



Posterior parietal cortex mediates encoding and maintenance processes in change blindness

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ABSTRACT

It is commonly accepted that right posterior parietal cortex (PPC) plays an important role in updating spatial representations, directing visuospatial attention, and planning actions. However, recent studies suggest that right PPC may also be involved in processes that are more closely associated with our visual awareness as its activation level positively correlates with successful conscious change detection (Beck, D.M., Rees, G., Frith, C.D., & Lavie, N. (2001). Neural correlates of change detection and change blindness. *Nature Neuroscience*, 4, 645–650.). Furthermore, disruption of its activity increases the occurrences of change blindness, thus suggesting a causal role for right PPC in change detection (Beck, D.M., Muggleton, N., Walsh, V., & Lavie, N. (2006). Right parietal cortex plays a critical role in change blindness. *Cerebral Cortex*, 16, 712–717.). In the context of a 1-shot change detection paradigm, we applied transcranial magnetic stimulation (TMS) during different time intervals to elucidate the temporally precise involvement of PPC in change detection. While subjects attempted to detect changes between two image sets separated by a brief time interval, TMS was applied either during the presentation of picture 1 when subjects were encoding and maintaining information into visual short-term memory, or picture 2 when subjects were retrieving information relating to picture 1 and comparing it to picture 2. Our results show that change blindness occurred more often when TMS was applied during the viewing of picture 1, which implies that right PPC plays a crucial role in the processes of encoding and maintaining information in visual short-term memory. In addition, since our stimuli did not involve changes in spatial locations, our findings also support previous studies suggesting that PPC may be involved in the processes of encoding non-spatial visual information (Todd, J.J. & Marois, R. (2004). Capacity limit of visual short-term memory in human posterior parietal cortex. *Nature*, 428, 751–754.).

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1. Introduction

The posterior parietal cortex (PPC) has been suggested to play an important role in spatial working memory (Jonides et al., 1993) and visuomotor control (Ellison & Cowey, 2006; Milner & Goodale,

1995; Mishkin, Ungerleider, & Macko, 1983; Nobre et al., 1997). These functions are consistent with the classic “ventral vs. dorsal” model (Goodale & Milner, 1992; Milner & Goodale, 1995; Mishkin et al., 1983) in which the PPC (dorsal) controls goal-directed movements in visual space beneath our conscious awareness. However, recent neurological studies have suggested that PPC, and the parietal lobe in general, may also be involved in processes beyond its preconceived “dorsal” functions (Berryhill & Olson, 2008; Culham & Kanwisher, 2001; Xu & Chun, 2006). Indeed, patient and functional magnetic resonance imaging (fMRI) studies indicate that PPC may be a critical area involved in visual short-term memory (VSTM) (Berryhill & Olson, 2008; Song & Jiang, 2006), a limited buffer that provides us with a sense of visual continuity. ERP studies also show that PPC activity can be used to predict individual differences in

Abbreviations: fMRI, functional magnetic resonance imaging; PPC, posterior parietal cortex; rTMS, repetitive transcranial magnetic stimulation; TMS, transcranial magnetic stimulation; VSTM, visual short-term memory.

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visual working memory capacity (Vogel & Machizawa, 2004), and is closely linked with conscious detection of visual changes (Pourtois, De Pretto, Hauert, & Vuilleumier, 2006). Moreover, studies using the change blindness paradigm in conjunction with fMRI and transcranial magnetic stimulation (TMS) further suggest that PPC may be directly involved in our visual awareness and conscious change detection (Beck, Rees, Frith, & Lavie, 2001; Beck, Muggleton, Walsh, & Lavie, 2006; also see Schott et al., 2005 for an example with recollection memory).

Change blindness is a visual phenomenon that describes people's failure or prolonged reaction time (RT) to detect changes between two alternating pictures (A and A') that are separated by a brief visual disruption (Rensink, O'Regan, & Clark, 1997). Even when the changes look rather obvious in hindsight, the search process can sometimes take up to a minute until conscious detection occurs. This is because the bottom-up signals that we rely heavily on can be masked by disruptions such as a blink, saccade, or artificially induced flicker or movie cut (Bridgeman, Hendry, & Stark, 1975; Rensink et al., 1997; Levin & Simons, 1997). The effect of change blindness is robust, and has been used extensively in studies of visual representation and awareness: namely how and what do we encode, retain, retrieve, and compare in the processes that ultimately lead to change detection (Hollingworth & Henderson, 2002; Hollingworth, 2006; O'Regan and Noe, 2001; Pashler, 1988; Simons & Rensink, 2005)?

