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Cortical control of Inhibition of Return: Exploring the causal contributions of the left parietal cortex

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ABSTRACT

Inhibition of Return (IOR) refers to longer response times (RTs) when processing information from an already inspected spatial location. This effect encourages orienting towards novel locations and may be hence adaptive to efficiently explore our environment. In a previous study (Bourgeois, Chica, Valero-Cabre, & Bartolomeo, 2013), we demonstrated that repetitive Transcranial Magnetic Stimulation (rTMS) over right hemisphere parietal sites, such as the intra-parietal sulcus (IPS), or the temporo-parietal junction (TPJ), lastingly interfered with manual but not saccadic IOR, for ipsilateral right-sided targets. For contralateral left-sided targets, rTMS over the right IPS, but not over the right TPJ, impaired both manual and saccadic IOR. In the present study, we investigated hemispheric differences in the cortical control of IOR by stimulating left parietal sites with the same design. Contrary to the stimulation of the right hemisphere, rTMS over the left IPS or TPJ did not produce significant modulations of either manual or saccadic IOR. This evidence extends to IOR the validity of current models of hemispheric asymmetries in the control of visuo-spatial attention.

1. Introduction

The processing of an already inspected spatial location generates longer response times (RTs) as compared to the processing of new locations. This phenomenon, referred to as Inhibition of Return (IOR) (Lupiáñez, Klein, & Bartolomeo, 2006; Posner, Rafal, Choate, & Vaughan, 1985), reflects a bias to preferentially attend to novel spatial locations, avoiding the perseverant scanning of already visited locations (Klein, 1988). IOR is typically observed during exogenous attentional orienting, and has been proven independent of endogenous or voluntary orienting (Berlucchi, Chelazzi, & Tassinari, 2000;

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Chica & Lupiáñez, 2009). It can be generated under both overt and covert orienting, that is, when gaze moves to a peripheral cue or target (saccadic IOR), or when it has to remain on central fixation while participants respond with a manual key press (manual IOR) (Posner et al., 1985).

Even if the retinotectal visual pathway is traditionally considered important for IOR (Sapir, Soroker, Berger, & Henik, 1999), this phenomenon probably develops in concert with upstream cortical structures such as the posterior parietal cortex (Dorris, Klein, Everling, & Muñoz, 2002). Prior research has shown that key dorsal and ventral attentional right parietal regions, such as, respectively, the intra-parietal sulcus (IPS), and the temporo-parietal junction (TPJ), are plausible candidates for the cortical control of IOR (Chica, Bartolomeo, & Valero-Cabre, 2011). Accordingly, we have previously demonstrated that repetitive Transcranial Magnetic Stimulation (rTMS) over the right IPS or TPJ lastingly interfered with manual but not saccadic IOR, for right-sided targets (Bourgeois, Chica, Valero-Cabre, et al., 2013). For left-sided targets, rTMS over the right IPS, but not over the right TPJ, impaired both manual and saccadic IOR. Although right to left hemispheric differences could be predicted at least for the TPJ, on the basis of a prevalent right hemisphere localization of the ventral attentional network (Corbetta & Shulman, 2002), the relative contribution to IOR, either manual or saccadic from key dorsal and ventral attentional parietal regions of the left hemisphere have never been tested. In the present study, we used the same design and behavioral paradigm to investigate hemispheric differences in the cortical control of IOR, by stimulating IPS and TPJ in the left hemisphere, and compared the potential modulatory role on manual and saccadic IOR of parietal stimulation in either hemisphere.

2. Methods

2.1. Participants

Twenty-two healthy participants (11 women, all right-handed, mean age 22 years, range 21–31) with normal or corrected-to-normal vision, and no history of neurological and psychiatric disorders, participated in this study. Written informed consent, as well as safety-screening questionnaire to undergo magnetic resonance imaging (MRI) and TMS interventions, was obtained from each participant. The study was reviewed by the INSERM ethical committee and received the approval of an Institutional Review Board (CPP *Ile de France* 1). None of the participants had participated to the previous study (Bourgeois, Chica, Valero-Cabre, et al., 2013), with identical tasks and similar rTMS stimulation to regions of the right hemisphere. Participants of the two studies matched in age and gender ($t = 1.09$, $df = 39$, $p = .29$ and $\chi^2 = .10$, $df = 1$, $p = .75$, respectively).

