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Review

The Spatial Orienting paradigm: How to design and interpret spatial attention experiments

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ABSTRACT

This paper is conceived as a guide that will describe the very well known Spatial Orienting paradigm, used to explore attentional processes in healthy individuals as well as in people suffering from psychiatric disorders and brain-damaged patients. The paradigm was developed in the late 1970s, and since then, it has been used in thousands of attentional studies. In this review, we attempt to describe, the paradigm for the naïf reader, and explain in detail when is it used, which variables are usually manipulated, how to interpret its results, and how can it be adapted to different populations and methodologies. The main goal of this review is to provide a practical guide to researchers who have never used the paradigm that will help them design their experiments, as a function of their theoretical and experimental needs. We also focus on how to adapt the paradigm to different technologies (such as event-related potentials, functional resonance imaging, or transcranial magnetic stimulation), and to different populations by presenting an example of its use in brain-damaged patients.

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[1] Other variables to manipulate such as: Number of cue and target positions on the screen; Target temporal predictability; Presence of distractors; Stimuli modality; Meridian effect; Target probability; and Target contrast; have been described in Supplementary material.

[2] Other variables to control for, such as: Stimulus size and distance to the screen; Simon effect; and Participants' position; have been described in Supplementary material.

1. The Spatial Orienting paradigm

This guide on how to use the Spatial Orienting paradigm is intended to help the naïf reader in designing their tasks and interpreting their results. Of most importance, when designing an attentional orienting experiment, one of the first decisions to be taken is related to the type of orienting we are interested in (endogenous vs. exogenous), which will determine the cue type to be used. Depending on our interest on facilitation and/or Inhibition of Return (IOR; see below), we will have to decide other crucial variables such as cue validity, the task to be performed, cue and target duration, Stimulus Onset Asynchrony (SOA), etc. The online supplementary material contains a programmed E-prime (Schneider et al., 2002) experiment where all these variables can be manipulated. Further files containing typical analyses (mean RT and accuracy) are also provided.

In a typical implementation of the Spatial Orienting paradigm (Wright and Ward, 2008), participants are presented with a fixation point, flanked by a placeholder (for example, a squared box) on each side. The first stimulus, usually an attentional cue, is presented some time after the fixation point onset. As in the example of Fig. 1, the cue can consist of a change in luminance of one of the two placeholders. After a short interval, a second stimulus, referred to as the target, is presented inside one of the two placeholders. The time interval between the onset of the cue and that of the target is known as Stimulus Onset Asynchrony (SOA). Usually, both the cue and target are equally likely to appear at the left or right location. In most designs, participants are not required to respond to the cue, and have to respond to the target (see below). Both speed of response and accuracy are usually measured as dependent variables (although other psychophysical measures are used in some studies; Handy et al., 1999; Hawkins et al., 1990). After a response is detected, or a fixed amount of time has elapsed (for example 2000 ms), an inter-trial interval (ITI) is presented (in which the screen typically remains empty) for about 1000 ms. This is a description of the original task (Posner, 1980; Posner et al., 1978), which is also known as the "costs and benefits paradigm" (see below).

Attentional cues can either be valid, invalid, or neutral. Valid cues are presented at the location of the upcoming target, or indicate target appearance at this location. Invalid cues are presented at a different location to the upcoming target or indicate a wrong location. Neutral cues are presented at or indicate either a location where the target is never presented (usually the central location), or all possible locations in the display. Therefore, after the appearance of the cue, targets can be presented either at the valid location (also known as cued location), at the invalid location (also known as uncued location), or following a neutral cue. The valid-invalid and cued-uncued terminology may be interchangeably used. We generally prefer to use the terms cued-uncued, because as it will be explained below, attentional cues can or cannot predict the spatial location of target appearance. The valid-invalid terminology is more easily associated with spatially predictive cues, while the

cued-uncued terminology seems more adequate to refer to both spatially predictive and non-predictive cues.

As it will be described in detail, there are many variants of the Spatial Orienting paradigm. One of the most important variants is the target–target paradigm (see for example, Maylor, 1985b; Taylor and Klein, 2000). In this variant, no attentional cues are presented, and participants are requested to respond to successive targets. The trial is considered valid or cued, when two targets are successively displayed at the same spatial location, while the trial is considered invalid or uncued when targets are successively presented at different spatial locations (see Fig. 1).

Another important variant of the cue–target or target–target paradigm is the use of covert or overt orienting (see for example, Maylor, 1985b; Posner, 1980; Rafal et al., 1989). Although attentional shifts are usually associated with eye movements to the attended location (for example, when someone enters the room and we look on his/her direction), there are many situations in which we can pay attention without moving our eyes (for example, when we see someone entering the room but we would like to seem busy looking at the computer screen). During covert attention, participants are required to fixate a central location while stimuli are presented in the periphery. Thus, under these conditions, eye movements do not accompany attentional shifts. Overt attention, on the other hand, refers to conditions in which participants are required to move their eyes freely or to the cue or target location. Under these conditions, eye movements accompany attentional shifts. The exact form and degree of oculomotor activity permitted or required to the participant varies greatly between experiments and can dramatically change both the performance of the participant and the inferential meaning of the data. In cue–target paradigms, participants are typically required to move their eyes to the location indicated by the cue, and back to the center, before the target appears (see for example, Chica et al., 2010a). They can also be required to maintain fixation during the cue period, and move their eyes to the target location; or they could be asked to move their eyes to the location indicated by the cue, back to the center before the target appears, and then to the target location (Taylor and Klein, 2000). In the target–target paradigm, participants are usually required to move their eyes to the target location, and back to the center, before the next target appears (Bourgeois et al., 2012, 2013; Maylor, 1985b; Posner, 1980).

2. Types of orienting

In everyday life, attention can be oriented to locations in space in two ways: (1) top-down, "voluntarily", and endogenously (according to our goals, intentions, or task demands), or (2) bottom-up, "involuntarily", and exogenously (to salient or potentially relevant stimuli) (Jonides, 1981). These two types of orienting can be implemented in cue–target paradigms by manipulating cue type and cue validity.

Endogenous orienting is usually manipulated by using central symbolic cues that predict with high probability the spatial location
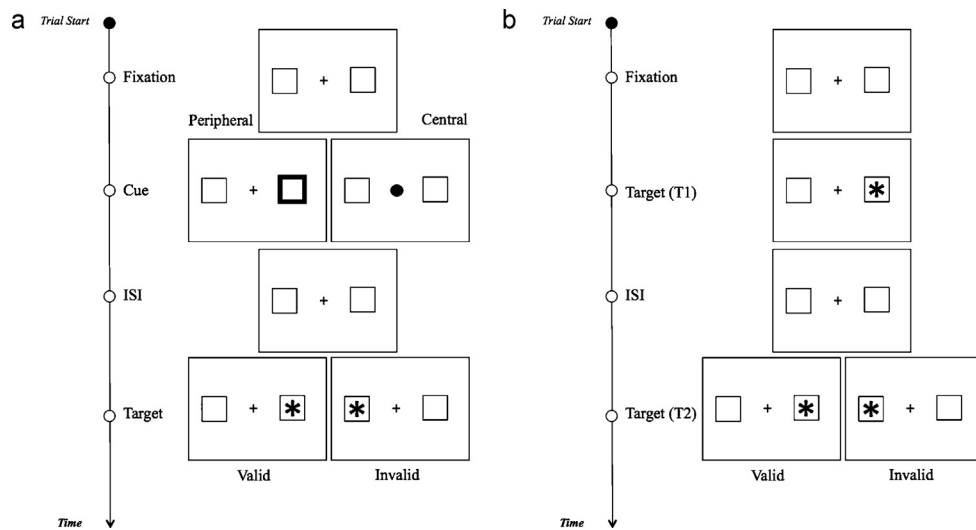
Fig. 1. Illustration of the Spatial Orienting paradigm. (A) Cue–target paradigm with central and peripheral cues. Participants respond to the target but not to the cue. The central cue is represented as a colored circle; in the example, a full circle indicates target appearance more likely on the right placeholder, while an empty circle would indicate target appearance more likely on the left placeholder. (B) Target–target paradigm in which participants respond to consecutively presented targets, which can appear either at the same spatial location (cued trials) or at different spatial locations (uncued trials).

