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Research report

Cortical control of inhibition of return: Causal evidence for task-dependent modulations by dorsal and ventral parietal regions

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ABSTRACT

Inhibition of return (IOR) reflects a bias to preferentially attend to non-previously attended or inspected spatial locations. IOR is paramount to efficiently explore our environment, by avoiding repeated scanning of already visited locations. Patients with left visual neglect after right parietal damage or fronto-parietal disconnection demonstrated impaired manual, but not saccadic, IOR for right-sided targets (Bourgeois et al., 2012). Here we aimed at investigating in healthy participants the causal role of distinct cortical sites within the right hemisphere in manual and saccadic IOR, by evaluating the offline effects of repetitive Transcranial Magnetic Stimulation (rTMS) on the right intra-parietal sulcus (IPS) and the right temporo-parietal junction (TPJ). Our results show that rTMS over both sites lastingly interfered with manual but not saccadic IOR for right-sided targets. This behavioral pattern closely mimicked the performance of neglect patients evaluated with the same paradigm. In contrast, for left-sided targets, rTMS over the right IPS impaired both manual and saccadic IOR, while rTMS over the right TPJ produced no modulation in either task. We concluded that distinct parietal nodes of the dorsal and ventral spatial attention networks of the right hemisphere make different contributions to exogenous orienting processes implicated in IOR, and that such effects are hemifield- and task-dependent.

1. Introduction

Our visual system is constantly overloaded with information from the environment. Hence, when several events compete for limited perceptual resources, selective attention mechanisms are necessary to efficiently devote processing to relevant objects and respond to them appropriately. Activity within fronto-parietal orienting systems allows us to drive

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spatial attention to an object either voluntarily (endogenously) or involuntarily (exogenously) (Chica et al., 2011, 2013; Corbetta and Shulman, 2002; Indovina and Macaluso, 2007; Nobre et al., 1997; Perry and Zeki, 2000; Rosen et al., 1999). The sudden appearance of a peripheral stimulus often triggers an exogenous attentional capture, which facilitates the early processing of a subsequent target, increasing accuracy and reducing response times (RTs) of targets presented at the attended or inspected location. However, after 100–400 msec, depending on the task at hand (Chica et al., 2006; Lupiáñez et al., 1997), responses to previously attended or inspected locations are slower and/or less accurate, as compared to responses to non-previously attended or inspected locations (Berlucchi, 2006; Klein, 2000; Lupiáñez et al., 2006; Posner and Cohen, 1984; Posner et al., 1985). This phenomenon is known as inhibition of return (IOR); it is generated under both overt and covert orienting, that is when gaze moves to a peripheral stimulus (saccadic IOR), or has to remain on central fixation while participants respond manually (manual IOR) (Posner et al., 1985).

Psychophysical observations from a single brain-damaged patient (Sapir et al., 1999), neuroimaging data obtained in intact humans (Anderson and Rees, 2011), and neurophysiological evidence in monkeys (Dorris et al., 2002), indicate that the superior colliculus (SC), a structure of the midbrain tectum involved in sensory-guided eye and upper trunk movements, critically contributes to IOR. The SC contribution to IOR could be developed in concert with up-stream cortical structures such as the posterior parietal cortex (Dorris et al., 2002). Consistent with this notion, event-related Transcranial Magnetic Stimulation (TMS) over areas of the right posterior parietal cortex has proven able to disrupt manual IOR (Chica et al., 2011), and IOR spatial remapping (Van Koningsbruggen et al., 2010).

Also consistent with the hypothesized importance of right posterior parietal cortical sites in IOR, patients with right hemisphere damage and signs of left visual neglect demonstrated facilitation, instead of IOR, for the detection of consecutive right-sided targets using manual responses (Bartolomeo et al., 1999; Bourgeois et al., 2012; see also Vivas et al., 2003, 2006). In contrast, patients with right hemisphere damage but no signs of visuo-spatial neglect seem to display normal manual IOR for stimuli presented in both the right and the left hemi-spaces (Bartolomeo et al., 1999).

We have recently demonstrated that unlike manual IOR, saccadic IOR for right-sided targets was preserved in the same group of neglect patients (Bourgeois et al., 2012) (see Table 1). Moreover, in this study, disruption of manual IOR was associated with cortical lesions involving areas of the right postero-inferior parietal cortex or their white matter connections with prefrontal regions. Unfortunately, the extension of the brain lesions made it difficult to establish whether right parietal structures pertaining to the dorsal attentional network, such as the intra-parietal sulcus (IPS), or to the ventral attentional network, such as the temporo-parietal junction (TPJ) (Corbetta and Shulman, 2002), or both, could be causally implicated in the modulation of IOR, and whether such modulation would also be present in the intact human brain.

To address these issues, we applied inhibitory patterns of focal repetitive TMS (rTMS) on these two areas of the right parietal cortex (right IPS and right TPJ) to induce transient lasting interference of local and connectivity-mediated brain activity, which we hypothesized would mimic the behavioral effects observed in our population of neglect patients (Valero-Cabré et al., 2011; Wagner et al., 2007). To establish causality, we then gauged the impact that such disruption on either cortical site would exert on manual and saccadic IOR for ipsilateral (right-sided) and contralateral (left-sided) visual targets.

2. Methods

2.1. *Participants*

Twenty-two participants (12 women, all right-handed, mean age 25 years, range 18–36 years) with normal or corrected-to-normal vision and no history of neurological or psychiatric disorders participated in this study. A control group of sixteen age- and sex-matched participants (8 women, all right-handed, mean age 22 years, range 19–30 years, $t > 1$ for mean age and sex comparisons) was also included. This study was reviewed by the INSERM ethical committee and received the approval of an Institutional Review Board (CPP *Ile de France* 1). Written informed consent was obtained from each participant. In addition, participants filled in a safety-screening questionnaire to rule out risk factors for magnetic resonance imaging (MRI) and TMS interventions. Before the experiment, all participants underwent structural high-definition MRI, which was then 3D-reconstructed and served to navigate the position of the TMS coil in native brain space.

Table 1 – Summary table indicating the presence of an IOR effect or a facilitatory effect, in healthy participants, and right brain-damaged patients with and without neglect, for left and right-sided targets, under manual or saccadic responses (Bartolomeo et al., 1999; Bourgeois et al., 2012).

	Manual		Saccadic	
	Left targets	Right targets	Left targets	Right targets
Healthy participants	IOR	IOR	IOR	IOR
RBD patients without neglect	IOR	IOR	IOR	IOR
RBD patients with neglect	IOR	Facilitation	No IOR[a]	IOR

a Bourgeois et al.'s (2012) study did not find a significant IOR effect for left-sided targets under saccadic responses in patients with left visual neglect, although no strong conclusions were extracted at this point, because the authors were not confident on this newly observed result, which might have been explained by the increased RT variability often observed in neglect patients' performance for left-sided targets.

