{(2,22)} = 14.245$, $P < 0.001$], and no significant differences were observed in the right visual field [$F_{(2,22)} = 0.06$, $P = 0.942$; Fig. 3].

Comparison of TMS effects on rTPJ and rFEF

To investigate whether TMS affected the identification of targets under different distractor conditions, three 3×2 two-way repeated measure ANOVAs were performed with the factors of stimulation condition and distractor location. In the distractor-absent condition, there was no

Figure 4.

Effect of TMS on accuracy from Experiment 2. Both TMS conditions showed significant capture effect, but there was no significant difference between no-TMS and ITPJ-TMS condition. Error bars represent 95% confidential interval.

difference between three stimulation conditions [$F_{(2,22)} = 0.307$, $P = 0.739$]. In the NTC condition, the main effect of stimulation condition was significant [$F_{(2,22)} = 3.476$, $P < 0.05$]: rFEF TMS improved detection performance in comparison with the no-TMS condition ($P < 0.05$). However, there was no difference between rFEF TMS and rTPJ TMS ($P = 0.215$) nor was there any significant interaction. In the TC condition, there was a significant interaction between stimulation condition and distractor location [$F_{(2,22)} = 5.644$, $P < 0.05$]. Simple effects were analyzed for each distractor location separately using paired t -tests (Fig. 4). In the left visual field, the accuracy of rTPJ TMS was lower than no-TMS [$t(11) = 2.387$, $P < 0.05$] but marginally lower than rFEF-TMS [$t(11) = 2.188$, $P = 0.051$]. The right visual field, in contrast, showed higher accuracy with rTPJ TMS than no-TMS [$t(11) = 2.308$, $P < 0.05$] and rFEF TMS [$t(11) = 2.321$, $P < 0.05$]. No difference between rFEF TMS and no-TMS was observed in either visual field (all $P > 0.05$).

Capture effects in the left ventral attentional network

The aim of Experiment 2 was to examine the right hemispheric dominance of the ventral network and investigate whether the rTPJ TMS effect can be induced when stimulation was applied over ITPJ. A $2 \times 3 \times 2$ repeated measure ANOVA was performed with the factors of stimulation condition (no-TMS, ITPJ), distractor type (absent, NTC, TC), and distractor location (left, right). There was only a significant main effect of distractor type [$F_{(2,18)} = 15.782$, $P < 0.01$]. The main effect and the interaction of the stimulation conditions were not significant (all $P > 0.1$). Although the three-way interaction was not significant, we conducted a two-way repeated measure ANOVA

under the ITPJ-TMS condition to be consistent with the analyses in Experiment 1, with the factors of distractor type (absent, NTC, TC) and distractor location (left, right). This analysis provided a helpful comparison to understand the difference between the effects of rTPJ and ITPJ stimulation. The results were consistent with the previous three-way ANOVA: there was no significant effect of the distractors' location or two-way interaction (all $P > 0.1$), except for the main effect of distractor type [$F_{(2,18)} = 4.794$, $P < 0.05$]. Moreover, another two-way repeated measure ANOVA was performed with factors of stimulation condition and distractor location. The results also showed that there is no significant main effect or interaction between ITPJ TMS and no-TMS condition in three separate distractor conditions [absent condition $F(1,9) = 3.209$, $P = 0.107$; NTC condition $F(1,9) = 0.01$, $P = 0.976$; TC condition $F(1,9) = 1.949$, $P = 0.196$; Other main effects all $P > 0.2$].

DISCUSSION

In Experiment 1, the pattern of TMS results indicates a functional dissociation of the dorsal and ventral attentional network in the task. In the dorsal network, rFEF TMS improved performance in the NTC distractor condition but did not affect contingent capture. Conversely, rTPJ TMS modulated the contingent capture effect differently depending on the visual field of the TC distractor: rTPJ TMS increased the contingent capture effect in the contralateral visual field and decreased the effect in the ipsilateral visual field. Meanwhile, this modulation of the contingent capture effect was not induced with left TPJ stimulation. Together, these findings suggest an involvement of both attentional networks and reveal different crucial functions of each network, dorsal and ventral, with regards to attentional reorienting.