Neuroimaging studies have reported increased parietal activity when visual working memory load increases (Todd & Marois, 2004; Xu & Chun, 2006). Furthermore, in a recent ERP study, Pourtois et al. (2006) found enhanced activity in bilateral posterior parietal cortices when their subjects consciously detected a change but not when they missed it. Similar findings were also reported by Beck et al. (2001) using fMRI. Beck and colleagues' later TMS study further demonstrated that when repetitive pulses of TMS (rTMS hereafter) were applied repeatedly over the *right* PPC throughout a 500 ms 1-shot change blindness trial (200 ms picture A, 100 ms flicker, and 200 ms picture A' without repeated alternation), participants' miss rates increased significantly (Beck et al., 2006). This indicated that right, but not left, PPC plays a causal role in conscious change detection. Such dissociation in function between left and right PPC has been suggested by many, with the left specializing in motor attention (Rushworth, Ellison, & Walsh, 2001) and temporal events (Coull & Nobre, 1998), and the right specializing in spatial representation (Coull & Nobre, 1998; Husain & Nachev, 2007). However, since Beck et al. (2006)'s rTMS duration covered each trial in its entirety, their study could not differentiate the time point at which PPC involvement was critical, and so the specific processes that right PPC mediates in change blindness are still unclear. When viewing images in a change blindness paradigm, it is necessary to encode and hold the items from picture A in VSTM, and successfully compare the stored items with those of picture A' in order to ensure accurate change detection. Therefore, there is a serial order of stages that starts with encoding and maintenance, and ends with retrieval and comparison. Failure in any of these steps would result in poor detection performance. Neuropsychological studies have pointed to both limitations in storage (Luck & Vogel, 1997) and failures in retrieval and comparison (Hollingworth, 2003) for an explanation. As mentioned above, neuroimaging and patient studies have also established a link between right PPC and working memory, and successful change detection. Imaging and patient studies, however, cannot differentiate the precise timing of PPC's involvement in change detection tasks. Findings from previous studies of timing of PPC involvement in the performance of various tasks have been mixed. Studies have suggested different windows of effect for PPC: 120–160 ms after stimulus onset in a visual search task (Ashbridge, Walsh, & Cowey, 1997; Kalla, Muggleton, Juan, Cowey, & Walsh, 2008) and 300–350 ms in a visual-spatial discrim-

ination task (Ellison & Cowey, 2007; Oliveri et al., 2001). Therefore, the specific role of right PPC behind change awareness and blindness still remains unclear. The present study employed temporally specific TMS to determine the time points during which the right PPC is critically involved.

Since TMS is a tool with high temporal resolution, varying the timeframe of the pulses may selectively interfere with different processes and reveal the stages in which right PPC is heavily involved. While it is less clear when the processes of maintenance and retrieval begin and end (e.g. maintenance can start before the offset of picture A, or restart after retrieval; likewise, retrieval may start before the onset of picture A'), the timings of encoding and comparison processes are less ambiguous as a major portion of these processes should overlap in time with the duration of picture A and A', respectively. While picture A' should also require a certain amount of encoding, this would be expected to be considerably less than picture A since comparisons can be made while viewing picture A' online. In the present study, temporally restricted TMS of 10 Hz rTMS over right PPC for 200 ms (i.e. 3 pulses) was employed. This rTMS protocol has been widely used to investigate the functional roles of visual cortices in many tasks. Juan & Walsh, 2003 used this rTMS protocol over V1 and found that rTMS impaired participants' performance of visual search in two different time windows (for review see Juan, Campana, & Walsh, 2004). Juan et al. (2008) further used this protocol to temporally dissociate the processes of visual selection and saccade preparation in human FEF. A similar approach was also used to investigate the different temporal involvement between FEF and PPC (Kalla et al., 2008), and occipital cortex and PPC (Ellison & Cowey, 2007).

The predictions of the present study are as follows. If right PPC is responsible for encoding items into VSTM, or maintaining them thereafter, participants' performance should worsen when rTMS is applied during the early 200 ms phase and remain intact in the latter 200 ms phase. Conversely, participants' performance should decline in the latter 200 ms phase if right PPC is involved in the comparison processes. If right PPC, however, is responsible for more general functions such as directing attention to salient stimuli (Nobre et al., 2004; For review see Nobre, 2001; Rushworth & Taylor, 2006) and computing temporal order of events (Battelli, Pascual-Leone, & Cavanagh, 2007; Coull & Nobre, 1998; Leon & Shadlen, 2003) that are vital both to the processes of encoding and comparison, then TMS applied to either phase should yield poor change detection.