2.2. *Apparatus, stimuli, and procedure*

A PC Dell Latitude D600 running E-prime software (Schneider et al., 2002) controlled the presentation of stimuli, timing operations, and data collection. Stimuli were presented on an eye-tracker screen (Tobii 1750, 1024 × 768, 16 bit), also used to monitor and record the location of gaze every 20 msec. Eye movement recording was calibrated before each session. Participants sat at approximately 57 cm from the monitor. The fixation point consisted of a circle placed at the center of the screen, surrounded by four black circles. The diameter of each circle subtended 1° of visual angle. The center of the four peripheral circles was placed at a distance of 5° of visual angle from the center of the fixation circle (Fig. 1A). All stimuli were displayed on a grey background and were presented with an equally sufficient luminance in order to activate most retinal receptors and both the magnocellular and parvocellular visual pathways (Guenther and Brown, 2012; Sumner et al., 2004).

2.2.1. *Manual response task (covert attention)*

Participants were instructed to maintain their gaze at the central fixation circle through the trials. The fixation display (containing the fixation and the four peripheral circles) was presented for a random time period ranging from 1100 to 2100 msec. Immediately afterwards, one of the peripheral circles became white. Participants were required to respond as fast and as accurately as possible to this occurrence by pressing the right mouse button with their right index finger. The target disappeared when a response was detected or after 3000 msec if no response was made. Then the central circle turned white during 500 msec (cue back). Participants were instructed not to respond to the cue back. A new trial then started, with a new fixation display followed by a new peripheral target. The experiment consisted of a total of 180 trials.

2.2.2. *Saccadic response task (overt attention)*

The procedure was identical to the manual task, with the following exceptions: participants were required to respond by moving their eyes to the target as fast and as accurately as possible, and subsequently by moving their eyes back to the center when the central circle turned white (cue back). Each display was presented until a saccade was produced to the target or after 3000 msec (500 msec for the cue-back display) if no saccade was made.

Two independent groups of participants participated in the study. Each group received rTMS stimulation on either the

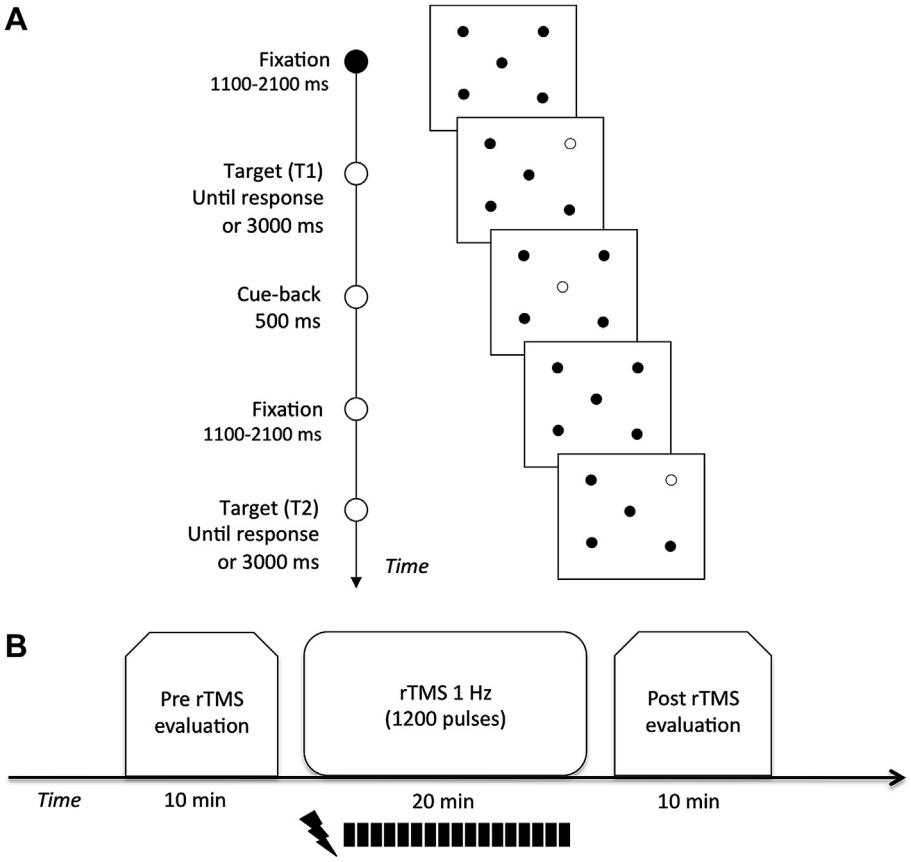

Fig. 1 – (A) Sequence and timing of events in a given trial. In the manual task, participants were required to keep their eyes at fixation and manually detect the appearance of peripheral targets. In the saccadic task, participants were required to move their eyes to peripheral targets and back to the center when the cue-back appeared. (B) Timeline of the behavioral and rTMS conditions. Two runs of each task (manual and saccadic) were performed for each participant in two different sessions. One run was performed immediately before (pre-rTMS evaluation) and the other one immediately after (post-rTMS evaluation) the rTMS stimulation. Each task lasted for about 10 min. Repetitive TMS patterns consisted of 1200 TMS pulses applied at 1 Hz with an inter-pulse interval of 1 sec (for a total of 20 min).

right IPS or the right TPJ region. All participants from each group performed, in separate sessions, two runs of each task (manual and saccadic). One run was performed immediately before (pre-rTMS) and the other one immediately after the rTMS (post-rTMS) (Fig. 1B). Each task lasted for about 10 min. Task order was counterbalanced between participants and separated by at least 72 h to avoid inter-session rTMS accrual effects.

2.3. rTMS

Structural T1-weighted MRI scans were acquired for all participants at the CENIR MRI center (Salpêtrière Hospital, Paris). We used a 3 T Siemens MPRAGE (flip-angle = 9, Repetition Time = 2300 msec, Echo Time = 4.18 msec, slice thickness = 1 mm). Right TPJ ($x = 51$, $y = -51$, $z = 26$) and right IPS coordinates ($x = 16$, $y = -63$, $z = 47$) were chosen from previous event-related functional magnetic resonance imaging (fMRI) (Kincade et al., 2005) and TMS studies (Chica et al., 2011), which explored the brain networks underlying the orienting of attention. Statistical Parametric Mapping 5 (SPM5) software (UCL, London, UK) running under Matlab 7.4 license (Mathworks, USA) was used to localize and label these two regions in each individual brain. We first created the regions of interests in the Montreal Neurological Institute (MNI) space [right TPJ ($x = 57$, $y = -50$, $z = 29$) and right IPS ($x = 19$, $y = -61$, $z = 54$) coordinates] using the Marsbar toolbox for Matlab (http://marsbar.sourceforge.net/). The structural images of the participants were segmented into white and gray matter. The regions created were then de-normalized by using an inverse segmentation matrix created for each participant (spatial smooth isotropic Gaussian Kernel of 1-mm full-width half-maximum). The resulting regions were co-registered with the participant's structural image, which resulted in the precise location of the relevant areas for each individual brain (Fig. 2).