Stimulus-Driven Effects in the Dorsal Network

Previous studies have shown that the dorsal network is principally related to the orienting of attention in relation to both voluntary and stimulus-driven aspects [Kelley et al., 2008; Kincade et al., 2005]. Thus, any attentional orienting should evoke activation from this network. In the current RSVP paradigm, this orienting could either be the result of stimulus-driven capture or the voluntary shifts of attention back to the central stream after the preceding capture. In fact, the current results show that rFEF TMS improved accuracy, which is likely to have originated from the interference with orienting to distracting peripheral stimuli. Notably, this improvement is restricted to the NTC condition, suggesting that the involvement of the dorsal network is more specific to stimulus-driven reorienting than contingent reorienting in this paradigm. This is because the NTC distractor is an irrelevant item in the current experimental design as it does not share the same color with the target. This confirms previous findings that the dorsal network is involved in exogenous orienting [Asplund et al., 2010; Kincade et al., 2005], but also showed that it has no critical involvement in contingent reorienting. Moreover, this rFEF TMS effect is only significant while it is being compared to the behavioral baseline and not to the other TMS condition. This may be due to the fact that shifts of attention are unnecessary in the current task (the target was always appeared in the central RSVP stream), which may have lessened the involvement of the dorsal network. Also, note that rFEF TMS also increased accuracy to be on par with the distractor-absent baseline performance. Thus, it remains possible that rFEF TMS also improved performance under noncontingent reorienting, but its effect was masked by the lower baseline performance.

Ventral Network

In contrast to the dorsal network, the role of the rTPJ is regarded to be specific to contingent reorienting, engaged only by the peripheral relevant stimuli instead of irrelevant ones. Imaging studies have shown that task relevance is a critical factor to evoke activation of the ventral network [Downar et al., 2001; Indovina and Macaluso, 2007; Serences et al., 2005; Shulman et al., 2009, 2010]. Therefore, neither a purely stimulus-driven peripheral distractor nor an uninformative exogenous cue should activate this network [de Fockert et al., 2004; Kincade et al., 2005]. This contingency, which was found in the current rTPJ TMS results, is in agreement with previous studies: rTPJ TMS modulated accuracy only in the TC distractor condition. Moreover, the ventral network has been considered as right hemisphere dominant. Shulman et al. [2009] found higher activations in the right ventral network when subjects needed to monitor a 100% valid exogenous cue. As previously mentioned, modulation was not observed with ITPJ TMS. These results confirm the critical role of the ven-

tral network in contingent reorienting. This differs from the dorsal system as rFEF TMS did not affect the contingent capture effect.

The function of the ventral network, according to Corbetta's model [2002, 2008], is to detect task-relevant stimuli outside of the focus of attention. This can be a target-colored distractor or a target in the invalid cueing condition; thus, the ventral network initiates a reorienting response that is contingent on the voluntary attentional set. Another proposed function of rTPJ is to filter out the irrelevant distractor [Shulman et al., 2007]. When subjects were asked to detect a digit target among four streams of letters, a significantly higher rTPJ deactivation was observed when subjects detected the target than when they missed it. This deactivation was thought to reflect the function of filtering out distractors until the subsequent target appeared. The current study is consistent with both accounts in showing that rTPJ TMS has an impact on different functions of the ventral network. Because the effect of theta burst stimulation is highly dependent on the initial neural state of the stimulation site, the theta burst effect current study could have arisen from either an increased or decreased cortical excitability. In other words, our rTPJ TMS may have inhibited the ability of rTPJ to properly filter out the peripheral nontarget stream or enhanced the detection of the same target-colored stimuli, which would both lead to the same behavioral consequence. These two accounts are both possible, as the effects of TMS can result in state-dependent modulation [Silvanto et al., 2007].