2. Material and methods

2.1. Experimental subjects

Ten right-handed participants (7 males, 3 females, aged between 20 and 27 years, mean age 23.3) took part in the experiment for monetary payments. All had normal or corrected-to-normal vision and gave informed written consent prior to the experiment. The experiment was approved by Institutional Review Board of the Chang-Gung Memorial Hospital, Taoyuan.

2.2. Stimuli and procedure

The task, programmed in E-prime, running on an IBM compatible PC, consisted of presentation of two successive stimuli on a monitor and subjects were instructed to perform a two-alternative forced choice task, indicating whether or not the stimuli were identical. Unlike the conventional change blindness flicker paradigm, our task was a 1-shot detection trial that had only two displays without any repetition. Each trial started with a 500 ms fixation cross, followed by a 200 ms presentation of picture A, a 100 ms blank screen, then a 200 ms presentation of picture A', and ended

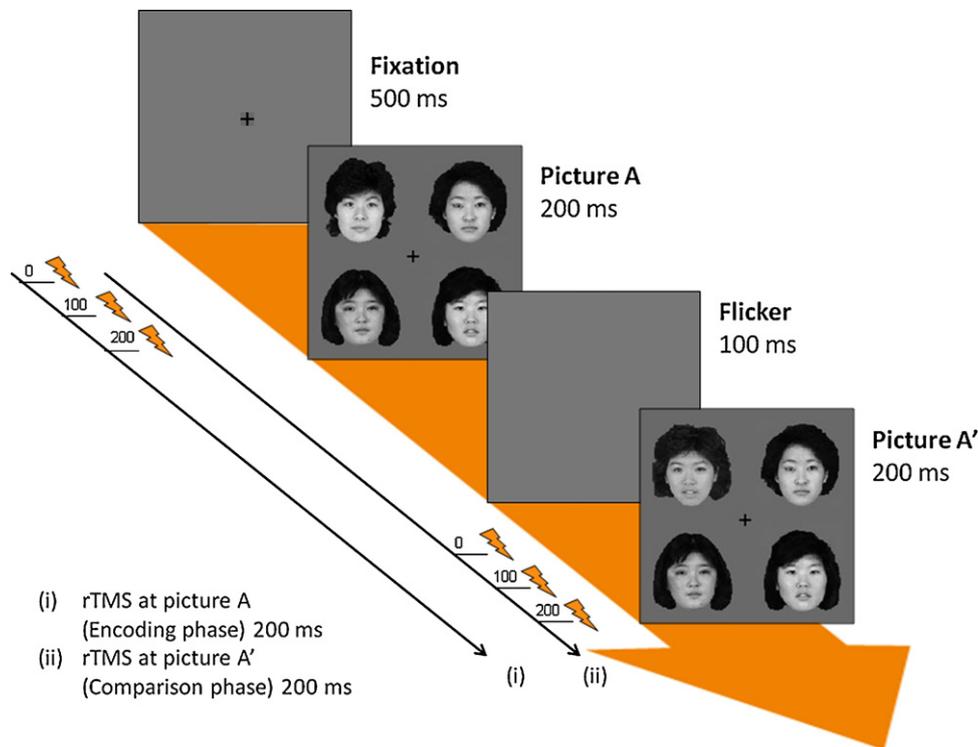


Fig. 1. Task procedure. The change blindness task includes a fixation cross (500 ms), picture A (200 ms), Flicker (100 ms), and picture A' (200 ms). rTMS (10 Hz) was applied either during the viewing of picture A (encoding phase) or A' (comparison phase) at the 0, 100, and 200 ms time points.

with a 2500 ms response interval (see Fig. 1). Premature responses that took place in the first 100 ms of the 2500 ms response interval were excluded from analyses (<1% of all trials).

Both pictures A and A' consisted of four female Asian faces in a 2×2 layout, one in each corner. The four faces that appeared in picture A were chosen from a pool of five. Half of the time, the fifth face would replace one of the four faces in picture A'. The remaining half did not contain a change. All faces which changed and the corners in which they appeared were counter-balanced. The entire display subtended 5° by 5° in visual angles at 86 cm viewing distance with each face subtending 2.5° visual angle. Participants were instructed to press the key "1" or "2" on the keyboard number pad with their right index and middle fingers to indicate whether they thought there was either a change or not. They were also asked to respond as fast as they could.