Repetitive TMS patterns were delivered by means of a biphasic repetitive stimulator (Super Rapid 2, Magstim, Withland, UK) and a 70 mm TMS figure-of-eight coil (Magstim, Withland, UK), which was held tangentially to the skull with the axis of the coil oriented approximately 45° from the mid-sagittal axis (lateral to medial and caudal to rostral). Repetitive TMS patterns consisted of 1200 TMS pulses applied at 1 Hz with an inter-pulse interval of 1 sec (for a total of 20 min). Previous studies have suggested that this protocol transiently reduces cortical excitability within the stimulated sites outlasting for approximately 50–75% of the stimulation duration (Boroojerdi et al., 2000; Chen et al., 1997; Hilgetag et al., 2001; Maeda et al., 2000; Valero-Cabré et al., 2007). The time window of reduced excitability in our study was then estimated in about 10–15 min.

The TMS coil was positioned on the two areas of interest by means of a neuronavigation system (eXimia NBS System, Nexstim, Helsinki, Finland) with the capacity to estimate and track in real time the relative position, orientation, and tilting of our figure-of-eight coil on the sectional and 3D reconstruction of the participants MRI with a precision of .5 mm. The two areas of interest for our study, the right IPS and the right TPJ, were localized in the MRI 3D reconstruction and labeled so that the center of the TMS coil and the perpendicular projection of the estimated magnetic field accurately coincided with their locations. All participants received stimulation at suprathreshold intensity levels with respect to their individual motor thresholds. We aimed at using a fixed

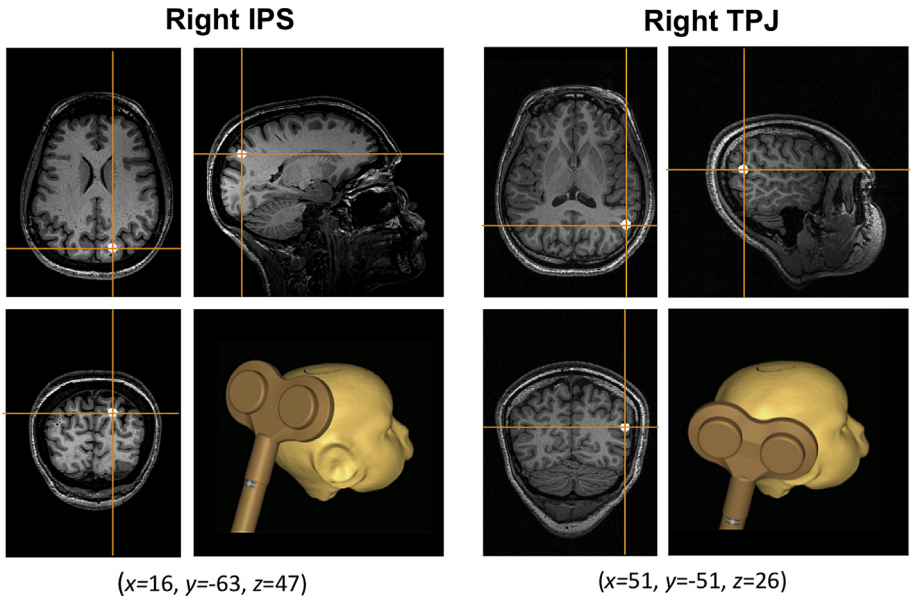

Fig. 2 – Axial, coronal, and sagittal MRI sections (top and bottom left, and top right, respectively) of two representative participants with the targeted right IPS and right TPJ location, labeled as a white dot. The targeted right IPS site ($x = 16$, $y = -63$, $z = 47$) and right TPJ site ($x = 51$, $y = -51$, $z = 26$) was extracted from the averaged Talairach coordinates of prior fMRI (Kincade et al., 2005) and TMS (Chica et al., 2011) studies. Such coordinates were labeled in each individual MRI and reconstructed in 3D. By means of a frameless stereotaxic neuronavigation system, the TMS coil was placed and kept during the stimulation in the scalp location underlying the targeted brain region and oriented in a lateral to medial and rostral to caudal orientation (bottom right panel).

TMS intensity of 80% of the maximum stimulator output throughout all the participants. Nonetheless, stimulation intensity had to be progressively reduced for those individual cases in which the spread of the TMS field induced facial or tongue sensations, involuntary blinks or jaw activations, until those events were no longer induced. The TMS intensity for the stimulation applied to either the IPS or the TPJ for manual and saccadic tasks was identical within participants (stimulation intensity for TPJ = 55%; for IPS = 80%). Similar TMS intensity levels applied to those exact same parietal areas in intact individuals induced attentional orienting effects in a recent experiment (Chica et al., 2011), and were used as guidance for the current study.

2.4. Data analysis

In order to assess IOR, we compared RTs to targets presented at previously stimulated visual field locations with RTs to targets occurring at non-previously stimulated sites. To this end, following a previously described procedure (Bourgeois et al., 2012), we selected consecutively presented targets, as a function of the spatial location of the first and second target (henceforth, T1 and T2). This resulted in four different conditions: (1) *Same location (SL) trials*: T1 and T2 appeared exactly at the same spatial location (similar to valid trials in cue-target designs with just two spatial locations). (2) *Different location same side (DLS) trials*: T2 appeared on the same side as T1, but not at the same spatial location. (3) *Different location opposite side near (DLON) trials*: T2 appeared at the opposite side but at the nearest location to T1. (4) *Different location opposite far (DLOF) trials*: T2 appeared at the opposite farthest side from the T1. The last three conditions can be considered as invalid locations, in analogy with cue-target designs.

Each target was analyzed with respect to its predecessor. However, in the case of the same location trials, we excluded from the analysis trials in which a target was presented at the same location than the previous two targets. That is, if a target was presented at the same location three consecutive times, the third target was not analyzed, because it could suffer from stronger IOR after repeated cueing (Dukewich, 2009). To assess and present in a clear manner the complex pattern of TMS-induced modulations (post- *vs* pre-TMS effects) on the magnitude of IOR, we calculated an IOR index. This number simply expresses the RT differences between targets consecutively presented in the same, valid, location (SL) minus targets occurring at invalid locations (DLS, DLON, DLOF). It then estimates the modulatory effect of the rTMS stimulation for each of the targeted posterior parietal regions, and for each task (manual or saccadic), by subtracting pre-rTMS from post-rTMS RT differences. The IOR index was calculated by means of the following formula: [SL – average (DLS, DLON, DLOF)] post-rTMS *minus* [SL – average (DLS, DLON, DLOF)] pre-rTMS.