of the target. Arrow cues are the most used, but given our extended practice with this kind of stimuli, it has been discovered that they can orient attention even if they are not predictive about the target location (Bayliss et al., 2005; Hommel et al., 2001; Marotta et al., 2012; Ristic et al., 2002). This indicates that, to some extent, arrow cues orient attention involuntarily to the location they are pointing at. Moreover, arrow directed attention is additive with endogenous and exogenous attention, manipulated using central predictive digits and non-predictive peripheral cues, respectively. This indicates that arrow directed attention constitutes a distinct form of attention orienting (Ristic and Kingstone, 2012). Other symbolic cues ought to be used, such as for example, a central dot indicating the target location according to its color (e.g., red can indicate target appearance more likely on the left side of space, and blue can indicate target appearance more likely on the right side of space) (Dodd and Wilson, 2009; Funes et al., 2007). As in many other manipulations, color meaning has to be counterbalanced between participants to avoid unexpected effects, such as a better orienting to the left side after red cues. When central cues are truly symbolic, they do not produce any orienting of attention if they do not predict the target location. Therefore, central cues have to be spatially predictive about the target location to induce endogenous orienting. Cue predictability can be manipulated at different rates, but one of the most used conditions, in a two-placeholder display, as the one presented in Fig. 1, is ~75% predictability, i.e. the target appears at the location indicated by the cue on 75% of the trials, and at the uncued location on 25% of the trials. Note that, 50% predictiveness would work well in an 8-placeholder array (50% cued vs. 12.5% cued). Participants should be given some practice trials to learn the arbitrary cue–target relationship.

Exogenous orienting, on the other hand, is generally manipulated using peripheral cues. These cues can consist of a change of luminance of one of the placeholders (usually this change in luminance gives the impression of a brief flash). A new object can also be presented, such as for example, a small circle presented near one of the peripheral placeholders. Offsets have also been used as peripheral cues; for example, one of the placeholders can disappear some time after the fixation point is presented, which has also been reported to produce attentional effects (Riggio et al., 1998). Peripheral cues attract attention exogenously given its saliency, even if they are spatially non-predictive of the target location. In

the usual procedures with two possible target locations, spatially non-predictive peripheral cues are presented at the target location on 50% of the trials, and at the opposite location on the remaining 50% of the trials. This implicates a pure exogenous capture. However, peripheral cues can also be spatially predictive of the target location. They can predict, with high probability, target appearance at the same location than the cue (for example, by having 75% cued trials and 25% uncued trials). In this case, cue appearance captures attention to its location exogenously, and this initial attentional capture is enhanced given the high probability of target appearance at this location. Finally, exogenous cues can also be counter-predictive, that is, they can predict with high probability that the target will be presented at the opposite (uncued) location (for example, by having 25% cued trials and 75% uncued trials) (Warner et al., 1990). In this case, cue appearance captures attention to its location exogenously, while endogenous attention enhances the processing of the opposite (uncued) location (Chica et al., 2006, 2008; Posner et al., 1982). These hybrid cues do not always produce the same effects as spatially non-predictive peripheral cues or spatially predictive symbolic cues (see Section 3).

3. Typical results

Although the results observed when using the Spatial Orienting paradigm critically depend on many variables, as it will be described in detail below, we will firstly present the typical results observed with the most frequent manipulations used (see Fig. 2 and Table 1). When using *spatially predictive central symbolic cues*, reaction times (RTs) and/or accuracy are usually improved for cued as compared to uncued trials. This improvement of performance is known as "facilitation". The effects of central symbolic cues are observed at cue–target SOAs of ~300 ms, when participants have had enough time to interpret the cue and orient attention accordingly (Remington and Pierce, 1984), and last for several seconds (Posner, 1980). These effects seem to be similar in magnitude in detection and discrimination tasks (Berger et al., 2005), although we are not aware of any study performed to directly test this assumption (Jonides, 1981).

When using *peripheral non-predictive cues*, facilitation is usually observed at SOAs as short as ~50 ms. However, this facilitatory effect is not long lasting, and is usually not observed after ~300 ms.

Table 1

Meta-analysis of a subset of studies from our lab. Data are divided according to Cue Type (Central and Peripheral cues), Cue Validity (25% predictive of the cued location, 50% predictive of the cued location, and 75% predictive of the cued location), SOA (short: ≤300 ms, and long ≥500 ms), and Task (Detection and Discrimination). The Cueing effect represented corresponds to the mean RT for uncued minus cued trials, and therefore, positive values indicate facilitatory effects, and negative values indicate Inhibition of Return (IOR).