The experiment consisted of two blocks: one with TMS and one without. The orders of the blocks were counter-balanced between subjects. Each block consisted of 240 interleaved change and no-change trials, with 120 trials of each type. In the TMS condition, the 120 change trials were further divided in half into two types: early TMS (encoding) and late TMS (comparison), indicative of the timing in which rTMS was applied. Participants were allowed to take a short break every 60 trials, and a longer break between the blocks.

2.3. rTMS parameters and design

A Magstim Super-Rapid Stimulator and a 70 mm figure of eight coil were used to deliver rTMS at 60% of maximum machine output (approx. 1.2 T, duration of one pulse: less than 1 ms) over the right PPC. rTMS onset and duration (10 Hz, 3 pulses total at 0, 100, and 200 ms) matched either the first 200 ms (i.e. the encoding phase) or the latter 200 ms (i.e. the comparison phase). Therefore, in the early TMS condition, participants received three rTMS pulses per trial at the onset (0 ms), middle (100 ms), and offset (200 ms) of picture

A. Likewise, the same rTMS pulses were applied during picture A' in the late TMS condition. A fixed stimulation level was used by both because it has proven successful and replicable in many studies over a wide range of tasks (e.g.: Ashbridge et al., 1997; Chen, Muggleton, Tzeng, Hung, & Juan, 2009; Ellison & Cowey, 2007; Hung, Driver, & Walsh, 2005; Juan et al., 2008; Muggleton, Juan, Cowey, & Walsh, 2003) and because it has been shown that a stimulation threshold in one region does not provide a guide of that in other areas (Stewart, Walsh, & Rothwell, 2001).

Beck et al. (2001, 2006) have demonstrated that the right PPC (Talairach coordinates: 24, -60, 60, see Fig. 2) is critical for performance of a change blindness task. We therefore adopted the coordinates for each of our subjects in the experiments. The localization procedures were as follows. First, using the FSL software (FMRIB, Oxford), individual MRIs were normalized against a standard template, resulting in a matrix describing the transformation. Then these transforms were reverse-applied to the right PPC coordinates to obtain the corresponding location in the individual original MRI scans. Our participants then 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) which forms part of the BrainSight system (Rogue Research, Montreal, Canada), subsequently allowing the skull point overlying the region to be stimulated to be identified.

3. Results and statistical analysis

As with Beck et al.'s study, miss rates were used to assess how often our participants were blind to the changes under each condition. To be specific, a miss was scored when participants responded "no-change" to a trial where a change occurred. These miss rates were submitted to a one-way repeated-measure analysis of variance (ANOVA) with three factors: no-TMS, early TMS (encoding), and late TMS (comparison). The analysis showed a significant effect