3. Results

3.1. RTs

For the *manual* task analyses, we created fictive squared regions of interest around the central fixation and the four peripheral circles, subtending 1.61 × 1.61 degree of visual angle. In order to control for eye movements, we discarded trials in which participants failed to keep their gaze within the area around the fixation point at any time during the fixation period, and trials in which participants looked at the target before responding. Those exclusions accounted for 1.05% of the trials. For the saccadic task, we excluded those trials in which participants failed to move their eyes to visual regions surrounding the peripheral circles or back to the central area around the fixation circle when the cue back was presented (.79% of trials). In both tasks, manual and saccadic, RTs above or below 2.5 standard deviation (SD) from each individual mean were also eliminated as outliers (2.96% and 2.35% of total trials for the manual and saccadic task, respectively). Two participants were excluded from the analysis because their RTs were abnormally slow (>2.5 SD from the participants' mean data in at least one of the conditions).

Mean RTs were submitted to a repeated measures analysis of variance (ANOVA) with the within-participant factors of task (manual, saccadic), target side (left, right), block (pre- and post-TMS), and validity (*SL*, *DLS*, *DLON*, *DLOF*). Stimulated region (right IPS, right TPJ) was included in the analysis as a between-participants factor. Overall, the analysis revealed main effects of task, $F(1,18) = 15.96$, MSE = 13,205, $p = .001$; validity, $F(3,54) = 10.80$, MSE = 500, $p = .001$; and block, $F(1,18) = 9.22$, MSE = 2923, $p = .007$. There were also significant interactions between task and block, $F(1,18) = 18.35$, MSE = 3862, $p = .001$[1]; between task and side, $F(1,18) = 4.84$, MSE = 1174, $p = .041$; between block and side, $F(1,18) = 10$, MSE = 424, $p = .005$; between task and validity, $F(1,54) = 2.79$, MSE = 503, $p = .049$; and between task, block, side, and validity, $F(3,54) = 2.94$, MSE = 375, $p = .041$.

RTs in the pre-TMS block were analyzed in order to confirm the presence of an IOR effect before the rTMS stimulation. *T*-tests demonstrated that IOR (slower RTs for valid than invalid conditions) was significant in all conditions (all *p*s < .03), except for left targets in the manual task (IOR effect, 1.17 msec; $t = .83$, df 19, $p = .42$). However, further *t*-test comparisons indicated significantly slower RTs for the SL and DLS conditions than for the DLON and DLOF conditions ($p = .03$). In this case, in agreement with previous reports (Berlucchi et al., 1989), the IOR effect seemed to spread to the whole cued hemi-space, and to affect targets presented within the same visual hemifield (DLS condition) (see Tables 2 and 3).

3.2. IOR rTMS modulation index

In order to better understand the complex interaction between task, block, side, and validity, we performed an ANOVA on the above-mentioned IOR index (IOR post-TMS *minus* IOR pre-TMS) for each experimental condition with the intra-

[1] This interaction resulted from faster responses after rTMS than before rTMS in the manual but not in the saccadic task. Importantly, this effect was similarly observed for the two regions (interaction between task, block, and region, $F(1,18) = 1.49$, MSE = 3862, $p = .238$). These results are reassuring in suggesting a substantial homogeneity between the TPJ- and IPS-stimulated groups, making it unlikely that the dissociations observed after rTMS for manual and saccadic tasks were due to a difference between the two stimulated groups.

Table 2 – Mean correct RTs (in msec), and percentage of correct detections pre-rTMS on the right TPJ and right IPS as a function of validity (SL, DLOF, DLON, DLS), and target side (left, right). Standard errors are reported in parentheses. Same-location responses, important to calculate IOR, are reported in bold.

		Left				Right			
		SL	DLS	DLON	DLOF	SL	DLS	DLON	DLOF
TPJ									
Manual	Pre-rTMS	**317** (16)	321 (20)	322 (17)	309 (18)	**322** (18)	301 (17)	295 (16)	307 (16)
	Percentage correct	97	98	96	97	97	97	98	97
Saccadic	Pre-rTMS	**268** (10)	248 (10)	252 (8)	250 (7)	**264** (7)	262 (10)	251 (7)	256 (9)
	Percentage correct	97	98	98	97	98	99	98	99
IPS									
Manual	Pre-rTMS	**316** (16)	321 (20)	302 (17)	315 (18)	**321** (18)	311 (17)	301 (16)	301 (16)
	Percentage correct	97	98	97	95	97	96	97	97
Saccadic	Pre-rTMS	**271** (10)	247 (10)	246 (8)	242 (7)	**263** (7)	251 (10)	246 (7)	250 (9)
	Percentage correct	99	99	100	100	99	100	100	100

Table 3 – Mean correct RTs (in msec), and percentage of correct detections post-rTMS on the right TPJ and right IPS as a function of validity (SL, DLOF, DLON, DLS), and target side (left, right). Standard errors are reported in parentheses. Same-location responses, important to calculate IOR, are reported in bold.

		Left				Right			
		SL	DLS	DLON	DLOF	SL	DLS	DLON	DLOF
TPJ									
Manual	Post-rTMS	**283** (18)	275 (18)	270 (17)	270 (13)	**284** (14)	280 (14)	270 (15)	270 (16)
	Percentage correct	98	98	99	98	97	98	99	99
Saccadic	Post-rTMS	**271** (13)	252 (9)	253 (8)	269 (14)	**304** (21)	288 (14)	279 (12)	274 (13)
	Percentage correct	98	99	98	97	97	98	98	97
IPS									
Manual	Post-rTMS	**271** (18)	284 (18)	277 (17)	285 (13)	**274** (14)	278 (14)	280 (15)	287 (16)
	Percentage correct	95	94	95	95	94	94	95	96
Saccadic	Post-rTMS	**255** (14)	248 (8)	246 (9)	247 (13)	**270** (21)	247 (14)	251 (12)	243 (13)
	Percentage correct	99	99	99	99	100	100	100	100

participant factors of task and side, and the between-participant factor of stimulated region. This analysis revealed a significant interaction between task and side, $F(1,18) = 7.16$, MSE = 1069, $p = .015$. Two further ANOVAs for each target side revealed, for left-sided targets, a significant main effect of stimulated region, $F(1,18) = 4.56$, MSE = 858, $p = .047$, which was independent of task, $F(1,18) = 1.08$, MSE = 422, $p = .312$. As it can be observed in Fig. 3, rTMS modulated both manual and saccadic IOR after right IPS stimulation, while rTMS over right TPJ had no impact on either type of IOR. For right-sided targets, however, we observed a significant main effect of task, $F(1,18) = 6.26$, MSE = 1421, $p = .022$, which was independent of the stimulated region, $F < 1$. Thus, the stimulation of either the right IPS or the right TPJ impaired manual but not saccadic IOR (see Fig. 3).