Cue type	Cue validity	Soa	Task	Experiments	Cueing effect	F		p	Partial eta-squared	Observed power (alpha = 0,05)	SD difference	Estimated sample size
Central	50%	Long	Detection	Total 3 exps.	9	$F(1,63)$	19.88	$p < 0.0001$	0.23	0.99	15	39
				Exp.1 (1) (*)	7	$F(1,35)$	6.69	0.0139	0.16	0.71		
				Exp.2 (1)	11	$F(1,15)$	18.75	0.0005	0.55	0.98		
				Exp.3 (1)	9	$F(1,11)$	3.98	0.0712	0.26	0.44		
			Discrimination	Total 3 exps.	8	$F(1,63)$	16.26	$p < 0.0001$	0.20	0.97	16	54
				Exp.1 *	9	$F(1,35)$	8.55	0.0060	0.19	0.81		
				Exp.2 *	6	$F(1,15)$	3.42	0.0840	0.18	0.40		
				Exp.3 *	8	$F(1,11)$	4.32	0.0616	0.28	0.47		
	75%		Detection	Total 3 exps.	56	$F(1,41)$	45.52	$p < 0.0001$	0.52	0.99	56	16
				Exp.1 *	60	$F(1,13)$	13.00	0.0003	0.63	0.99		
				Exp.2 *	54	$F(1,13)$	7.70	0.0157	0.37	0.73		
				Exp.3 *	60	$F(1,13)$	22.61	0.0003	0.63	0.99		
			Discrimination	Total 4 exps.	30	$F(1,90)$	47.69	$p < 0.0001$	0.34	0.99	44	30
				Exp.1 *	23	$F(1,48)$	13.14	0.0007	0.21	0.94		
				Exp.2 *	40	$F(1,13)$	14.84	0.0010	0.53	0.94		
				Exp.3 *	35	$F(1,13)$	15.49	0.0017	0.54	0.95		
				Exp.4 *	45	$F(1,13)$	12.24	0.0039	0.48	0.89		
Peripheral	25%	Short	Detection	Total 4 exps.	−34	$F(1,95)$	77.69	$p < 0.0001$	0.44	1.00	38	19
				Exp.1 (2)	−33	$F(1,23)$	19.29	0.0002	0.45	0.98		
				Exp.2 (2)	−19	$F(1,19)$	2.37	0.1394	0.11	0.31		
				Exp.3 (2)	−31	$F(1,19)$	35.28	$p < .0001$	0.65	0.99		
				Exp.4 (3) (*)	−41	$F(1,31)$	76.66	$p < .0001$	0.71	1.00		
			Discrimination	Total 6 exps.	−12	$F(1,198)$	9.01	0.0030	0.04	0.84	56	285
				Exp.1 (2)	8	$F(1,23)$	1.29	0.2668	0.05	0.19		
				Exp.2 (2)	3	$F(1,19)$	$F < 1$	0.7667	0.004	0.05		
				Exp.3 (2)	−6	$F(1,19)$	1.01	0.3267	0.05	0.15		
				Exp.4 (4)	−50	$F(1,55)$	56.15	$p < .0001$	0.50	1.00		
				Exp.5 (3) (*)	−3	$F(1,31)$	$F < 1$	0.6187	0.008	0.07		
				Exp.6 (5)	−12	$F(1,46)$	2.05	0.1583	0.04	0.28		
		Long	Detection	Total 5 exps.	−49	$F(1,99)$	209.69	$p < 0.0001$	0.67	1.00	34	9
				Exp.1 (2)	−60	$F(1,23)$	34.55	$p < .0001$	0.60	0.99		
				Exp.2 (2)	−45	$F(1,19)$	40.26	$p < .0001$	0.67	0.99		
				Exp.3 (2)	−45	$F(1,19)$	52.21	$p < .0001$	0.73	0.99		
				Exp.4 (3) (*)	−47	$F(1,15)$	47.71	$p < .0001$	0.76	0.99		
				Exp.5 (6)	−43	$F(1,19)$	70.14	$p < .0001$	0.78	1.00		
			Discrimination	Total 7 exps.	−29	$F(1,249)$	89.62	$p < 0.0001$	0.26	1.00	47	37
				Exp.1 (2)	−35	$F(1,23)$	15.15	0.0007	0.39	0.96		
				Exp.2 (2)	−25	$F(1,19)$	6.87	0.0167	0.26	0.70		
				Exp.3 (2)	−33	$F(1,19)$	15.90	0.0007	0.45	0.96		
				Exp.4 (4)	−35	$F(1,55)$	28.24	$p < .0001$	0.33	0.99		
				Exp.5 (3) (*)	−25	$F(1,15)$	15.18	0.0014	0.50	0.95		
				Exp.6 (6)	−25	$F(1,19)$	27.24	0.0005	0.58	0.99		
				Exp.7 (5)	−21	$F(1,93)$	15.93	0.0001	0.14	0.97		
Peripheral	50%	Short	Detection	Total 4 exps.	10	$F(1,125)$	15.19	$p < 0.0001$	0.11	0.97	28	104
				Exp.1 (7)	7	$F(1,87)$	4.97	0.0283	0.05	0.59		
				Exp.2 (8)	9	$F(1,8)$	2.67	0.1407	0.25	0.30		
				Exp.3 (8)	17	$F(1,18)$	10.66	0.0043	0.37	0.87		
				Exp.4 (9)	19	$F(1,9)$	12.40	0.0065	0.57	0.86		
			Discrimination	Total 6 exps.	31	$F(1,218)$	140.94	$p < 0.0001$	0.39	1.00	38	22
				Exp.1 *	35	$F(1,46)$	20.45	$p < 0.0001$	0.30	0.99		
				Exp.2 (5)	10	$F(1,12)$	2.75	0.1227	0.02	0.33		
				Exp.3 (10)	35	$F(1,90)$	82.12	$p < 0.0001$	0.47	1.00		
				Exp.4 (7)	25	$F(1,8)$	2.77	0.1343	0.25	0.31		

				Exp.5 (8)	40	$F(1,17)$	30.89	$p<0.0001$	0.64	0.99		
				Exp.6 (9)	30	$F(1,40)$	35.96	$p<0.0001$	0.47	0.99		
		Long	Detection	Total 14 exps.	−27	$F(1,332)$	307.03	$p<0.0001$	0.48	1.00	29	18
				Exp.1 (11)	−40	$F(1,53)$	96.47	$p<0.0001$	0.64	1.00		
				Exp.2 (12)	−36	$F(1,8)$	122.14	$p<0.0001$	0.93	1.00		
				Exp.3 (13)	−14	$F(1,17)$	38.49	0.0087	0.69	0.99		
				Exp.4 (1)	−30	$F(1,9)$	11.08	$p<0.0001$	0.55	0.84		
				Exp.5 (1) (*)	−27	$F(1,41)$	75.87	$p<0.0001$	0.64	1.00		
				Exp.6 (1)	−20	$F(1,13)$	8.69	0.0113	0.40	0.77		
				Exp.7 *	−20	$F(1,47)$	63.52	$p<0.0001$	0.57	1.00		
				Exp.8 (7)	−24	$F(1,35)$	60.39	$p<0.0001$	0.63	1.00		
				Exp.9 (8)	−30	$F(1,15)$	175.76	$p<0.0001$	0.92	1.00		
				Exp.10 (8)	−24	$F(1,11)$	79.38	$p<0.0001$	0.87	1.00		
				Exp.11 (9)	−30	$F(1,31)$	53.09	$p<0.0001$	0.63	1.00		
				Exp.12 *	−24	$F(1,13)$	3.33	0.0908	0.20	0.39		
				Exp.13 *	−45	$F(1,13)$	6.78	0.0218	0.34	0.67		
				Exp.14 *	−18	$F(1,13)$	1.51	0.2401	0.10	0.20		
			Discrimination	Total 18 exps.	−9	$F(1,682)$	33.79	$p<0.0001$	0.04	.99	42	285
				Exp.1 *	−14	$F(1,63)$	6.43	0.0136	0.09	0.70		
				Exp.2 (3)	10	$F(1,46)$	1.29	0.2618	0.02	0.19		
				Exp.3 (5)	−20	$F(1,93)$	9.47	0.0027	0.09	0.86		
				Exp.4 (11)	−10	$F(1,46)$	13.36	0.0007	0.22	0.94		
				Exp.5 (10)	−10	$F(1,12)$	3.58	0.0826	0.23	0.42		
				Exp.6 (13)	5	$F(1,46)$	0.51	0.4778	0.01	0.10		
				Exp.7 *	−8	$F(1,63)$	22.95	$p<.0001$	0.26	0.99		
				Exp.8 *	0	$F(1,45)$	$F<1$	0.9768	0.000019	0.05		
				Exp.9 *	−5	$F(1,23)$	2.96	0.0984	0.11	0.37		
				Exp.10 *	−6	$F(1,23)$	2.46	0.1309	0.09	0.32		
				Exp.11 *	−5	$F(1,23)$	$F<1$	0.4138	0.02	0.12		
				Exp.12 *	−4	$F(1,23)$	1.11	0.3027	0.04	0.17		
				Exp.13 (7)	−23	$F(1,54)$	18.11	$p<.0001$	0.25	0.98		
				Exp.14 (8)	−27	$F(1,26)$	31.31	$p<.0001$	0.54	0.99		
				Exp.15 (9)	−10	$F(1,40)$	1.95	0.1695	0.04	0.27		
				Exp.16 *	−10	$F(1,13)$	4.35	0.0570	0.25	0.48		
				Exp.17 *	0	$F(1,13)$	$F<1$	0.9374	0.0004	0.05		
				Exp.18 *	25	$F(1,13)$	4.99	0.0435	0.27	0.54		
Peripheral	75%	Short	Detection	Total 4 exps.	10	$F(1,97)$	14.61	0.0002	0.14	0.96	26	90
				Exp.1 (2)	9	$F(1,23)$	3.52	0.0736	0.13	0.43		
				Exp.2 (2)	9	$F(1,19)$	1.89	0.1846	0.09	0.25		
				Exp.3 (2)	4	$F(1,19)$	$F<1$	0.3594	0.04	0.14		
				Exp.4 (3) (*)	13	$F(1,31)$	10.50	0.0028	0.25	0.88		
			Discrimination	Total 5 exps.	36	$F(1,142)$	83.83	$p<0.0001$	0.37	1.00	47	25
				Exp.1 (2)	34	$F(1,23)$	20.23	0.0016	0.46	0.99		
				Exp.2 (2)	26	$F(1,19)$	12.09	0.0025	0.38	0.90		
				Exp.3 (2)	34	$F(1,19)$	13.24	0.0017	0.41	0.93		
				Exp.4 (3) (*)	30	$F(1,31)$	38.06	$p<.0001$	0.55	0.99		
				Exp.5 (5)	42	$F(1,46)$	23.26	0.0002	0.33	0.99		
		Long	Detection	Total 5 exps.	−11	$F(1,99)$	18.27	$p<0.0001$	0.16	0.98	25	70
				Exp.1 (2)	−22	$F(1,23)$	24.75	$p<.0001$	0.51	0.99		
				Exp.2 (2)	−12	$F(1,19)$	4.54	0.0462	0.19	0.52		
				Exp.3 (2)	−15	$F(1,19)$	9.77	0.0055	0.33	0.84		
				Exp.4 (3) (*)	9	$F(1,15)$	3.78	0.0708	0.20	0.44		
				Exp.5 (6)	0	$F(1,19)$	$F<1$	0.9688	0.00008	0.05		
			Discrimination	Total 7 exps.	15	$F(1,249)$	28.24	$p<0.0001$	0.10	0.99	45	119
				Exp.1 (2)	−10	$F(1,23)$	2.71	0.1132	0.10	0.35		
				Exp.2 (2)	16	$F(1,19)$	6.46	0.0198	0.25	0.67		
				Exp.3 (2)	5	$F(1,19)$	$F<1$	0.3428	0.04	0.15		
				Exp.4 (11)	12	$F(1,55)$	6.91	0.0110	0.11	0.73		
				Exp.5 (3) (*)	20	$F(1,15)$	10.31	0.0058	0.40	0.85		
				Exp.6 (5)	−16	$F(1,19)$	11.57	0.0029	0.37	0.89		
				Exp.7 (5)	22	$F(1,93)$	14.04	0.0003	0.13	0.96		