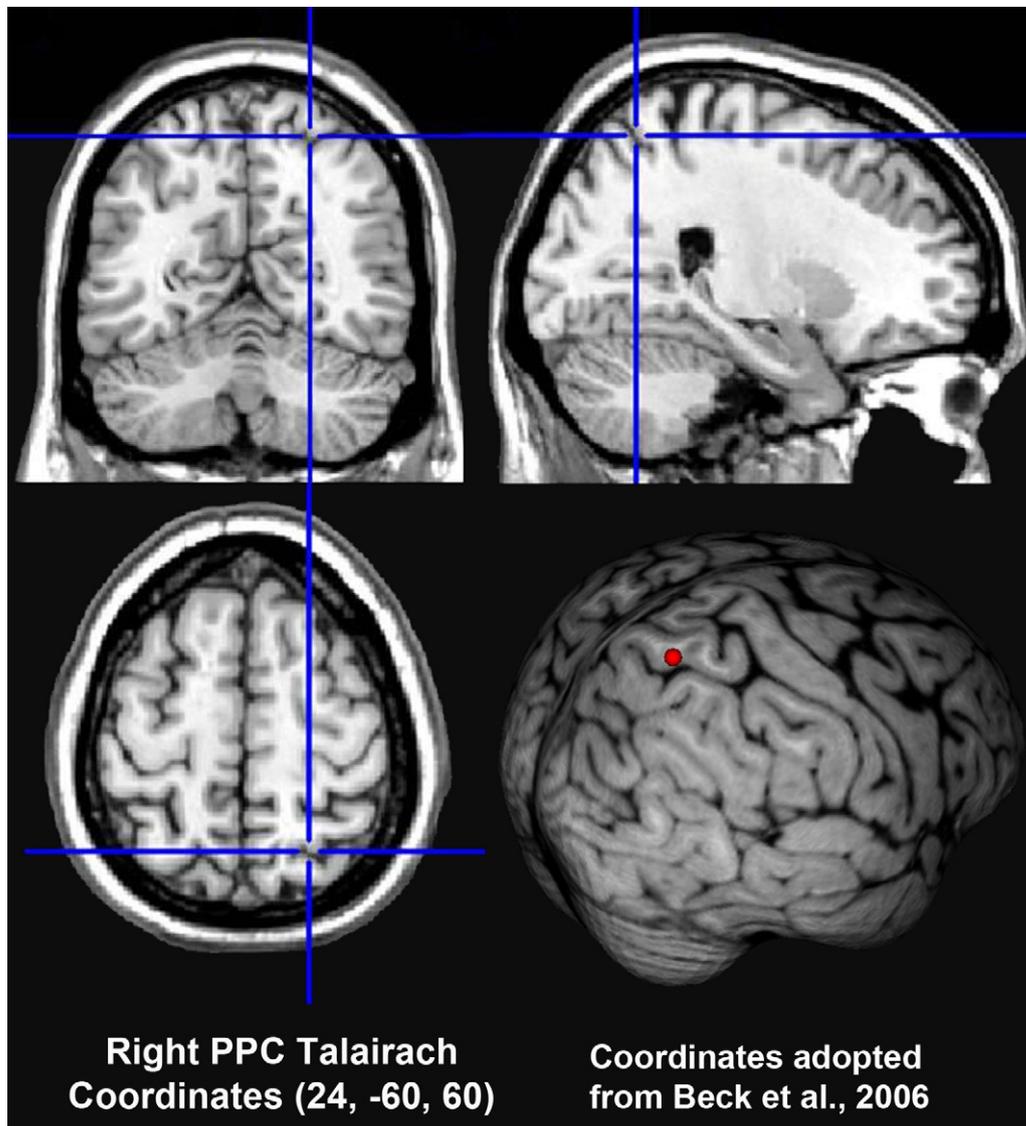


Fig. 2. Site localization. The right PPC magnetic stimulation sites were localized using theBrainsight TMS–MRI co-registration system (Rogue Research, Montreal, Canada). The Tailarach coordinates of 24, –60, are 60 reported by Beck et al. (2006) were used.

of condition [$F=7.133$, $p=.017$]. Post hoc analyses revealed that participants' miss rates were significantly higher in the early TMS condition than for no-TMS [$p=.014$], and late TMS [$p=.01$] conditions. There was no significant difference in miss rates between the no-TMS and late TMS conditions [$p=.216$] (see Fig. 3). Therefore, change blindness occurred significantly more often only when right PPC activity was disrupted during the encoding phase of the trial. In order to test whether results were driven by strategy-related biases, a signal detection analysis was conducted and the d' score for change detection for each individual was calculated. d' measures the distance between one's "signal" and "noise" distributions independent of response criterion, and therefore is a more accurate estimator of ability to detect a signal (change in this case). One-way ANOVA on the d' measures revealed the same pattern as our miss rates [$F=5.909$, $p=.027$]. That is, participants performed worse in the early TMS condition in comparison to the no-TMS [$p=.011$] and late TMS [$p=.01$] conditions. There was also no significant difference in d' between the no-TMS and late TMS conditions [$p=.205$] (see Fig. 4). The C bias values were also calculated for each individual and showed no differences across conditions in a one-way ANOVA [$F=.051$, $p=.951$]. These analyses show that the results were not likely to be driven by participants' shift of biases

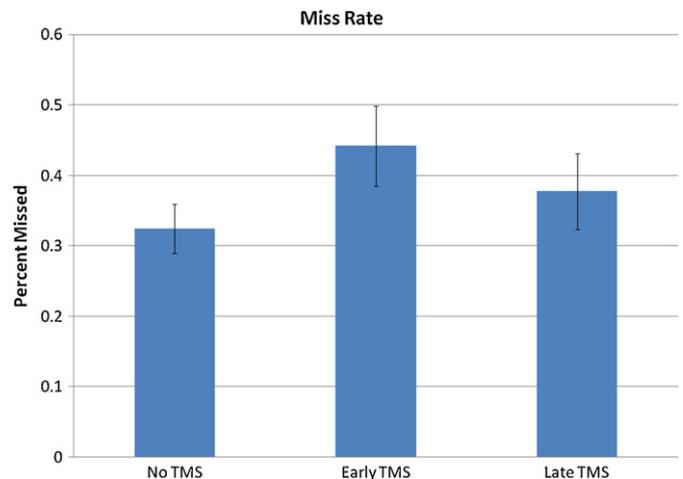


Fig. 3. Miss rates. Mean percentage of changes that were missed during the encoding and comparison phase, with or without TMS. Data showed a significantly higher miss rate in the early TMS (encoding) condition than the no-TMS [$p=.014$] and late TMS [$p=.01$] conditions while the latter two were not significantly different from each other [$p=.216$].