3.3. *Control analyses and experiments*

As stated in the Procedure section, we initially aimed to stimulate both regions (IPS and TPJ) at similar intensity levels (80% of the maximum stimulator output). However, the stimulation of right TPJ induced face and tongue sensations, involuntary blinks, or jaw contractions, which forced us to decrease TMS intensity until these effects disappeared (see also Chica et al., 2011). In order to test whether the intensity of rTMS stimulation affected the observed pattern of results, we ranked and divided participants in the right TPJ group in two subgroups, i.e. those with higher stimulation intensities (mean stimulation intensity = 68%, $N = 5$) or lower stimulation intensities (mean stimulation intensity = 49%, $N = 5$) (this analysis could not be performed for IPS because all participants were stimulated with a fixed intensity of 80%). The main result reported in this paper is the abolition of IOR for right-sided targets after either right IPS or right TPJ rTMS stimulation. Two-tailed *t*-tests comparisons indicated no significant differences after rTMS over the right TPJ when low and high rTMS intensities were used in the manual IOR modulation for right-sided targets (IOR effect for the low rTMS intensity group = −8 msec; IOR effect for the high rTMS intensity group = −12 msec; $t < 1$). This result suggests that although the right TPJ rTMS stimulation intensity had to be reduced for practical reasons, stimulations at lower intensities were as effective in generating the main behavioral effect described above as stimulations at higher intensities.

Participants were assigned randomly to the right IPS or the right TPJ rTMS groups. The order of the task (manual or saccadic) in each group was counterbalanced between participants. In order to control for potential effects of

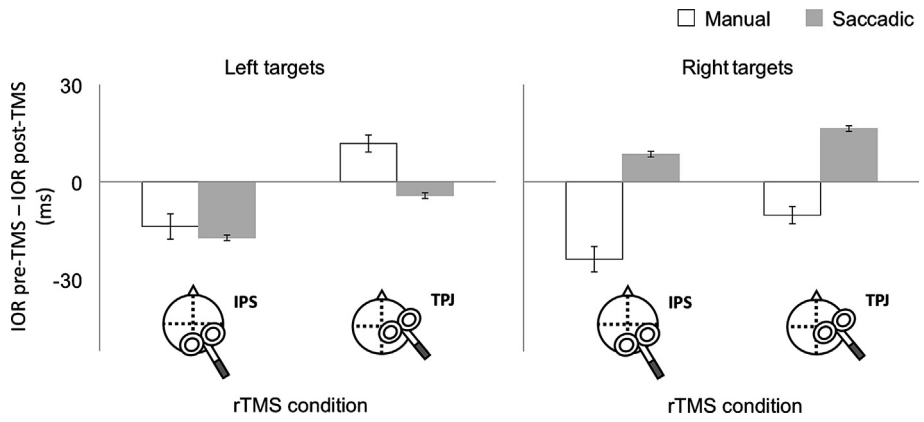

Fig. 3 – IOR index (IOR post-TMS–IOR pre-TMS), expressed in msec, after rTMS on the right TPJ or the right IPS, for targets presented in the left or in the right visual hemifield, for manual and saccadic responses. Scores below 0 on the y-axis indicate smaller IOR effects post- than pre-TMS, while scores above 0 indicate larger IOR effects post- than pre-TMS. Results for right-sided target revealed a main effect of task, which was independent on the stimulated region. IOR was abolished after stimulation of either right IPS or right TPJ for manual, but not saccadic IOR. For left-sided targets, there was a main effect of region, which was independent of task. IOR was abolished for manual and saccadic responses after right IPS stimulation, while stimulation of right TPJ had no impact on IOR.

counterbalancing, we performed an ANOVA on the mean RTs with the within-participant factors of task (manual, saccadic), target side (left, right), block (pre- and post-TMS), and validity (SL, DLS, DLON, DLOF). Region (right IPS, right TPJ) and task order (first session manual, first session saccadic) were included in the analysis as between-participants factors. This analysis revealed that the main result we observed, i.e., the significant interaction between task, block, side, and validity, $F(3,48) = 3.42$, MSE = 351, $p = .016$, was independent of the task order factor, $F < 1$, ruling out a potential confounding effect of this variable in our results.

Another potential concern with these results could be the lack of a sham rTMS condition, as a control for lasting TMS non-specific impact (noise and tapping), as well as for potential practice effects due to the repetition of the consecutive blocks of the IOR task. However, in view of the dissociations observed between manual and saccadic IOR, which occurred with participants always executing the same number of trials prior and after the delivery of rTMS, this concern seems implausible.

Table 4 – Mean correct RTs (in msec), and percentage of correct detections for the manual and saccadic control experiment as a function of validity (SL, DLOF, DLON, DLS). Standard errors are reported in parentheses. Same-location responses, important to calculate IOR, are reported in bold.

	SL	DLS	DLON	DLOF
Manual				
First block	**314** (20)	310 (17)	304 (19)	299 (17)
Percentage correct	93	95	96	95
Second block	**294** (17)	286 (16)	208 (17)	279 (17)
Percentage correct	96	97	97	97
Saccadic				
First block	**276** (20)	257 (20)	253 (19)	251 (17)
Percentage correct	99	99	98	99
Second block	**253** (17)	246 (16)	238 (17)	249 (17)
Percentage correct	100	100	100	99

Nonetheless, and to control for possible effects of practice or fatigue, we carried out a control experiment with sixteen new participants, who performed two blocks of either the manual or the saccadic task separated by a 20-min break. These two blocks mimicked the pre–post-TMS manipulation introduced in the TMS experiment. We performed a repeated measures ANOVA on mean RTs with the within-participant factors of block (pre- and post-TMS), and validity (*SL*, *DLS*, *DLON*, *DLOF*), and the between-participant factor of task (manual, saccadic) (see Table 4). The results demonstrated a main effect of block, $F(1,14) = 16.25$, MSE = 605, $p = .001$, with faster RTs in the second block as compared to the first one. The main effect of validity was also significant, demonstrating an overall IOR effect, $F(3,42) = 13.12$, MSE = 128, $p = .001$. Importantly, the validity effect did not interact with block, $F(3,42) = 1.61$, MSE = 108, $p = .201$. The interaction between validity, block, and task was not significant either, $F(3,42) = 1.48$, MSE = 108, $p = .234$. We can therefore conclude that the modulation of the IOR effect observed after rTMS on right IPS and right TPJ parietal regions is not likely to have resulted from practice or fatigue during the execution of two consecutive blocks of the task.