References: *Unpublished data. (1) Martín-Arévalo et al. (2013b). (2) Chica et al. (2006). (3) Lupiáñez et al. (2013). (4) Chica et al. (2007). (5) López-Ramón et al. (2011). (6) Chica and Lupiáñez (2009). (7) Lupiáñez et al. (1997). (8) Lupiáñez et al. (2001b). (9) Lupiáñez and Milliken (1999). (10) Chica et al. (2011a). (11) Chica et al. (2010b). (12) Chica et al. (2010a). (13) Martín-Arévalo et al. (2013a).
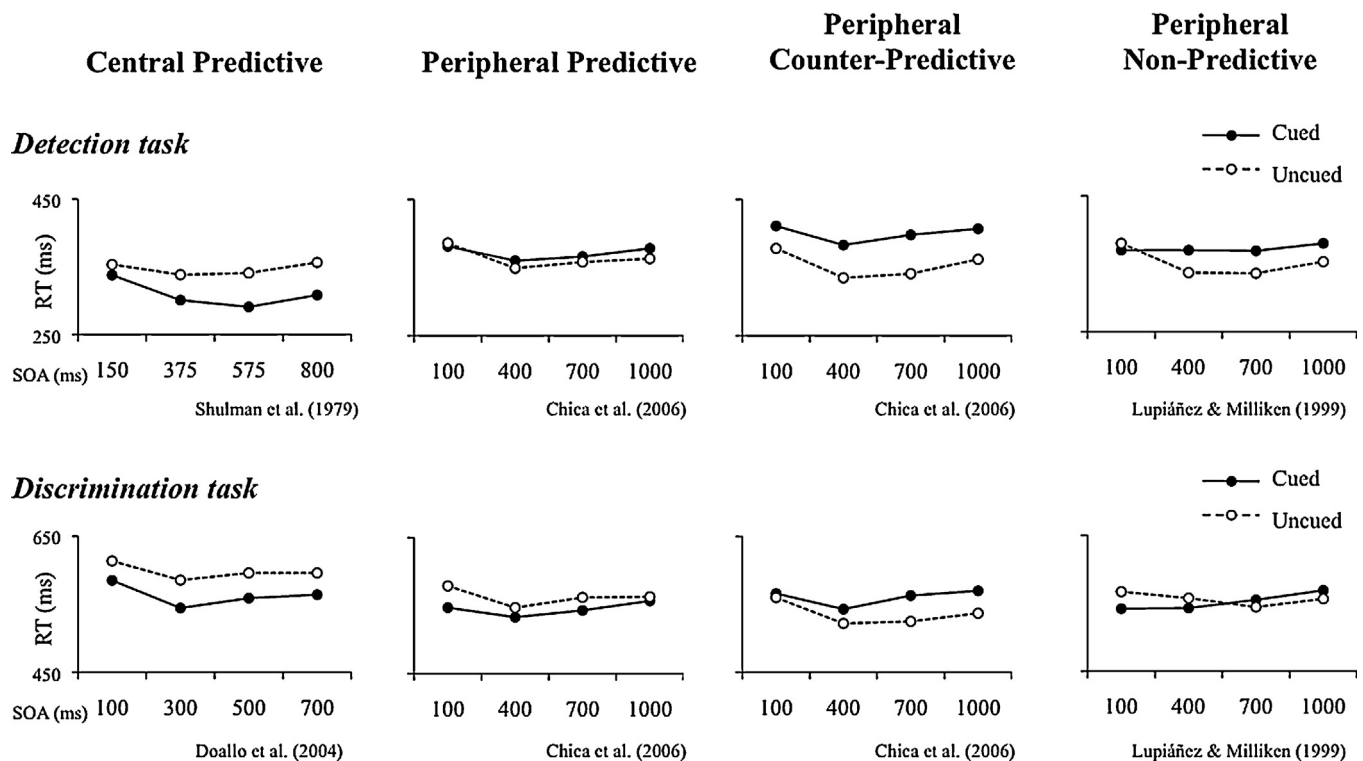
Fig. 2. RT (in ms) as a function of SOA, for cued and uncued trials, for detection and discrimination tasks, when attention is oriented using central predictive cues, and peripheral predictive, counter-predictive, and non-predictive cues.

Indeed, at SOAs longer than 300 ms (depending on the task at hand, Lupiáñez et al., 1997; see below), RTs and/or accuracy can be impaired at the cued location as compared to the uncued location, as first reported by Posner and Cohen (1984). This effect was later named Inhibition of Return (IOR) by Posner et al. (1985) (see Klein, 2000; Lupiáñez et al., 2006, for more recent reviews) (see Fig. 2, results from non-predictive peripheral cues in detection and discrimination tasks). IOR is exclusively behaviorally observed with spatially non-predictive peripheral cues (although it has been reported with central gaze cues under specific conditions, see Section 4.1). Its temporal course depends on task demands (Chica et al., 2006; Lupiáñez et al., 1997) (note in Fig. 2 that IOR appears at longer SOAs in discrimination than in detection tasks), and can last for SOAs as long as 3 s (Samuel and Kat, 2003). The IOR effect has been proposed to reflect an important mechanism to thoroughly explore the visual environment, by avoiding re-inspection of previously attended locations (Klein, 1988). Therefore, once a location has been explored or attended, the attentional system prioritizes attending or exploring "new" (uncued) locations. For a long time, IOR was believed to reflect the inhibition of the return of attention to a previously attended location (Klein, 2000; Posner et al., 1985), the so-called "re-orienting" hypothesis, which was assumed by many researchers in the field. However, more recent studies have consistently demonstrated that IOR is observed at endogenously attended locations (from where no attentional disengagement has taken place) (Berlucchi, 2006; Chica and Lupiáñez, 2009; Chica et al., 2006, see results from Fig. 2 in the detection task with predictive cues, discussed below), and even at fixated locations (Rafal et al., 2006). Furthermore, IOR has also been proved independent of some forms of exogenous orienting, such as gaze cueing (Martín-Arévalo et al., 2013b). These results have challenged the "re-orienting" hypothesis, and other perceptual and motoric mechanisms have been proposed to underlie the IOR effect (Berlucchi, 2006; Chica and Lupiáñez, 2009; Chica et al., 2006, 2010b; Dukewich, 2009; Dukewich and Boehnke, 2008; Gabay et al., 2012; Lupiáñez, 2010;

Lupiáñez et al., 2013; Martín-Arévalo et al., 2013a; Taylor and Klein, 2000). Many results indicate that IOR is not due to the inhibition of the return of attention to the previously attended location, but it might be due to a reluctance to respond to a location where we have previously responded (motor hypothesis), or to a habituation of attentional capture or a detection cost in coding a new object presented in a previously stimulated location (perceptual–attentional hypothesis).