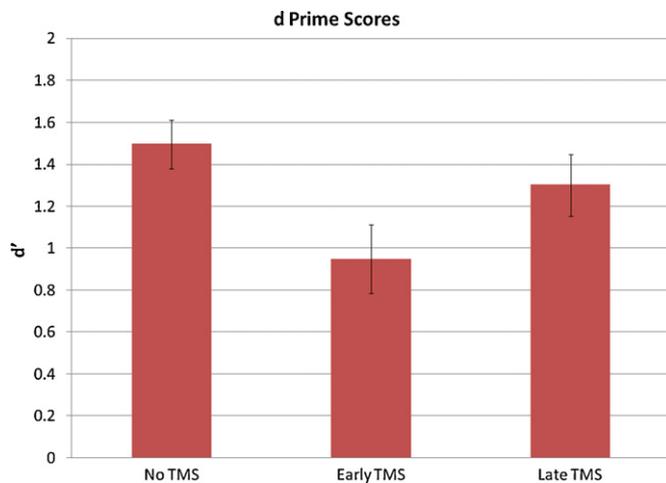


Fig. 4. d' scores. Mean d' scores from each experimental condition. Participants' d' scores in the early TMS condition were significantly lower than the no-TMS [$p = .01$] and late TMS [$p = .01$] conditions. The no-TMS and late TMS d' scores were not different from each other [$p = .205$]. Since d' also takes false alarms into account, our data suggest that TMS during encoding phase indeed disrupted the encoding processes rather than shifted participants' response criterion.

in response. Rather, early rTMS impaired participants' abilities to detect changes. Together, the d' and miss rate analyses provide converging evidence for an impaired performance during the encoding and maintenance phase.

To make sure the observed effects were not driven by the noises that are typically generated by TMS, we collected additional data from ten more participants. Each participant completed one block of 120 control trials (no-TMS), and one block of sham TMS trials (120 early TMS and 120 late TMS). Sham TMS was done by placing the TMS coil perpendicularly above each participant's right PPC. Thus the tactile and auditory sensations (e.g. the touch of the TMS coil and the loud bursts), as well as their timings (early and late TMS), all mimicked those of real TMS trials. Hit rates and d' scores were submitted to a 2-way ANOVA. The analysis revealed no main effect of condition (control vs. sham) [hit rate: $F = .504$, $p = .496$; d' : $F = .149$, $p = .708$], TMS timing (early vs. late) [hit rate: $F = .846$, $p = .382$; d' : $F = .437$, $p = .525$], or the interaction between the two [hit rate: $F = 1.224$, $p = .297$; d' : $F = .499$, $p = .498$]. Therefore, our findings were not likely to be driven by the loud noises that are typically associated with TMS.

It should be noted that previous studies have also reported an enhanced visual-spatial attention ipsilateral to the site of rTMS (Hilgetag, Théoret, & Pascual-Leone, 2001). This is based on the logic that rTMS can create interference for the contralateral visual space, thus indirectly facilitating the ipsilateral space. Based on this finding, we might expect to see an enhanced detection rate to faces that were presented on the right, and vice versa. We therefore submitted hit rates from the left and right sides of visual space, either with or without TMS, to a repeated-measure two-way ANOVA. The analysis indicated a significant effect of TMS [$F = 5.301$, $p = .047$], but did not reveal any difference in hit rates on changes that were presented to the left or right [$F = 1.22$, $p = .298$], nor an interaction between TMS and side [$F = .237$, $p = .638$] (see Fig. 5). Similar results were also reported by Beck et al. (2006), who observed poor change detection in both visual fields when TMS was applied to the right PPC. TMS to the left was ineffective in either visual field. These results can be explained by the idea that right parietal cortex may possess a bilateral representation of visual space (Heilman & Van Den Abell, 1980; Mesulam, 1981). It is also consistent with the phenomenon of visual neglect in which impaired visual awareness follows right, but not left, parietal lesions. Therefore, we believe this lack of difference between left and right in our change detection paradigm