2.2. Apparatus, stimuli and procedure

The methods (Fig. 1) were identical to those used in the right hemisphere study (Bourgeois, Chica, Valero-Cabre, et al., 2013), with the exception of the hemisphere stimulated.

Two independent groups of participants were recruited to participate in this study, respectively receiving rTMS over either the left IPS or the left TPJ. All participants from both groups 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). 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 cumulative effects (see Fig. 1).

2.3. rTMS

We used exactly the same rTMS parameters and procedure as in our previous study (Bourgeois, Chica, Valero-Cabre, et al., 2013), with the exception that this time left hemisphere locations for IPS and TPJ were stimulated (Fig. 2).

Repetitive TMS was 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). Repetitive TMS patterns consisted of 1200 pulses applied at 1 Hz (i.e., with an inter-pulse interval of 1 sec) for a total of 20 min. The TMS coil was positioned and kept on the two areas of interest by means of a frameless TMS neuronavigation system (Brainsight, Rogue Systems, Montreal, Canada) 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. As previously done elsewhere (Bourgeois, Chica, Valero-Cabre, et al., 2013; Chica et al., 2011), we aimed at using a fixed TMS intensity of 80% of the maximum stimulator output throughout all the participants. However, stimulation intensity had to be reduced for those individual cases in which the TMS field induced facial or tongue sensations, involuntary blinks, or jaw twitching, until those events were no longer present. In particular, identical TMS stimulation intensities as those used for right hemisphere regions were employed on left sites (80% of the maximum stimulator output for both the left and the right IPS stimulation; 55% and 60% of the maximum stimulator output for the right and the left TPJ stimulation, respectively, $t = .92$, $df = 19$, $p = .37$).

2.4. Data analysis

In order to assess IOR, we compared RTs to targets presented at previously inspected visual field locations with RTs to targets occurring at non-previously inspected sites. To this end, following a previously described procedure (Bourgeois, Chica, Valero-Cabre, et al., 2013), 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. (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.

In order to compare our rTMS results with those previously obtained after right parietal rTMS stimulation (Bourgeois, Chica, Migliaccio et al., 2013), we computed an IOR index