When peripheral cues are spatially predictive of target appearance at their same spatial location, an initial facilitation at the cued location is behaviorally measured, and no IOR is behaviorally observed (see Chica and Lupiáñez, 2009; Chica et al., 2006). However, facilitation is not usually observed at long SOAs, even if cues are highly predictive (Chica et al., 2006; Posner et al., 1982) (see Fig. 2 and Table 1), unless the cue overlaps in time with the target. Moreover, in detection tasks, this facilitatory effect is not usually observed (see Fig. 2 and Table 1; the absence of facilitatory effects in detection tasks is also discussed in Section 4.3). Many researchers believe that peripheral predictive cues do cause IOR, but it is masked by the endogenous orienting of attention to the cued location, which causes a null effect on RT and/or accuracy at long SOAs. Finally, when peripheral cues are predictive of target appearance at the opposite location, an initial facilitation at the cued location can be observed at short SOAs (which indicates an automatic orienting of attention to the cued location), especially in discrimination tasks, followed by improved performance at the predicted (uncued) location (Chica et al., 2006; Posner et al., 1982; Warner et al., 1990). The RT improvement for uncued as compared to cued trials at long SOAs is believed to reflect additive effects of IOR and spatial expectancy.

In target–target paradigms, IOR refers to slower reaction times when a target is successively presented at the same location as compared to conditions in which successive targets are presented at spatially different locations. When participants discriminate the identity or orientation (as well as other features) of targets, IOR is

observed if the second target appears at the same location than the previous one, but a large facilitatory effect is observed if the stimulus features repeat or if an overt response is repeated (Tanaka and Shimojo, 1996; Terry et al., 1994). However, when the participants' task is to localize targets (report their location with a keypress for left targets and a different keypress for right targets), repeating the same stimulus has no effect, i.e., IOR occurs any time stimulus location repeats, no matter whether the stimulus features remains unchanged or if an overt response is repeated (Taylor and Donnelly, 2002).

4. Variables to manipulate[1]

4.1. Central cues

When manipulating endogenous orienting, arrow cues have been extensively used, assuming that they symbolically oriented attention to the location they were pointing at. This assumption was discarded when it was demonstrated that arrow cues orient attention to the location they are pointing at, even if they are not spatially predictive about the future location of the target (Bayliss et al., 2005; Dodd and Wilson, 2009; Hommel et al., 2001; Marotta et al., 2012; Ristic et al., 2002; Tipples, 2002). It was proposed that given our extended practice with this type of stimulus, spatial attention can be involuntarily or exogenously drawn to the indicated location.

Another line of research suggests that the eyes constitute a special stimulus in at least two ways. First, the structure of the eyes is such that it provides us with a particularly powerful signal to the direction of another person's gaze, and second, we may have evolved neural mechanisms devoted to gaze processing. As a result, gaze direction is rapidly and automatically analyzed, being able to trigger attention even if it carries no spatially predictive information (Friesen and Kingstone, 2003; Langton and Bruce, 1999, 2000; Marotta et al., 2013; Ristic et al., 2002).

However, a recent study has demonstrated that arrows and gaze stimuli might trigger attentional shifts as any other non-symmetrical stimuli (Callejas et al., 2014; Shin et al., 2011). The attentional orienting evoked by asymmetrical stimuli seems to be automatic enough to produce effects even if participants are not aware of the cue–target relationship (Shin et al., 2011). We can therefore conclude that symbolic cues should be symmetrical to produce a pure effect of endogenous orienting (Lambert et al., 2006).

An important difference between gaze and arrow cues is that, as stated above, although IOR is not observed with central arrow cues (Posner, 1980), it has been reported under clearly defined conditions with central predictive gaze cues. In order to observe IOR with gaze cues, a fixation cue or intervening event (also known as "cue-back") needs to be presented, for example, by shifting the gaze of the face back to the center and offsetting the face stimulus between cue and target appearance (Frischen and Tipper, 2004; Marotta et al., 2013; but see Mckee et al., 2007). In these conditions, IOR is observed but only at a considerably extended SOA of 2400 ms, whereas at shorter intervals of 1200 ms, no cueing effects were observed (Friesen and Kingstone, 1998; Langton and Bruce, 1999). This gaze-evoked IOR dramatically contrasts with that evoked by peripheral cues, with which IOR is usually observed from around 300–400 ms (depending on the task at hand) following cue onset

and reliably within 1000 ms (see Lupiáñez et al., 1997; see also Samuel and Kat, 2003, for a review and meta-analysis).

Numbers have also been used as symbolic cues (Posner et al., 1980). However, the perception of numbers also involves a spatial component: low numbers are associated with the left side of space and higher numbers with the right side of space. Concerning spatial orienting, it has been demonstrated that looking at spatially non-predictive numbers causes an attentional shift to the left or right side, depending upon the number's magnitude (Fischer et al., 2003a). This observation implies the automatic activation of a numerical mental number line representation when numbers are perceived. Similar results have been observed with reference to time (i.e., words referring to the past orient attention to the left, whereas words referring to the future orient attention to the right; e.g., Ouellet et al., 2010), as well as other abstract concepts, which are spatially embodied, such as positive-negative word valence (Gozli et al., 2013).

4.2. SOA

As exposed above, the SOA manipulation is critical for cuing effects. E.g., Klein and Pontefract (1994) incorrectly concluded that IOR was not observed in a discrimination task because they did not parametrically manipulate SOA. When using spatially predictive central symbolic cues, facilitatory effects are observed only when participants have had enough time to interpret the information provided by the cue and orient attention accordingly. The time necessary to interpret the cue and orient attention depends on the type of cue. For example, arrow cues are interpreted in ~300 ms, given our extended practice with them. However, color cues need ~600 ms to be interpreted and orient endogenous attention accordingly with their meaning. It is therefore recommended to pilot different SOAs if symbolic cues were to be used, to make sure that participants have enough time to orient attention.

When using peripheral non-predictive cues, the SOA manipulation critically determines whether facilitatory or IOR effects will be observed. In general, facilitation is observed at short SOAs, ranging from ~80 to 300 ms depending on the task at hand (Lupiáñez et al., 1997), while IOR is usually observed at SOAs longer than ~300 ms (see Fig. 2 and Table 1). Moreover, it is important to note the range of SOAs used in the task also determines cuing effects in discrimination but not in detection tasks (Milliken et al., 2003). For example, when three SOAs (100, 500, and 900 ms) are used within the same block of trials in a discrimination task, facilitation is observed for the short, 100 ms SOA, and IOR is observed for the long, 900 ms SOA. However, when short SOAs are made more probable within the block of trials, both facilitation and IOR effects are larger. Contrary, if long SOAs are made more probable, facilitation is reduced (Gabay and Henik, 2010; Milliken et al., 2003). A shorter range of SOA also delays the onset of IOR as compared to a longer range of SOAs (Cheal and Chastain, 2002).

4.3. Task

One of the variables having a larger influence on cuing effects is the task to be performed. Here, we will describe cuing effects observed on the most commonly used tasks: detection, discrimination, localization, Go–No go, pointing, and reaching tasks.