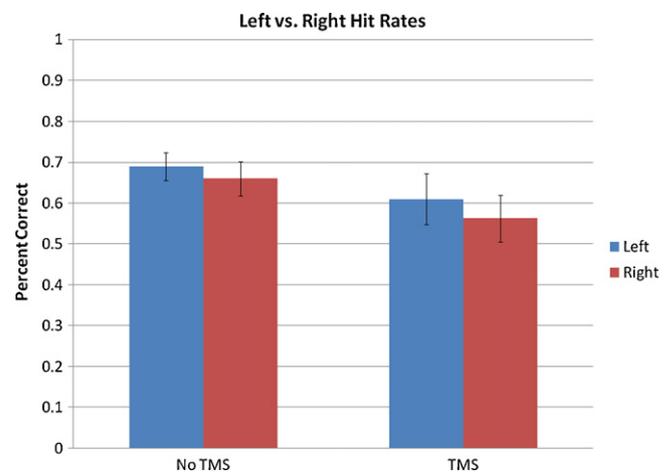


Fig. 5. Left vs. right hit rates. Mean hit rates of the stimuli that were presented either to the left or right side of the fixation cross. There was no effect of the side on which the changes occurred.

is consistent with the distributed spatial representation of right parietal cortex.

4. Discussion

Our data is consistent with Beck et al.'s study (2006) and extends their finding by specifying the nature of the role of PPC through the use of a temporally precise TMS method. Previously there have been many theoretical accounts for PPC function: updating spatial mapping (Andersen, Essick, & Siegel, 1985; Merriam, Genovese, & Colby, 2003; Morris, Chambers, & Mattingley, 2007), coding numbers (Hubbard, Piazza, Pinel, & Dehaene, 2005), directing attention to salient stimuli (Nobre, 2001; Constantinidis & Steinmetz, 2005; Hodsoll, Mevorach, & Humphreys, 2009; Mevorach, Humphreys, & Shalev, 2006; Rushworth & Taylor, 2006), binding features (Friedman-Hill, Robertson, & Treisman, 1995; Ashbridge, Cowey, & Wade, 1999; Ellison, Lane, & Schenk, 2007), keeping track of temporal patterns (Carmel, Lavie, & Rees, 2006; Coull & Nobre, 1998), and maintaining items in VSTM (Todd & Marois, 2004, 2005; Vogel & Machizawa, 2004). While our finding here does not contradict any of these explanations, it strongly supports a role for PPC involvement in encoding or maintaining information in VSTM. It is important to note, however, that we are not arguing that right PPC is the neural locus of visual encoding. Although its activity level is positively correlated with one's VSTM capacity (Todd & Marois, 2005), its function need not necessarily be encoding and maintenance *per se*. For example, deploying top-down attentional bias (Kastner & Ungerleider, 2001; Pessoa & Ungerleider, 2004) has been suggested as one of right PPC's many functions, and its impairment can impact negatively on the encoding processes more so than on the retrieval processes. Since change detection depends on a large distributed activity of the attentional network (Pourtois et al., 2006), it is also likely that our TMS pulses might have disrupted the attentional activation required for sufficient processing and awareness of changes. As mentioned above, there is ample evidence suggesting multiple roles for right PPC. This study further establishes a causal link between right PPC and the process of visual encoding.

4.1. What information does PPC help encode?

Our study suggests that PPC is involved in the network that encodes and maintains information from picture A. However, what information exactly is being encoded and maintained by such net-