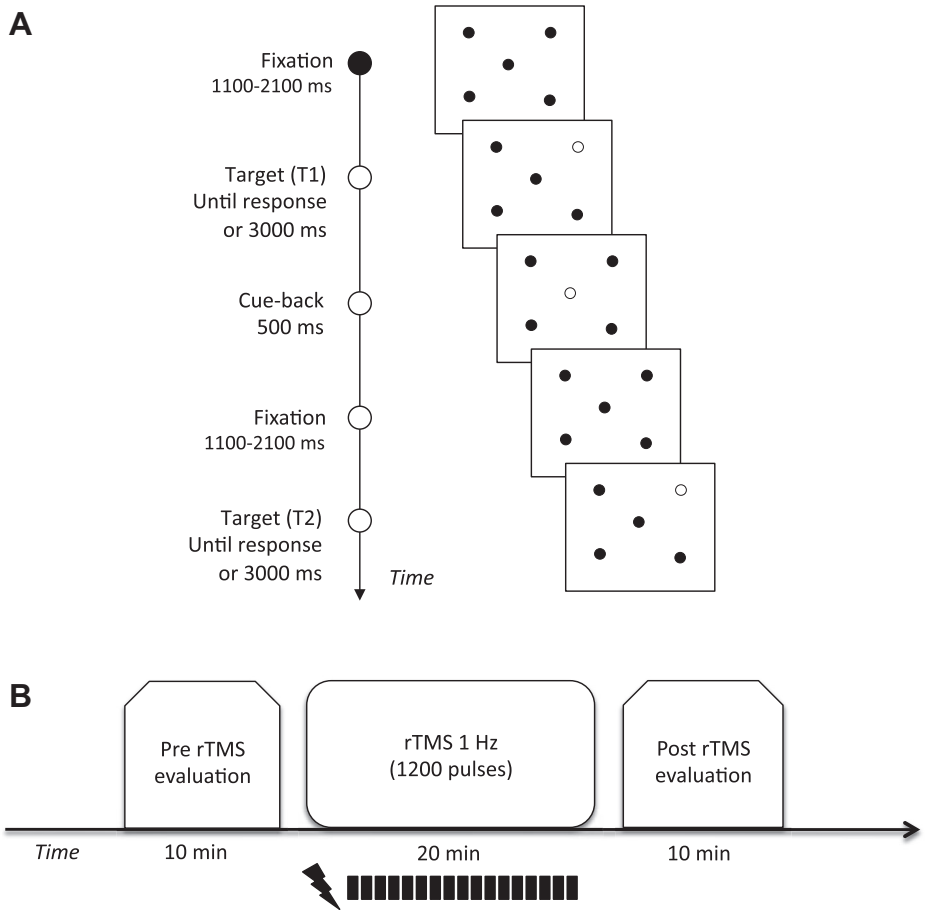

Fig. 1 – (A) Sequence and timing of events in a given trial. All stimuli were displayed on a gray background. A PC Dell Latitude D600 running E-prime software (Schneider, Eschman, & Zuccolotto, 2002) controlled the presentation of stimuli, timing operations, and data collection. Stimuli were presented on an eye-tracker screen (Tobii T50, Technology AB, Danderyd, Sweden, 17″ wide, 1024 × 768, 16.67 ms refresh rate), used to monitor and record the location of gaze every 20 ms. 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 centers of the four peripheral circles were placed at a distance of 5° of visual angle from the center of the fixation circle. For the manual task, 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 ms. 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 ms if no response was made. Then the central circle turned white during 500 ms (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. The procedure for the saccadic task was identical to the manual task, but participants were required to respond by moving their eyes to the target as fast and as accurately as possible, and to subsequently move their eyes back to the center when the central circle turned white. Each display was presented until a saccade was produced to the target, or after 3000 ms if no saccade was made. (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).

which allowed us to display in a clearer manner the patterns of rTMS-induced modulations (post-rTMS–pre-rTMS effects) on the magnitude of IOR. This number simply expresses the RT differences pre–post-rTMS stimulation for either saccadic or manual responses, for targets consecutively presented at the same location (SL) as compared to targets occurring at different locations (DLS, DLON, DLOF). The IOR index was calculated by means of the following formula: (SL – average [DLS, DLON, DLOF]) after rTMS *minus* (SL – average [DLS, DLON, DLOF]) before rTMS.