4. Discussion

We benefited from the spatial resolution and causal power of TMS to explore the potential implication of two posterior parietal regions in the right hemisphere, IPS and TPJ, in the exogenous attentional orienting processes underlying manual and saccadic IOR. Our endeavor was inspired by a previous study on right-brain damaged (RBD) patients with left visuo-spatial neglect, in whom we demonstrated a dissociation between impaired manual and preserved saccadic IOR for repeated right-sided targets (Bourgeois et al., 2012). We show here that rTMS over both the right TPJ and the right IPS lastingly abolished manual but not saccadic IOR for right-sided targets in healthy participants, a result that mimics fairly well the

performance patterns found in left neglect patients with damage to the right inferior parietal lobule or its connections to the ipsilateral prefrontal cortex (Bourgeois et al., 2012). For left-sided targets, rTMS interventions did not affect IOR after right TPJ stimulation, while both manual and saccadic IOR were impaired after rTMS over the right IPS. Previous results on IOR for left-sided targets in left visual neglect were inconclusive. Some previous studies reported normal IOR for left-sided targets after right parietal damage with no signs of neglect (Bartolomeo et al., 1999; Vivas et al., 2003), while others have reported variable patterns of IOR or paradoxical facilitation for valid trials (Bartolomeo et al., 2001b). These inconsistent findings were usually explained by the substantial variability on RTs to left-sided targets in patients with chronic neglect (Anderson et al., 2000), perhaps as a result of their impaired leftward exogenous orienting (Bartolomeo et al., 2001a). Until now, no strong conclusion was thus possible about the IOR effect for left-sided targets in RBD patients with or without neglect. Our TMS results shed light on this issue and demonstrated that manual IOR is abolished for left-sided targets after right IPS, but not right TPJ, interference. This suggests that right parietal lesions can differently affect contralateral IOR depending on whether the right IPS is damaged or spared (see below for further discussion on the role of right IPS in the representation of saliency maps for left and right visual stimuli).

Our rTMS right IPS and TPJ disruption patterns do reveal a close resemblance with both manual and saccadic IOR behavioral patterns after parietal lesions in neglect patients. Furthermore, these results are in agreement with studies demonstrating that rTMS patterns could indeed mimic lesion diaschisis and generate not only local, but also transynaptic effects, particularly when delivered on the parietal lobe, in distant regions such as the primary visual cortices, the posterior thalamus nuclei, and most importantly, the superficial and middle layers of the SC (Valero-Cabré et al., 2005, 2007). Indeed, the task-dependent and hemifield selective IOR modulation patterns described here could be hypothetically explained by a direct disruption of critical processing occurring at either one or the other locally targeted area (the right IPS and TPJ), through a trans-synaptic impact in richly connected distant sites (as for example the ipsilateral SC), or a combination of both effects.

For example, in the present study we found an absence of manual IOR for right-sided targets after rTMS-induced disruption of the right TPJ. This parietal site may be specifically important for the detection of novel and behaviorally relevant stimuli (Asplund et al., 2010; Indovina and Macaluso, 2007). A fundamental mechanism contributing to IOR is the relative lack of novelty of a target appearing at the same location of a previously presented event, separated by a long stimulus-onset asynchrony (SOA) (Milliken et al., 2000). "Habituation" of the orienting response some time after the onset of the first stimulus can contribute to IOR (Dukewich, 2009; Lupiáñez, 2010; Milliken et al., 2000). Such phenomena would bias attention toward locations that have neither been previously attended nor inspected. Thus, the absence of local inhibition after right TPJ rTMS in the healthy participants explored in the present study (or after right parietal damage or fronto-parietal disconnection in visual neglect patients, Bourgeois et al., 2012), could be interpreted as an abnormal processing of novelty, which causes attention to be perseveringly oriented to the previously attended location (Asplund et al., 2010; Downar et al., 2000).

At variance with the effects on right TPJ, abolition of manual IOR for both right-sided and left-sided targets after offline rTMS over the right IPS may result from a local interference in the processing of target saliency. Indeed, studies in monkeys (Colby and Goldberg, 1999; Gottlieb et al., 1998) and humans (see Silver and Kastner, 2009 for review; Van Koningsbruggen et al., 2010) have demonstrated that IPS contains an explicit two-dimensional map that encodes the saliency or conspicuity of objects. The bilateral abolition of manual IOR in our study might reflect the fact that the right parietal cortex controls shift of attention to both sides of space. In this context, previous studies demonstrated a hemispheric asymmetry in representing parietal saliency maps. For example, TMS over the right but not the left parietal lobule prevented remapping of IOR for both visual fields (Van Koningsbruggen et al., 2010).

The manual–saccadic dissociation observed in our study after right IPS or TPJ stimulation is also important to understand the nature of the IOR effect. Different hypotheses have been put forward concerning the mechanisms underlying it. While the *attentional* hypothesis proposes that the IOR effect is the result of an inhibition to orient attention to a previously attended location (Posner and Cohen, 1984), the *oculomotor* hypothesis proposes that it is caused by the inhibition of a previously prepared movement (to the cue) or the activation of an oculomotor program (Chica et al., 2010a; Rafal et al., 1989). As previously suggested by several behavioral studies (Bourgeois et al., 2012; Chica et al., 2010b; Hunt and Kingstone, 2003; Souto and Kerzel, 2009; Sumner et al., 2004; Taylor and Klein, 2000; Wang et al., 2012), our results suggest the existence of different mechanisms underlying manual and saccadic IOR. Furthermore, attentional and motor phenomena related to IOR might depend on the implication of different brain networks for performing manual and saccadic responses (Anderson and Rees, 2011). Our results confirm the role of right IPS and TPJ in manual IOR, while only the right IPS seems to be implicated in saccadic IOR.

Finally, our data report for the first time a significant abolition of saccadic IOR for left-sided targets after rTMS on the right IPS. The cortical control of saccadic responses relies on fronto-parietal circuits including the frontal eye field (FEF) and the human homolog of the lateral intra-parietal area within the right IPS. These dorsal fronto-parietal networks are primarily concerned with contralateral stimuli (Corbetta et al., 1998). Thus, TMS on the right IPS might have interfered with the processing of repeated left-sided targets, thereby decreasing saccadic IOR. This effect could be accounted for by the transynaptic inhibition of the ipsilateral SC, as induced by an rTMS suppression of the parietal cortico-tectal excitatory drive (Valero-Cabré et al., 2005, 2007). In the rat and the cat, but particularly in the monkey, the posterior parietal regions and the lateral bank of the IPS, respectively, are densely connected to the ipsilateral SC (Clower et al., 2001; Lynch et al., 1985) and thus cortico-tectal connectivity could easily underlie these modulatory effects which have been found for example in feline studies after posterior parietal rTMS stimulation (Valero-Cabré et al., 2005, 2007). Furthermore, Dorris et al. (2002) found reduced firing activity in single neurons of the superficial and intermediate layers of the SC in response to targets

presented at a previously inspected location, which correlated with the magnitude of the saccadic IOR in monkeys. However, when gazing was induced by direct microstimulation of SC neurons, saccades toward the previously inspected location were faster, rather than slower, as compared to saccades to non-previously inspected locations. On the basis of these data, these authors proposed the parietal cortex as a possible upstream source of regulation of SC activity during IOR. This same assumption could be extrapolated to the human brain, since it has been shown that parieto-collicular pathways convey an on-line visual signal that provides the oculomotor system with visuo-spatial information regarding novel and salient visual stimuli (Gaymard et al., 2003), whereas blood oxygen level dependent (BOLD) signals recorded from the SC have been found to correlate with IOR (Anderson and Rees, 2011). Sumner et al. (2004) have also shown that chromatic (S-cone) stimuli, which do not activate the retino-tectal or magnocellular pathway, and do not prompt reflexive eye movements in a remote distracter paradigm, do generate IOR when measured by manual key presses responses, but not by saccadic eye movements. More recent evidence, however, indicated that the SC can respond to chromatic stimuli, albeit through a slower pathway than for achromatic (black and white) signals (Bompas and Sumner, 2011; White et al., 2009).