In this study, the specific modulation of rTPJ-TMS clarifies the functional role of the ventral network in the theoretical attention model. Moreover, the current results reveal an important spatial characteristic of the ventral network. The rTPJ TMS stimulation exhibited different modulation depending on the relevant visual field. Although it increased the capture effect on the contralateral side, it reduced this effect on the ipsilateral side. These asymmetrical effects reflect the natural difference in the processing of the two visual fields. In behavioral studies, a RSVP task showed that the contingent capture effect is also asymmetrical between the two visual fields: the target-colored distractor induced a stronger capture effect in the left visual field than in the right [Burnham et al., 2011; Du and Abrams, 2010]. In addition, healthy participants who show pseudo-neglect can also exhibit a leftward bias in the line bisection task [Bowers and Heilman, 1980; Jewell and McCourt, 2000]. These behavioral patterns suggest that asymmetry between the visual fields is quite widely observed and that the contingent stimulus-driven process actually prefers contralateral target-defining stimuli, a spatially sensitive mechanism.

In our study, the target-colored distractor was also more effective in the left visual field. Thus, the stronger capture effect on the left was amplified by the theta burst TMS, increasing the magnitude of the previously reported asymmetry in attentional control in the left visual field. Although the contingent attentional capture did not show

the asymmetry in our behavioral session, the data from rTPJ TMS conditions showed that TMS induced a stronger imbalance than previous studies. Under the common framework, the ventral network is often associated with non-spatial-sensitive processing [Corbetta and Shulman, 2002; Corbetta et al., 2008; Doricchi et al., 2009; Shulman et al., 2009], and reports of spatial selectivity are relatively infrequent in neural imaging studies. However, there still is evidence indicating the possibility that this network may exhibit spatial selectivity. In the original imaging study of the current contingent capture paradigm, the activation of rTPJ is stronger when TC distractors are presented on the contralateral side [Serences et al., 2005]. Additionally, a relevant contextual cue in the contralateral side evoked a larger activation of rTPJ than in the ipsilateral side [Geng and Mangun, 2011]. The crucial difference in the report of spatial selectivity may be due to the specific task demand of processing peripheral relevant stimuli. For example, peripheral target-colored distractor had to be ignored in the present paradigm [e.g., Serences et al., 2005], but in other paradigms, a relevant valid exogenous cue may be essential for detecting a peripheral sequential target [e.g., Shulman et al., 2009]. The fundamental differences between the spatial aspects of these paradigms, then, can be the cause that explains whether studies report the ventral network as spatially sensitive or not. This spatial contralateral preference is similar to the dorsal attentional network, where repetitive TMS over right posterior-parietal cortex (rPPC) amplified the contralateral visual-field advantage [Verleger et al., 2010]. The converging patterns on spatial attentional processing here perhaps confirm the close connection between rTPJ and rPPC, as evidenced by studies using psychophysiological interactions [Geng and Mangun, 2011] and diffusion tensor imaging-based fiber tracking [Umarova et al., 2009].

ITPJ TMS did not induce any significant effect in the current experiment. This weaker, nonsignificant effect supports the notion of ventral network being lateralized in the right hemisphere [Corbetta and Shulman, 2002; Corbetta et al., 2008; Shulman et al., 2010]. However, the slightly altered capture effect in the right visual field is similar to the rTPJ TMS condition. This may reflect the left ventral network playing a supportive role when the right dominant site is intact, and taking charge when the right network is damaged. However, this is still speculative and should be investigated in the future by using different methods of brain stimulation, such as different protocols of TMS or different polarities of transcranial direct current stimulation. This method may further clarify the interaction between the hemispheres.

In conclusion, our data demonstrate the casual relationships between both attentional networks and attentional reorienting. Dissociations in our results showed that the dorsal network is involved in exogenous reorienting while the ventral network is critical to contingent reorienting. Furthermore, the current findings confirm the lateralization of the ventral network and revealed its spatial selec-

tivity. These results extend the functional role of the ventral network in the theoretical model of attentional orienting.

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