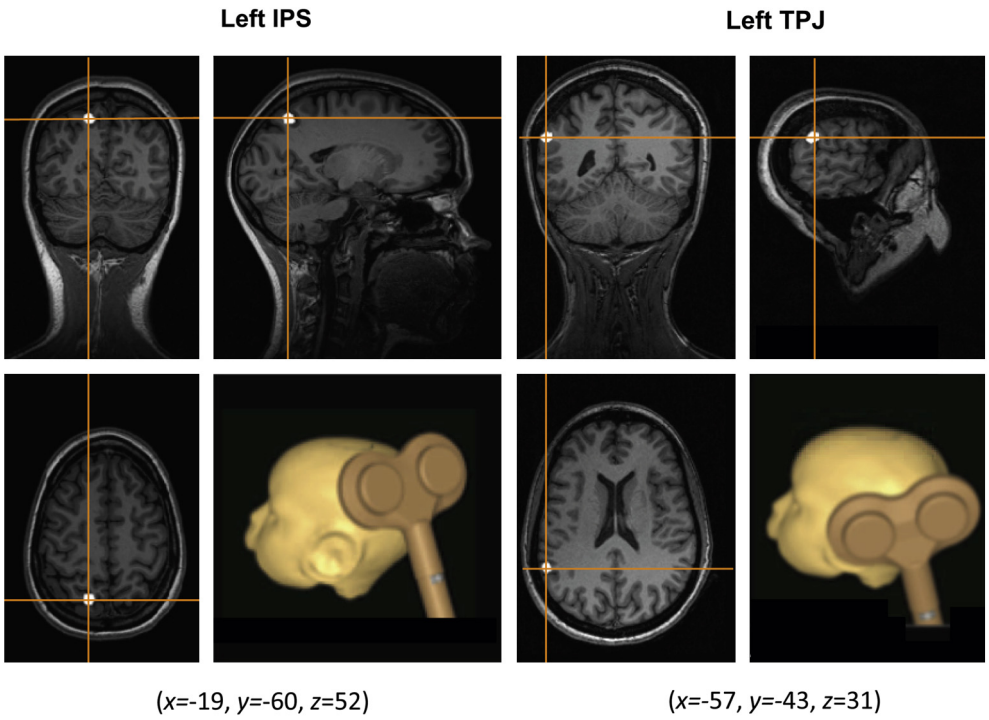

Fig. 2 – Coronal, axial, and sagittal MRI sections (top and bottom left, and top right, respectively) of two representative participants with the targeted left IPS and left TPJ location, labeled as a white dot. Structural T1-weighted MRI scans were acquired on a 3T Siemens MPRAGE (flip-angle, 9; Repetition Time, 2300 ms; Echo Time, 4.18 ms; slice thickness, 1 mm) for all participants at the CENIR MRI center (Brain and Spine Institute, Salpêtrière Hospital, Paris). Left TPJ Talairach coordinates ($x = -57$, $y = -43$, $z = 31$) and left IPS Talairach coordinates ($x = -19$, $y = -60$, $z = 52$) were extracted from a previous event-related fMRI study (Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005), which explored the brain networks underlying orienting of spatial attention. Such coordinates were labeled in each individual MRI and reconstructed 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 in the figure).

3. Results

For the manual task analyses, we defined fictive squares around the central fixation and the four peripheral circles, subtending 1.61 × 1.61 degrees of visual angle. We discarded trials in which participants failed to fixate the area around the fixation point at any time during the fixation period, and trials in which participants directed their gaze to the target before responding (3.66% of the trials). For the saccadic task, we excluded those trials in which participants failed to move their eyes to the area surrounding the peripheral circles when the target was presented, or back to the central area around fixation circle when the cue-back was presented (1.61% of trials). Two participants were excluded from the analysis because of technical problems to record eye movements. In both tasks, manual and saccadic RTs above or below 2.5 SD from each individual mean were also eliminated as outliers (2.56% and 2.06% of total trials, respectively).

In order to explore potential hemispheric differences for the cortical control of IOR, we compared our results with the effects obtained in prior observations using identical tasks, analyses, and rTMS patterns, in homologue regions of the right hemisphere (see Bourgeois, Chica, Valero-Cabre, et al., 2013), by carrying out an overall analysis on manual and saccadic RTs, after right and left IPS or TPJ stimulation.

We first of all performed an overall ANOVA on RTs in the pre-TMS block for each experimental condition with the within-participant factors of task (manual, saccadic), target side (left and right), and validity (*SL*, *DLS*, *DLON*, *DLOF*), and the between-participants factor of stimulated region (IPS, TPJ) and stimulated hemisphere (left, right), in order to further demonstrate that each group of participants displayed an equivalent IOR effect. The analysis indicated a main effect of validity, $F(3,108) = 29.44$, MSE = 284, $p = .001$, that interacted neither with the stimulated region, nor with the stimulated hemisphere ($F(3,108) = 1.03$, MSE = 284, $p = .38$, and $F(3,108) = .60$, MSE = 284, $p = .62$, respectively). In order to further confirm this conclusion, we compared the magnitude of the IOR effect for each homologue region. No comparison reached significance (all $ps > .81$).