In conclusion, in good agreement with neglect patients' performance on the same task, our results demonstrate that rTMS over both the right IPS and the right TPJ interfered with manual but not with saccadic IOR for right-sided targets. Moreover, right IPS interference abolished both manual and saccadic IOR for left-sided stimulation. If, guided by our lesion study (Bourgeois et al., 2012), we explored the impact of right posterior parietal locations, future *ad hoc* patient and TMS experiments in intact participants should investigate the potential contributions of left-hemisphere sites and laterality issues on the control of IOR. Most importantly, the present data identify a specific contribution of dorsal and ventral attentional parietal regions to exogenous orienting processes implicated in IOR, whose underlying anatomical and functional connectivity, particularly with the SC, deserves to be explored in further detail.

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REFERENCES

Anderson B, Mennemeier M, and Chatterjee A. Variability not ability: Another basis for performance decrements in neglect. *Neuropsychologia*, 38(6): 785–796, 2000.

Anderson EJ and Rees G. Neural correlates of spatial orienting in the human superior colliculus. *Journal of Neurophysiology*, 106(5): 2273–2284, 2011.

Asplund CL, Todd JJ, Snyder AP, and Marois R. A central role for the lateral prefrontal cortex in goal-directed and stimulus-driven attention. *Nature Neuroscience*, 13(4): 507–512, 2010.

Bartolomeo P, Chokron S, and Sieroff E. Facilitation instead of inhibition for repeated right-sided events in left neglect. *NeuroReport*, 10(16): 3353–3357, 1999.

Bartolomeo P, Sieroff E, Chokron S, and Decaix C. Variability of response times as a marker of diverted attention. *Neuropsychologia*, 39(4): 358–363, 2001a.

Bartolomeo P, Sieroff E, Decaix C, and Chokron S. Modulating the attentional bias in unilateral neglect: The effects of the strategic set. *Experimental Brain Research*, 137(3–4): 432–444, 2001b.

Berlucchi G. Inhibition of return: A phenomenon in search of a mechanism and a better name. *Cognitive Neuropsychology*, 23(7): 1065–1074, 2006.

Berlucchi G, Tassinari G, Marzi CA, and Di Stefano M. Spatial distribution of the inhibitory effect of peripheral non-informative cues on simple reaction time to non-fixated visual targets. *Neuropsychologia*, 27(2): 201–221, 1989.

Bompas A and Sumner P. Saccadic inhibition reveals the timing of automatic and voluntary signals in the human brain. *Journal of Neuroscience*, 31(35): 12501–12512, 2011.

Boroojerdi B, Prager A, Muellbacher W, and Cohen LG. Reduction of human visual cortex excitability using 1-Hz transcranial magnetic stimulation. *Neurology*, 54(7): 1529–1531, 2000.

Bourgeois A, Chica AB, Migliaccio R, Thiebaut de Schotten M, and Bartolomeo P. Cortical control of inhibition of return: Evidence from patients with inferior parietal damage and visual neglect. *Neuropsychologia*, 50(5): 800–809, 2012.

Chen R, Classen J, Gerloff C, Celnik P, Wassermann EM, Hallett M, et al. Depression of motor cortex excitability by low-frequency transcranial magnetic stimulation. *Neurology*, 48(5): 1398–1403, 1997.

Chica AB, Bartolomeo P, and Lupiáñez J. Two cognitive and neural systems for endogenous and exogenous spatial attention. *Behavioural Brain Research*, 237: 107–123, 2013.

Chica AB, Bartolomeo P, and Valero-Cabré A. Dorsal and ventral parietal contributions to spatial orienting in the human brain. *Journal of Neuroscience*, 31(22): 8143–8149, 2011.

Chica AB, Klein RM, Rafal RD, and Hopfinger JB. Endogenous saccade preparation does not produce inhibition of return: Failure to replicate Rafal, Calabresi, Brennan, & Sciolto (1989). *Journal of Experimental Psychology: Human Perception and Performance*, 36(5): 1193–1206, 2010a.

Chica AB, Lupiáñez J, and Bartolomeo P. Dissociating inhibition of return from endogenous orienting of spatial attention: Evidence from detection and discrimination tasks. *Cognitive Neuropsychology*, 23(7): 1015–1034, 2006.

Chica AB, Taylor TL, Lupiáñez J, and Klein RM. Two mechanisms underlying inhibition of return. *Experimental Brain Research*, 201(1): 25–35, 2010b.

Clower DM, West RA, Lynch JC, and Strick PL. The inferior parietal lobule is the target of output from the superior colliculus, hippocampus, and cerebellum. *Journal of Neuroscience*, 21(16): 6283–6291, 2001.

Colby CL and Goldberg ME. Space and attention in parietal cortex. *Annual Review of Neurosciences*, 22: 319–349, 1999.

Corbetta M, Akbudak E, Conturo TE, Snyder AZ, Ollinger JM, Drury HA, et al. A common network of functional areas for attention and eye movements. *Neuron*, 21(4): 761–773, 1998.

Corbetta M and Shulman GL. Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, 3(3): 201–215, 2002.

Dorris MC, Klein RM, Everling S, and Muñoz DP. Contribution of the primate superior colliculus to inhibition of return. *Journal of Cognitive Neuroscience*, 14(8): 1256–1263, 2002.

Downar J, Crawley AP, Mikulis DJ, and Davis KD. A multimodal cortical network for the detection of changes in the sensory environment. *Nature Neuroscience*, 3(3): 277–283, 2000.

Dukewich KR. Reconceptualizing inhibition of return as habituation of the orienting response. *Psychonomic Bulletin & Review*, 16(2): 238–251, 2009.

Gaymard B, Lynch J, Ploner CJ, Condy C, and Rivaud-Pechoux S. The parieto-collicular pathway: Anatomical location and contribution to saccade generation. *European Journal of Neuroscience*, 17(7): 1518–1526, 2003.