Detection and localization tasks: The first spatial orienting studies used manual detection tasks, in which participants had to press a button every time a target was detected, while refraining from responding if the target was not present (what is known as *catch trials*) (Posner, 1980). Contrary to what it is usually assumed by most researchers, when using detection tasks and spatially non-predictive peripheral cues, facilitation is not frequently observed even at short SOAs (see Table 1), unless there is a temporal

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[1] Other variables to manipulate such as: Number of cue and target positions on the screen; Target temporal predictability; Presence of distractors; Stimuli modality; Meridian effect; Target probability; and Target contrast; have been described in Supplementary material.

overlap between the cue and target (Collie et al., 2000), as it was the case in the first studies (Posner and Cohen, 1984). Instead of being a rather general finding, it may require special stimulus conditions. Indeed, in most of the classic studies that show evidence of early facilitation in a detection task, the effect is observed at very brief cue–target SOAs (i.e. <250 ms) (Maylor, 1985a; Maylor and Hockey, 1987; Posner and Cohen, 1984), or with relatively long cues (i.e. displayed until target offset) that overlap in time with the target (Collie et al., 2000). Concretely, Collie et al. showed that when there was temporal overlap between the cue and the target, significant facilitatory effects were observed at the short, 150 ms SOA. Even when cues are spatially predictive of target appearance at the same location, facilitation is observed in detection tasks but, contrary to what is generally believed, it is not as robust at short SOAs as one might think. Moreover, its magnitude is reduced at long SOAs as compared with discrimination tasks (Chica and Lupiáñez, 2009; Chica et al., 2006) (see Table 1). On the other hand, IOR is very robust for detection tasks, being observed at relatively short SOAs, starting around ~300 ms (Klein, 2000), or even at shorter SOAs (Tassinari et al., 1994); IOR is robustly observed at long SOAs when cues are counter-predictive, which might be due to the additive effects of IOR and expectancy of the target at the uncued location (Chica and Lupiáñez, 2009; Chica et al., 2006) (see Table 1). A similar finding is observed when participants are required to localize the target (reporting target location with a keypress for left targets and a different keypress for right targets), IOR being present from relatively short SOAs (see Gabay et al., 2012, for a comparison between localization and shape discrimination tasks; Maylor, 1985a; Tanaka and Shimojo, 1996, for a comparison between detection and localization tasks).

Discrimination and Go–No go tasks: When using spatially non-predictive peripheral cues, facilitatory effects at short SOAs are larger in discrimination than in detection tasks. Moreover, IOR appears at longer SOAs: e.g., in a letter discrimination task, IOR appears at ~700 ms (Lupiáñez et al., 1997) (see Table 1). In some perceptually demanding discrimination tasks, IOR is not observed (Funes et al., 2007), even at SOAs as long as 1000 ms (Lupiáñez et al., 2007). When cues are spatially predictive of target appearance at the same location, strong facilitatory effects are observed at short SOAs. At long SOAs, cuing effects are reduced, maybe because IOR counteracts expectancy effects (Chica and Lupiáñez, 2009; Chica et al., 2006) (see Table 1). In Go–No go tasks, results are similar to those of discrimination tasks, with larger facilitatory effects in Go–No go tasks than in detection tasks, and IOR appearing at longer SOAs (~700 ms) in Go–No go tasks as compared to detection tasks (Lupiáñez et al., 2001a).

Pointing and reaching tasks: In pointing tasks, participants are required to point to a given location when targets are presented (Briand et al., 2000). Fischer et al. (2003b) designed a detection and localization task with pointing responses. In the detection task, participants moved to the same peripheral response location regardless of the target location. In the localization task, participants were required to make an aimed limb movement to the target location. When peripheral targets were preceded by spatially non-predictive peripheral cues, IOR was observed in both conditions, although it was larger in the pointing detection task than in the pointing localization task. In other paradigms, participants have to move either their gaze or hand to a given target. Sheliga et al. (1997) required participants to make horizontal or vertical saccades at the presentation of visual imperative stimuli. The locations of visual imperative stimuli were orthogonal to the required saccade. Before stimulus presentation, participants were cued about its location and instructed to allocate attention to it without moving the eyes. They demonstrated that the allocation of endogenous attention deviated saccades away from the visual stimulus. In a cue–target paradigm requiring a hand reaching response, when the cue–target

interval was short (200 ms), hand paths deviated towards the cue; at longer SOAs (600 ms), however, robust IOR effects were observed in RT to begin the reach, but no inhibitory effect was observed in the movement components (movement time to complete the reach and the path of the reach; see Howard et al., 1999, for similar results).

4.4. Fixation cue

In order to potentiate the appearance of IOR, some researchers present a cue at fixation sometime between the peripheral cue and the target (see e.g. Posner and Cohen, 1984; Prime et al., 2006). Based on the reorienting hypothesis about IOR, this cue is assumed to summon attention back to the central location, thus inhibiting the return of attention to the previously cued location. Although it is generally true that presenting a fixation cue (also known as cue-back or intervening event) eliminates the facilitatory effect and potentiates IOR, its effect depends on factors such as the task at hand or target duration. Fixation cues are mostly effective in discrimination tasks, in which presenting a fixation cue between the peripheral cue and the target leads to IOR at SOAs at which facilitation will be observed in the absence of such fixation cues (Martín-Arévalo et al., 2013a; Prime et al., 2006) (see Fig. 3 and Table 2). In detection and Go–No go tasks, the effectiveness of fixation cues depends on other variables such as target duration (Martín-Arévalo et al., 2013a). In detection tasks, IOR is similar in magnitude when fixation cues are present or absent if target duration is short (50 ms). However, when the target is displayed until response, IOR is larger in magnitude when a fixation cue is present than when it is absent. In Go–No go tasks, fixation cues are also effective in modulating cuing effects, although target duration has to be considered: significant facilitation is observed when no fixation cues are presented and target duration is until response, while significant IOR is observed when a fixation cue is presented and target duration is short (50 ms) (Martín-Arévalo et al., 2013a, see Fig. 3).

4.5. Cue and target physical and temporal characteristics

When using spatially non-predictive peripheral cues, facilitatory effects are larger if the cue and target temporally overlap, and when the target is presented until response (Collie et al., 2000; Maruff et al., 1999; McAuliffe and Pratt, 2005; Pratt et al., 2001). Temporal overlap between the cue and target is one of the few conditions that produce facilitation in detection tasks (Collie et al., 2000; Maruff et al., 1999). Similarly, IOR is more easily observed if there is no temporal overlap between the cue and target (Collie et al., 2000). Finally, target duration also modulates the appearance of IOR, especially in detection and Go–No go tasks, while it produces no effect in discrimination tasks (Martín-Arévalo et al., 2013a, see Fig. 3). Taylor and Donnelly (2002) also found that the IOR effect in a target–target discrimination task depended on the interaction between the features of the cue and target. They showed that IOR was completely absent or not detectable on RT when the cues and targets were identical in identity and orientation (i.e., physical similarity between the cue and the target event led to modulations of cueing effects), but it was reliably observed when there was a partial match between the cue and target.