We then compared performance on the manual and saccadic task for each group by performing an ANOVA on the IOR index (IOR post-TMS *minus* IOR pre-TMS) with the intra-participant factors of task (manual, saccadic) and target side (ipsilateral and contralateral to the rTMS stimulation), and the between-participant factor of stimulated region (IPS, TPJ) and

stimulated hemisphere (left, right). The analysis demonstrated significant interactions between task and stimulated hemisphere, $F(1,36) = 5.34$, MSE = 721, $p = .027$, and between task, target side, and stimulated hemisphere, $F(1,36) = 7.64$, MSE = 901, $p = .009$. As previously demonstrated elsewhere (Bourgeois, Chica, Valero-Cabre, et al., 2013), Fisher LSD post-hoc analysis indicated an alteration of manual but not saccadic IOR for ipsilateral targets after right hemisphere stimulation, $p = .003$; this ipsilateral alteration of manual IOR was observed after right but not after left hemisphere stimulation ($p = .026$, for the left versus right hemisphere comparison). An alteration of saccadic IOR was also observed for contralateral targets as compared to ipsilateral targets after right but not left hemisphere stimulation ($p = .020$, for the contralateral versus ipsilateral comparison) (see Fig. 3A and B; and Tables 1 and 2).

It could be argued that the absence of significant IOR modulations observed after left IPS or TPJ rTMS could result from a lack of statistical power. To address the statistical power concern, we calculated the effect size of the task × target side interaction when either hemisphere was stimulated. The effect size (η^2) represents the proportion of the variance accounted for by our experimental manipulation. With stimulation of the right IPS or TPJ, there was a task × target side interaction with $p = .015$ and $\eta^2 = .72$. With stimulation of the left hemisphere homologue regions, the effect size associated to the task × target side was four times lower ($\eta^2 = .18$, $p = .284$). Consistent with this result, Fisher LSD post-hoc comparisons performed on the interaction between task, target side, and stimulated hemisphere demonstrated that the modulation of manual IOR for ipsilateral targets was significantly larger after the stimulation of right parietal regions (either IPS or TPJ), as compared to the stimulation of homologue regions in the left hemisphere. In order to further confirm the absence of rTMS-induced modulation of IOR after left parietal stimulation, we used G*Power3 (http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/) to calculate the power of the non-significant task × side interaction we observed ($\eta^2 = .18$, $p = .284$). This tool revealed the power to be .86, an adequate level by conventional standards. Importantly, graphic methods devised to assess statistical equivalence (Tryon, 2001; Tryon & Lewis, 2008) also demonstrated equivalence between pre- and post-TMS IOR with stimulation of left parietal regions (Fig. 3).

As stated in the Methods section, we initially aimed to stimulate both regions at similar intensity levels (80% of the maximum stimulator output). However, on the TPJ region, such high levels of TMS intensity induced face and tongue sensations, involuntary blinks, or jaw contractions, which forced us to decrease TMS intensity until these effects were not present anymore. In order to test whether the intensity of rTMS stimulation affected the observed pattern of results, we ranked and divided participants either from the right and the left TPJ group in two subgroups, with low (mean of stimulation intensity = 49%, and 55% for the right and the left TPJ, respectively) or high (mean of stimulation intensity = 68%, and 56% for the right and the left TPJ, respectively) stimulation intensities. Note that this same analysis could not be performed for IPS because all participants were stimulated with a fixed intensity of 80%. We performed an ANOVA on the IOR index with the intra-participants factors of Task and Side, and the within-participants factor of Stimulation Intensity. The analysis performed for the right TPJ group confirmed the results observed in the main analysis. There was a significant interaction between Task and Side, $F(1,8) = 6.18$, MSE = 739, $p = .038$. Importantly the interaction between Task, Side, and Stimulation Intensity was not significant, $F(1,8) = 2.08$, MSE = 705, $p = .187$. The analysis performed for the left TPJ group indicated no significant main effects or interactions (all $ps > .192$). Moreover, the interaction between Task, Side, and Stimulation Intensity was far from significance ($F < 1$). These results indicate that although the TPJ stimulation intensity had to be reduced for practical reasons, stimulation at lower intensities was as effective in generating the main behavioral effect observed in this study as stimulation at higher intensities.