Gottlieb JP, Kusunoki M, and Goldberg ME. The representation of visual salience in monkey parietal cortex. *Nature*, 391(6666): 481–484, 1998.

Guenther BA and Brown JM. Exploring the effect of stimulus characteristics on location-based inhibition of return using abrupt and ramped stimulus presentation. *Vision Research*, 60: 28–33, 2012.

Hilgetag CC, Theoret H, and Pascual-Leone A. Enhanced visual spatial attention ipsilateral to rTMS-induced 'virtual lesions' of human parietal cortex. *Nature Neuroscience*, 4(9): 953–957, 2001.

Hunt AR and Kingstone A. Inhibition of return: Dissociating attentional and oculomotor components. *Journal of Experimental Psychology: Human Perception and Performance*, 29(5): 1068–1074, 2003.

Indovina I and Macaluso E. Dissociation of stimulus relevance and saliency factors during shifts of visuospatial attention. *Cerebral Cortex*, 17(7): 1701–1711, 2007.

Kincade JM, Abrams RA, Astafiev SV, Shulman GL, and Corbetta M. An event-related functional magnetic resonance imaging study of voluntary and stimulus-driven orienting of attention. *Journal of Neuroscience*, 25(18): 4593–4604, 2005.

Klein RM. Inhibition of return. *Trends in Cognitive Sciences*, 4(4): 138–147, 2000.

Lupiáñez J. Inhibition of return. In Nobre AC and Coull JT (Eds), *Attention and Time*: 17–34. Oxford, UK.

Lupiáñez J, Klein RM, and Bartolomeo P. Inhibition of return: Twenty years after. *Cognitive Neuropsychology*, 23(7): 1003–1014, 2006.

Lupiáñez J, Milán EG, Tornay FJ, Madrid E, and Tudela P. Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics*, 59(8): 1241–1254, 1997.

Lynch JC, Graybiel AM, and Lobeck LJ. The differential projection of two cytoarchitectonic subregions of the inferior parietal lobule of macaque upon the deep layers of the superior colliculus. *Journal of Comportemental Neurology*, 235(2): 241–254, 1985.

Maeda F, Keenan JP, Tormos JM, Topka H, and Pascual-Leone A. Modulation of corticospinal excitability by repetitive transcranial magnetic stimulation. *Clinical Neurophysiology*, 111(5): 800–805, 2000.

Milliken B, Tipper SP, Houghton G, and Lupiáñez J. Attending, ignoring, and repetition: On the relation between negative priming and inhibition of return. *Perception & Psychophysics*, 62(6): 1280–1296, 2000.

Nobre AC, Sebestyen GN, Gitelman DR, Mesulam MM, Frackowiak RS, and Frith CD. Functional localization of the system for visuospatial attention using positron emission tomography. *Brain*, 120(Pt 3): 515–533, 1997.

Perry RJ and Zeki S. The neurology of saccades and covert shifts in spatial attention: An event-related fMRI study. *Brain*, 123(Pt 11): 2273–2288, 2000.

Posner MI and Cohen Y. Components of visual orienting. In Bouma H and Bouwhuis D (Eds), *Attention and Performance X*. London: Lawrence Erlbaum, 1984: 531–556.

Posner MI, Rafal RD, Choate LS, and Vaughan J. Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, 2: 211–228, 1985.

Rafal RD, Calabresi PA, Brennan CW, and Sciolto TK. Saccade preparation inhibits reorienting to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance*, 15(4): 673–685, 1989.

Rosen AC, Rao SM, Caffarra P, Scaglioni A, Bobholz JA, Woodley SJ, et al. Neural basis of endogenous and exogenous spatial orienting. A functional MRI study. *Journal of Cognitive Neuroscience*, 11(2): 135–152, 1999.

Sapir A, Soroker N, Berger A, and Henik A. Inhibition of return in spatial attention: Direct evidence for collicular generation. *Nature Neuroscience*, 2(12): 1053–1054, 1999.

Schneider W, Eschman A, and Zuccolotto A. *E-prime User's Guide*. Pittsburgh: Psychology Software Tools Inc., 2002.

Silver MA and Kastner S. Topographic maps in human frontal and parietal cortex. *Trends in Cognitive Sciences*, 13(11): 488–495, 2009.

Souto D and Kerzel D. Evidence for an attentional component in saccadic inhibition of return. *Experimental Brain Research*, 195(4): 531–540, 2009.

Sumner P, Nachev P, Vora N, Husain M, and Kennard C. Distinct cortical and collicular mechanisms of inhibition of return revealed with S cone stimuli. *Current Biology*, 14(24): 2259–2263, 2004.

Taylor TL and Klein RM. Visual and motor effects in inhibition of return. *Journal of Experimental Psychology: Human Perception and Performance*, 26(5): 1639–1656, 2000.

Valero-Cabré A, Pascual-Leone A, and Coubard OA. Transcranial magnetic stimulation (TMS) in basic and clinical neuroscience research. *Revue Neurologique*, 167(4): 291–316, 2011.

Valero-Cabré A, Payne BR, and Pascual-Leone A. Opposite impact on ^{14}C-2-deoxyglucose brain metabolism following patterns of high and low frequency repetitive transcranial magnetic stimulation in the posterior parietal cortex. *Experimental Brain Research*, 176(4): 603–615, 2007.

Valero-Cabré A, Payne BR, Rushmore J, Lomber SG, and Pascual-Leone A. Impact of repetitive transcranial magnetic stimulation of the parietal cortex on metabolic brain activity: A ^{14}C-2DG tracing study in the cat. *Experimental Brain Research*, 163(1): 1–12, 2005.

Van Koningsbruggen MG, Gabay S, Sapir A, Henik A, and Rafal RD. Hemispheric asymmetry in the remapping and maintenance of visual saliency maps: A TMS study. *Journal of Cognitive Neuroscience*, 22(8): 1730–1738, 2010.

Vivas AB, Humphreys GW, and Fuentes LJ. Inhibitory processing following damage to the parietal lobe. *Neuropsychologia*, 41(11): 1531–1540, 2003.

Vivas AB, Humphreys GW, and Fuentes LJ. Abnormal inhibition of return: A review and new data on patients with parietal lobe damage. *Cognitive Neuropsychology*, 23(7): 1049–1064, 2006.

Wagner T, Valero-Cabre A, and Pascual-Leone A. Noninvasive human brain stimulation. *Annual Review of Biomedical Engineering*, 9: 527–565, 2007.

Wang Z, Satel J, and Klein RM. Sensory and motor mechanisms of oculomotor inhibition of return. *Experimental Brain Research*, 218(3): 441–453, 2012.

White BJ, Boehnke SE, Marino RA, Itti L, and Munoz DP. Color-related signals in the primate superior colliculus. *Journal of Neuroscience*, 29(39): 12159–12166, 2009.