Another important consideration refers to the physical characteristics of the cues used, which foremost concerns peripheral cues. In general, onset cues (abrupt switching stimuli) are the most effective in triggering attention under most circumstances (Theeuwes, 1991). It is also important to highlight that color cues do not capture attention in many circumstances. It has been proposed that attentional capture is contingent on attentional control settings induced by task demands (Folk et al., 1992), and color cues seem to capture attention only if the target relevant feature for the task at hand is
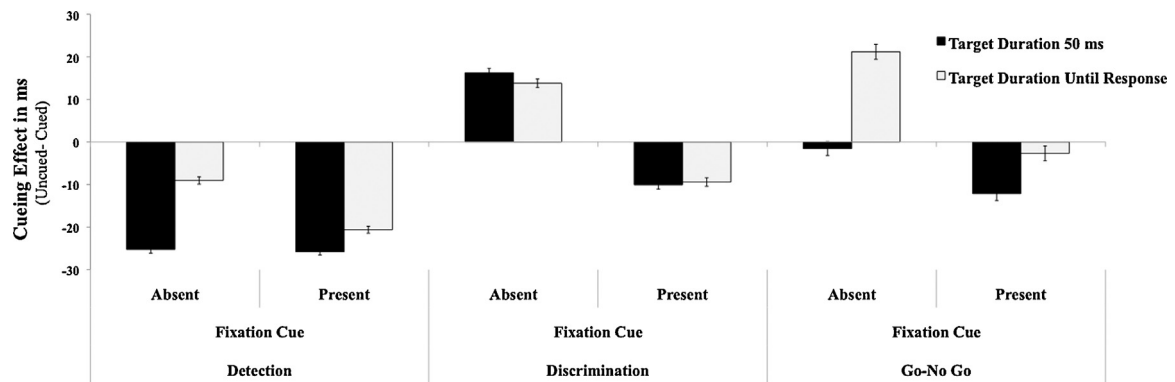
Fig. 3. Mean cueing effect (mean RT for uncued minus cued trials) as a function of fixation cue (absent and present) and target duration (50 ms and until response), in detection, discrimination, and Go–No go tasks. Error bars represent the standard error of the mean (SEM). Reproduced with permission from Martín-Arévalo et al. (2013a).

color. Although this idea is debated (see Folk and Remington, 2006; Theeuwes et al., 2000; see Ruz and Lupiáñez, 2002, for a review), it is recommended to use onset cues rather than color cues to increase cuing effects.

The effects of onset and offset peripheral cues have also been compared. Whereas the occurrence of early facilitation at short SOAs seems not to be consistently different when onset and offset cues were used, IOR is larger in those conditions in which cues onset and then offset before target presentation, as compared with onset cues that do not offset before target presentation, or offset cues (see e.g., Collie et al., 2000, discussed above; Posner and Cohen, 1984; see also Riggio et al., 1998; Samuel and Weiner, 2001). As compared to offset cues, onset cues lead to larger cueing effects by activating object-based effects (Luo et al., 2010; Rastelli et al., 2008).

4.6. Attention to space or objects

The study of spatial attention has proposed an important caveat, wondering whether spatial attention is allocated to unparsed regions of space or to perceptual objects. In some experimental manipulations, the placeholders where stimuli are presented consist of closed objects. In this case, only one edge of the object is cued, while the other edge is uncued. Exogenous attention (elicited by peripheral cues) to a part of an object has been demonstrated to spread to the whole object automatically, while endogenous attention (elicited by central predictive cues) does not spread automatically (Egly et al., 1994; Macquistan, 1997), unless specific instructions are given or when the attentional focus is controlled to be broad (Goldsmith and Yeari, 2003). Another way of investigating the role of objects on spatial cueing is to compare conditions in which placeholders are presented (where cues and targets appear), with conditions in which no placeholders are presented. Peripheral cueing effects are usually larger or longer lasting with than without placeholders (Jordan and Tipper, 1998; Luo et al., 2013).

4.7. Covert and overt attention

As exposed above, in cue–target and target–target paradigms, participants can be required to keep gaze at fixation or to move their eyes to peripheral cues and/or targets. When observers are asked to execute saccades to a peripheral target, the latency of these saccades can be dramatically reduced if the fixation point

Table 2
Meta-analysis of a subset of studies from our lab. Data are divided according to Task (Detection and Discrimination), the presence or absence of a Fixation Cue between the cue and target stimuli, target duration (TD) (Short or Long). Data from SOAs longer than 700 ms in the Discrimination task are presented to clarify that IOR is easily observed in these tasks when no fixation cues are presented and SOA is longer than 700 ms. The Cueing effect represented corresponds to the mean RT for uncued minus cued trials, and therefore, positive values indicate facilitatory effects, and negative values indicate Inhibition of Return (IOR).

Task	Variables	Total experiments	Cueing effect	F		p	Partial eta-squared	Observed power (alpha = 0.05)	SD of the difference	Sample size
Detection	Without Fixation Cue	Total 14 experiments (*, 1, 7, 8, 9)	−27	$F(1,261)$	219.75	$p < 0.0001$	0.45	1.00	32	21
	With Fixation Cue	Total 4 experiments (*, 11, 12, 13)	−29	$F(1,82)$	122.08	$p < 0.0001$	0.59	1.00	22	10
	Short TD	Total 8 experiments (*, 7, 8, 9, 11, 12, 13)	−31	$F(1,214)$	309.48	$p < 0.0001$	0.59	1.00	25	9
	Long TD	Total 7 experiments (*, 1, 13)	−26	$F(1,117)$	79.09	$p < 0.0001$	0.41	0.99	32	18
Discrimination	Without Fixation Cue	Total 18 experiments (*, 3, 5, 7, 8, 9, 10, 11)	−8	$F(1,532)$	17.81	$p < 0.0001$	0.03	0.99	45	414
	With Fixation Cue	Total 8 experiments (*, 3, 11, 13)	−14	$F(1,149)$	29.38	$p < 0.0001$	0.16	0.99	28	54
	Short TD	Total 9 experiments (*, 3, 5, 7, 8, 9, 10, 11, 13)	−12	$F(1,346)$	22.24	$p < 0.0001$	0.06	0.99	47	168
	Long TD	Total 12 experiments (*, 13)	−8	$F(1,299)$	24.93	$p < 0.0001$	0.08	0.99	28	134
	SOA longer than 700 ms	Total 9 experiments (*, 5, 7, 8, 9, 10, 11)	−16	$F(1,288)$	53.63	$p < 0.0001$	0.16	1.00	31	51

References: *Unpublished data. (1) Martín-Arévalo et al. (2013b). (2) Chica et al. (2006). (3) Lupiáñez et al. (2013). (4) Chica et al. (2007). (5) López-Ramón et al. (2011). (6) Chica and Lupiáñez (2009). (7) Lupiáñez et al. (1997). (8) Lupiáñez et al. (2001b). (9) Lupiáñez and Milliken (1999). (10) Chica et al. (2011a). (11) Chica et al. (2010b). (12) Chica et al. (2010a). (13) Martín-Arévalo et al. (2013a).

			First Target					
			No Response		Manual Response		Saccadic Response	
			Exo	End	Exo	End	Exo	End
Second Target	Manual	Exo	**-21**	**-16**	**-22**	**-33**	**-14**	**-19**
		End	-3	-1	-6	18	**-30**	**-24**
	Saccadic	Exo	**-11**	-7	**-14**	**-17**	**-21**	**-24**
		End	**-12**	5	**-29**	**-22**	**-19**	**-21**

Fig. 4. Design and results from Taylor and Klein (2000). Each box represents the cuing effects (mean RT for uncued minus cued trials) collected from one session in which participants ignored or made manual or saccadic responses to the first target, and then either made manual responses or saccades to the second target. In each session, whether the targets were central arrows (End) or peripheral events (Exo) varied randomly from trial-to-trial. Bold numbers indicate significant IOR scores; non-bold numbers indicate the absence of IOR. Redrawn from Taylor and Klein (2000).

is turned off some time (200 ms) before the target appears (e.g., Fischer and Ramsperger, 1984; Kingstone and Klein, 1993; Saslow, 1967; Schiller et al., 1987). This saccade latency reduction has been called the "gap effect" because it is most robustly generated when there is a 100–200 ms gap between the removal of fixation and the appearance of the target. Fixation removal is often used to boost the exogenous control of overt orienting.