4. Discussion

We used 1 Hz *off-line* rTMS stimulation over left hemisphere parietal regions to explore the causal contribution and address potential hemispheric asymmetries of key dorsal (IPS) and ventral (TPJ) parietal regions to attentional orienting, with both manual and saccadic responses. Similar stimulations over the right hemisphere lastingly interfered with manual but not saccadic IOR for right-sided targets (Bourgeois, Chica, Valero-Cabre, et al., 2013), mimicking the performance of neglect patients with damage of the right parietal cortex or its connections with the ipsilateral prefrontal cortex (Bourgeois, Chica, Migliaccio, et al., 2012). The present results show that, in sharp contrast with right parietal rTMS, stimulation of homologue regions belonging to the left hemisphere modulated neither manual nor saccadic IOR. Taken together, the previous and present TMS stimulation evidence strongly suggests a right hemisphere lateralization of the brain networks underlying the cortical control of IOR.

In keeping with existing models (Heilman & Van Den Abell, 1980; Mesulam, 1999), we propose that the right IPS and the right TPJ are able to deal with both sides of space when manual responses are required. Thus, interference on the right TPJ or IPS may have abolished manual IOR for repeated right-sided targets by inducing an imbalance in an attentional orienting system, thereby overcoming manual IOR for right-sided targets, in the absence of any possible compensation from homologue left hemisphere structures. After right TPJ or IPS rTMS stimulation, the left hemisphere might take over the control of performance, thereby inducing a rightward attentional bias, which would result in blunted IOR (see Berlucchi, Aglioti, & Tassinari, 1997, for a similar hypothesis concerning a split-brain patient). Locally suppressive TMS could have prevented to a certain critical extent the right parietal lobe (IPS, TPJ, or both) from influencing the processing of repeated ipsilateral right-sided stimuli. Under these circumstances, such sensitive process might have been rapidly remapped in the left hemisphere, all the way from visual perception to motor response, without any inhibitory tagging. On the other hand, stimulation of the left parietal lobe, which, according to the present hypothesis, lacks structures capable of signaling the lack of novelty of repeated visual stimulation, would not