work? In addition to the common belief that parietal lobe is heavily involved in processing the spatial characteristics of an object, we only observed a significant performance decline in the TMS encoding and maintenance phase condition but not in the TMS comparison phase. Since both phases pose similar demands on spatial attention, such dissociable TMS effects cannot be explained by disruption of spatial information alone, but also the encoding and maintenance processes. Indeed, imaging studies have suggested that PPC activation can be positively correlated with the load of identity-based information (Todd & Marois, 2004; Vogel & Machizawa, 2004), which makes this a likely candidate for encoding. Correlational evidence comes from several lines of research. First, Todd and Marois (2004) observed increased PPC activation in a spatial VSTM task, which is consistent with PPC's role in spatial attention and representation. Interestingly, and similar to our finding, the same activation pattern was still observed when target location was made irrelevant to the task. Based on this finding, Todd and Marois suggested that perhaps the PPC is involved in several forms of VSTM storage on top of spatial information. Song and Jiang (2006) also reported that PPC can be sensitive to the complexity of object features. Thus, increasing feature complexity (e.g. from color to shape) also increased PPC activation. Further, Assad and colleagues suggested that the lateral intraparietal cortex in monkeys (corresponding to human PPC) is sensitive to color when color is a behaviorally relevant feature (Toth & Assad, 2002; Assad, 2003). Therefore, depending on the nature of the task, PPC can be selectively activated by different non-spatial features in addition to its involvement in spatial attention and representation. Second, studies have suggested that right PPC plays a critical role in conjunction visual search tasks (Ashbridge et al., 1997, 1999; Ellison, Rushworth, & Walsh, 2003; Ellison, Schindler, Pattison, & Milner, 2004; Ellison et al., 2007), and even grapheme-color synaesthetic experience (Muggleton, Tsakanikos, Walsh, & Ward, 2007). Right PPC TMS can also impair performance in color-orientation conjunction tasks (Ellison et al., 2007) and inefficient feature-based visual search (Rosenthal, Walsh, Mannan, Anderson, Hawken, & Kennard, 2006). As of now, it is still unclear whether the right PPC is responsible for the binding of features or the selection of spatial location that contains certain features such as color (Ashbridge et al., 1997, 1999; Muggleton, Cowey, & Walsh, 2008), or both, in the context of a conjunction task. Nevertheless, it seems plausible to assume that right PPC is closely related to the processing of certain basic features. Lastly, neurological studies also suggest a causal link between parietal areas and color priming. Marangolo, Di Pace, Rafal, & Scabini, 1998 found that patients with parietal damage failed to show color priming in the contralateral visual space. Together, these findings suggest that in addition to its role in spatial memory, the right PPC is also involved in the processing of certain identity-based information, form, and orientation. Therefore, it is likely that the right PPC is also involved in the network that encodes these features for further visual processing. One possible beneficiary from such an encoding network is transsaccadic memory, a limited visual storage device that encodes the position and identity of pre-saccadic targets in order to maintain visual continuity and stability across saccades (Currie, McConkie, Carlson-Radvansky, & Irwin, 2000; Irwin, McConkie, Carlson-Radvansky, & Currie, 1994; McConkie & Currie, 1996) and guide errant saccades to their correct destinations (Hollingworth, Richard, & Luck, 2008); all of which depend heavily upon PPC's involvement in updating spatial representation, directing visuospatial attention, and encoding identity-based information. Supporting evidence comes from Prime, Vesia, & Crawford (2008)'s recent study that applied TMS to PPC during saccadic eye movements at three different SOAs (100, 200, and 300 ms after the saccade-go signal) and found that interference of *right*, but not left, PPC disrupted participants' transsaccadic memory significantly. Further research on this topic,

as well as the specific type of identity information encoded, is still needed.

4.2. Processes of encoding and maintenance

While we interpreted the early involvement of right PPC from an encoding perspective, one may argue that our paradigm did not entirely tease apart encoding from maintenance within the presentation of picture A because the two processes can happen in parallel. However, encoding must start before maintenance, and therefore it is plausible to assume that our three rTMS pulses (especially the first one at 0 ms) should have interfered with the encoding processes more so than maintenance. Nevertheless, we note that it is also possible that the *maintenance* processes, or the attentional demands behind it, were disrupted by the rTMS after visual information has been successfully encoded into VSTM. Several psychophysical studies have suggested such failure in maintaining details from picture A as the main cause of change blindness (Becker, Pashler, & Anstis, 2000; Landman, Spekreijse, & Lamme, 2003; Sampanes, Tseng, & Bridgeman, 2008). In other words, we may very well encode and possess a detailed visual representation of a scene while it lasts, but such rich representation is "overwritten" at the onset of the subsequent scene, leaving only the few areas of attended information 'un-erased'. It is possible that our early TMS pulses might have disrupted the maintenance of information in VSTM, thus making the attended (and encoded) information vulnerable to being overwritten even if they have already been safely stored in VSTM.

5. Conclusion

There is a growing literature suggesting a causal relationship between PPC and visual awareness. Particularly, VSTM capacity seems to rely heavily upon PPC activities (Todd & Marois, 2004; Vogel & Machizawa, 2004; Xu & Chun, 2006). While these may be due to parietal lobe's general involvement in spatial attention and action, in this paper we report that disruption of right PPC activity impaired change detection only when participants were looking at picture A during TMS and not A'. This signifies that right PPC plays a crucial role in the processes of encoding and maintaining item information in VSTM. As previously mentioned, there have already been several studies speculating that PPC may have a functional role in building visual awareness (Beck et al., 2001, 2006). The present study confirms such causal relationship between right PPC and conscious change detection, and suggests that right PPC is critical in encoding and maintaining information in VSTM.

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