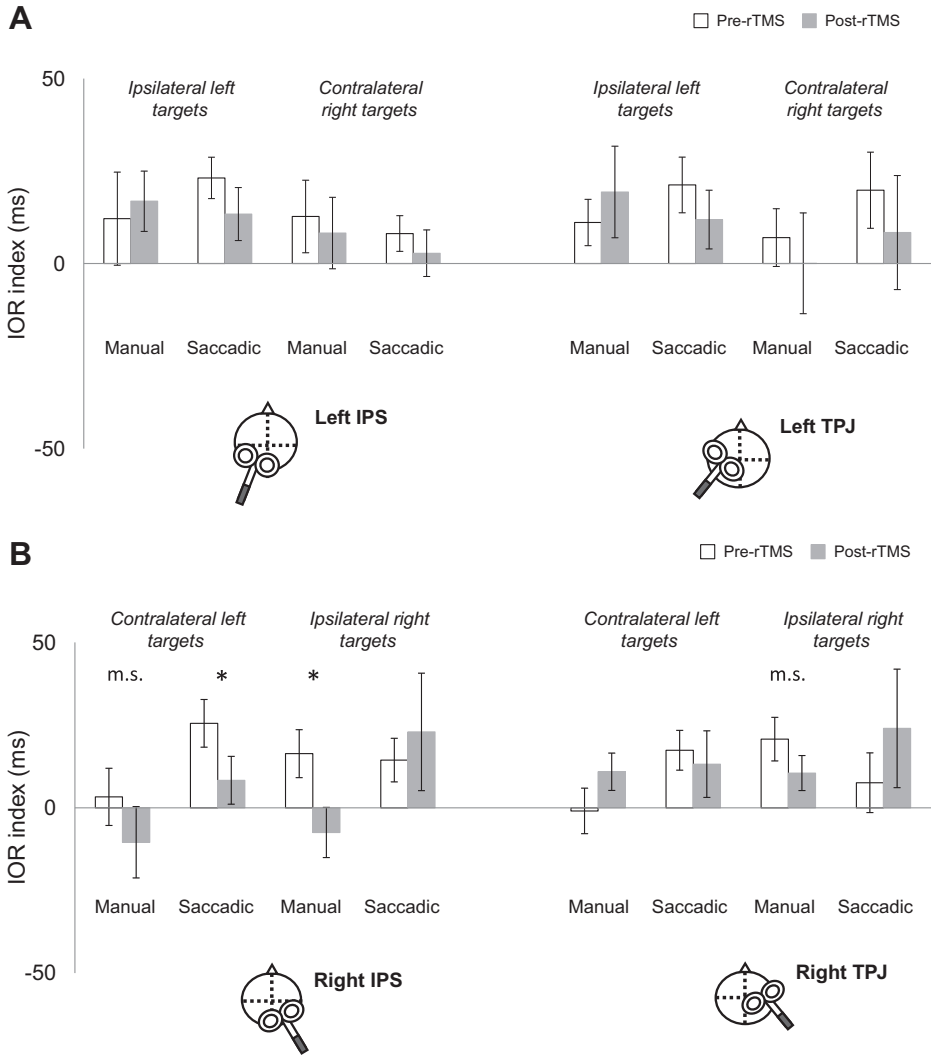

Fig. 3 – IOR expressed in ms with 95% inferential confidence intervals (ICIs), after rTMS on the left IPS and the left TPJ (Panel A), and on the right IPS and the right TPJ (Panel B), for targets presented on the left and right visual hemifield, for manual and saccadic responses. Scores below 0 on the y-axis indicate smaller IOR effects post versus pre-TMS, while scores above 0 indicate larger IOR effects post versus pre-TMS. Error bars denote the 95% ($\alpha = .05$) ICIs, calculated based on the method developed by Tryon (2001) and Tryon & Lewis (2008). According to this method, non-overlapping ICIs denote statistical difference, while an overlap between the ICIs indicates statistical equivalence. As it is evident, there is substantial overlap between the pre- and post- rTMS ICIs for the left hemisphere stimulated regions. This confirms the statistical equivalence of pre- and post-rTMS IOR in left hemisphere regions, in sharp contrast with the non-overlapping ICIs observed for some of the right hemisphere stimulated regions. For right IPS and right TPJ stimulation (where significant IOR modulations were observed), asterisks indicate significant IOR reduction post versus pre-TMS in a one-tailed t-test ($p < .05$). M.s.: marginally significant comparisons ($ps < .09$).

determine any detectable effects on manual IOR for targets occurring on either side of the space, thanks to the preservation of normal activity patterns in bilaterally competent homologue right parietal structures. In agreement with this hypothesis, there is evidence of increased metabolic activity in the right IPS for attentional shifts in both visual fields (Nobre et al., 1997). Our result that rTMS over the right IPS can also abolish manual IOR for contralateral left-sided targets, while rTMS over the left IPS produces no effects on attentional orienting, is consistent with these models, because the right IPS might be able to compensate for left IPS interference, thanks to its bilateral competence. In contrast to this hypothesis, the fMRI-based model put forward by Corbetta and colleagues proposes a contralateral competence for each dorsal fronto-parietal network in the orienting of endogenous attention (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). However, the low temporal resolution of fMRI prevents the capture of fast and brief events, such as blood-oxygen-level-dependent activity evoked by exogenously driven attentional orienting. In this context, our

Table 1 – Mean correct RTs (in ms), and percentage of correct detections pre-rTMS on the left TPJ and left 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
Left TPJ									
Manual	Pre-rTMS	**292** (19)	278 (21)	280 (20)	283 (18)	**276** (18)	272 (17)	270 (18)	266 (17)
	Percentage correct	96	96	97	97	96	95	96	97
Saccadic	Pre-rTMS	**257** (9)	244 (8)	238 (8)	226 (7)	**258** (9)	236 (10)	244 (8)	233 (9)
	Percentage correct	96	98	97	98	99	98	98	99
Left IPS									
Manual	Pre-rTMS	**336** (19)	331 (21)	223 (20)	318 (18)	**327** (18)	325 (17)	306 (18)	312 (17)
	Percentage correct	94	96	94	95	96	94	93	96
Saccadic	Pre-rTMS	**270** (9)	249 (8)	246 (8)	246 (7)	**263** (9)	252 (10)	256 (8)	255 (9)
	Percentage correct	99	97	98	98	98	99	99	98

Table 2 – Mean correct RTs (in ms), and percentage of correct detections post-rTMS on the left TPJ and left 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
Left TPJ									
Manual	Post-rTMS	**279** (20)	266 (18)	255 (17)	258 (15)	**254** (16)	258 (14)	250 (16)	254 (15)
	Percentage correct	95	97	97	96	96	95	96	97
Saccadic	Post-rTMS	**254** (11)	235 (8)	244 (9)	247 (14)	**256** (16)	250 (13)	235 (10)	258 (14)
	Percentage correct	98	98	97	98	98	98	99	98
Left IPS									
Manual	Post-rTMS	**313** (20)	300 (18)	288 (17)	301 (15)	**298** (16)	297 (14)	282 (16)	289 (15)
	Percentage correct	98	98	96	97	97	98	98	97
Saccadic	Post-rTMS	**259** (11)	258 (8)	240 (9)	238 (14)	**259** (16)	260 (13)	255 (10)	255 (14)
	Percentage correct	99	100	99	99	99	100	98	99

results, demonstrating a causal implication of the right IPS in exogenous processes underlying manual IOR, are in good agreement with previous event-related TMS evidence provided by Chica et al. (2011).

Our data also demonstrated that saccadic IOR was selectively abolished after rTMS over the right IPS but not the left IPS for contralateral left-sided targets, perhaps as a consequence of the inhibition of a parieto-collicular pathway (see e.g., Rafal, Calabresi, Brennan, & Sciolto, 1989; Sapir et al., 1999; Sumner, Nachev, Vora, Husain, & Kennard, 2004). The hemispheric differences we found suggest that the right parieto-collicular pathway may deal with both sides of space for saccadic IOR, while the left IPS-SC pathway might be only involved in the processing of the contralateral space. This proposal is consistent with the observation of an involvement of the right but not the left anterior IPS in the remapping of visual saliency across saccades (Van Koningsbruggen, Gabay, Sapir, Henik, & Rafal, 2010). It also suggests an implication of different brain networks for performing manual and saccadic responses (Anderson & Rees, 2011).

Different participants from those taking part in our right parietal experiment were recruited for the present study in order to avoid potential biasing effects of repeated practice of several blocks of IOR across more than two consecutive experimental sessions (Weaver, Lupiáñez, & Watson, 1998). In consequence, even if the present results are in line with the above reviewed evidence of hemispheric attentional asymmetries, it could be argued that the present sample of left-stimulated participants was different from the right-stimulated participants previously explored by Bourgeois, Chica, Valero-Cabre, et al. (2013), hence precluding a direct left versus right parietal comparison. This seems, however, implausible, since as shown in our analyses, both experimental groups matched in gender and age, they displayed at baseline and prior to TMS similar IOR effect magnitudes and were stimulated with identical patterns and intensity levels.

In conclusion, we have shown that rTMS stimulation of left hemispheric parietal regions does not have any measurable effect on manual or saccadic IOR, in sharp contrast with the stimulation of homologue regions in the right hemisphere. This evidence extends to IOR the validity of current models of hemispheric asymmetries in the control of visuospatial attention.

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