Moving the eyes, or refraining to do so, have important consequences on cuing effects. Taylor and Klein (2000) manipulated cue type (central and peripheral) and target type (central and peripheral). They also required participants to either not respond to the cue, or respond with either a manual or saccadic response. Manual or saccadic responses to the target were also manipulated. Results demonstrated that when the eyes were prohibited from moving to either the cue or the target, IOR occurred for manual responses to peripheral targets only. In contrast, when the eyes moved to the cue and/or to the target, IOR occurred for both manual and saccadic responses to both peripheral and central arrow targets (see Fig. 4). It has also been demonstrated that when the eyes move to the location of a peripheral cue and back to the center before the target appears, IOR is observed in detection tasks, although no IOR is observed in discrimination tasks, in which speed-accuracy trade-offs are observed, i.e., responses are faster but less accurate for uncued as compared to cued trials (Chica et al., 2010b).

4.8. Catch trials

Especially in detection tasks, the inclusion of catch trials is highly recommended. Participants would be required to respond to those trials in which targets are presented, but to refrain responding to catch trials, when the target is absent. A high rate of responses to catch trials can indicate that participants are not performing the task properly, as they might be pressing the response button after a fixed amount of time has elapsed, even if they do not see the target. In discrimination tasks, discrimination accuracy can be used to ensure task compliance, and catch trials are unnecessary. It should be taken into account that the number of catch trials included in the design modulates cuing effects observed with peripheral cues. In particular, a high percentage of catch trials (25% vs. 5%) might reduce IOR especially in detection tasks (Tipper and Kingstone,

2005; Wang et al., 2012), although not necessarily in discrimination tasks (Lupiáñez and Milliken, 1999).

4.9. Use of neutral trials

In neutral trials, the cue is presented at (or indicates) a location where the target is never presented (usually the central location), or it is presented at (or indicates) all possible locations in the display. Neutral trials are usually introduced in the design to determine whether the observed attentional effects are caused by benefits of orienting attention to the cued location, and/or costs of orienting attention to the uncued location. Attentional benefits refer to faster RTs for cued than neutral trials, while attentional costs refer to slower RTs for uncued than for neutral trials. This is an important conception after which the paradigm is also known as the "costs and benefits paradigm". In some studies the distinction between costs and benefits is crucial for testing attentional hypotheses. Costs are associated to attentional disengagement (Posner et al., 1987), and are crucial, for example, to isolate the disengaging deficits observed in neglect patients (Losier and Klein, 2001). It has also been show that while benefits are similar for central predictive and non-predictive arrow cues, costs are only observed for predictive but not for non-predictive arrow cues (Doricchi et al., 2010).

However, in order to extract any conclusion from the distinction between costs and benefits, it is critical that neutral cues are matched with attentional cues in physical appearance, potential alerting, and ease of encoding (Chica and Christie, 2009; Jonides and Mack, 1984). Therefore, when using a central symbolic cue, such as for example a colored circle indicating the most likely location of target appearance, the neutral cue could be a different colored circle (matched to the attentional cue in luminance, size, etc.), indicating both locations with equal probability. When using peripheral cues such as the brightening of one of the placeholders, the neutral cue could be a central placeholder of equal size and luminance than the peripheral cue.

In order to be useful, neutral cues should allow the measurement of benefits, costs, or both. In practice, and unfortunately more often than expected, responses to neutral trials are either faster or slower than responses to both cued and uncued trials (see e.g., Gibson and Egeth, 1994; Riggio et al., 1998). These results are quite difficult to understand and might be due to multiple factors (uncontrolled differences in physical appearance, potential alerting, ease of encoding, frequency of neutral trials, etc.). Moreover, it is difficult to conceptualize how attention would be distributed during neutral trials: Do participants un-focus their attention, or do they endogenously attend to one randomly chosen location? Do all participants use the same attentional strategy on neutral trials? Of course, most of these experiments with difficult-to-interpret results are not published, but we would like to advice in this tutorial paper that the use of neutral trials can be more problematic than expected when reviewing published research. In general, one should worry and look for possible methodological problems when performance in neutral trials is not between cued and uncued trials.

5. What you need to control for[2]

5.1. Eye movement control

It is always recommended to control gaze by using an eye tracker, both when overt and covert attention tasks are used. If eye movements are not controlled, any reported differences

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[2] Other variables to control for, such as: Stimulus size and distance to the screen; Simon effect; and Participants' position; have been described in Supplementary material.

in performance between conditions could be accounted for by foveal processing of stimuli, which is faster and more precise than non-foveal, peripheral processing. Also, some attentional effects might depend on whether eye movements are monitored or not (Prinzmetal et al., 2009). Unfortunately, many researchers do not have the possibility to control fixation in covert attention experiments. In this case, it is important to instruct participants to not move their eyes from fixation. If researchers are interested in facilitation, a short enough SOA can be used (for example 50 ms) to prevent eye movements between the cue and target. Because eye movements have a longer latency (∼100–300 ms), it is assumed that participants will not have time to move their eyes to the target location after cue presentation.

5.2. Instructions

When using spatially predictive central symbolic cues, it is important to instruct participants about the information provided by the cue, and report in any published papers the specific instructions given. Without such instructions, some participants do not show cuing effects (Bartolomeo et al., 2007). In the case of peripheral cues, participants are usually informed about cue spatial predictability. However, some studies have reported that cuing effects produced by peripheral cues are unaffected by instructions or by the capacity of participants to report cue–target contingencies after the experiment (Rieth and Huber, 2013). I.e. cuing effects produced by spatially predictive peripheral cues are similar when participants are informed about cue predictability and when they are not. Results are also similar for those participants that can verbally report cue–target contingencies and for those that cannot (Bartolomeo et al., 2007; López-Ramón et al., 2011). Other studies manipulating cue–target similarity have demonstrated that the intentional use of strategies about cue predictability can in fact modulate cuing effects (Vaquero et al., 2010). It is therefore recommended to give specific instructions about cue predictability (no matter whether the cue is spatially predictive or not), to increase the probability of avoiding uncontrolled effects of strategies to orient spatial attention.

It is however of extreme relevance to clearly indicate to our participants whether they should respond fast, accurately, or both. It is often the case to require fast and accurate responses, although some researchers can be interested on speeded responses only (to measure the associated changes in accuracy or speed-accuracy trade-offs) (see e.g., Chica and Christie, 2009), or in accurate responses only, with no time pressure.

6. Task design

6.1. Effect size and statistical power

Table 1 represents a meta-analysis of a subset of experiments from our lab. Data from this table can be used to perform power analyses and a priori sample size estimations, depending on key variables such as Cue Type, Cue Validity, SOA, and Task.

Table 1 demonstrates that for central cues (arrow cues, faces, and symmetrical stimuli), effect size is larger when cues are predictive than when they are not. Therefore, the estimated sample size is larger for central non-predictive than predictive cues.

For peripheral cues, effect size critically depends on the task at hand. With counter-predictive cues (25% validity) and short SOAs, the cueing effect (faster responses for uncued than cued trials) has a much larger effect size in detection than discrimination tasks. At long SOAs, effect size is still larger for detection than discrimination tasks, although in discrimination tasks IOR can be observed at long SOAs with a smaller sample of participants than at short SOAs.

With non-predictive cues and short SOAs, effect size is larger for discrimination than detection tasks, requiring a large number of participants to find facilitation in the latter. For long SOAs, the IOR effect size is larger for detection than discrimination tasks. In this analysis (in which key variables such as Fixation Cue presentation or Target Duration are not taken into account), the IOR effect for the discrimination task is very weak and requires a large number of participants to be observed. However, as stated above, IOR can be observed in discrimination tasks under certain circumstances. As it can be observed in Table 2, while Fixation Cue presentation or Target Duration have no effect on detection tasks, Fixation Cue presentation, but not Target Duration, has an important impact in discrimination tasks. The IOR effect size in discrimination tasks was the largest when a fixation cue was presented, or SOA was larger than 700 ms (Lupiáñez et al., 1997).

With predictive cues (75%) and short SOAs, effect size is larger in discrimination than in detection tasks. It is important to note that facilitatory effects can be observed in detection tasks when peripheral cues are spatially predictive, but they are not robust, needing a large sample size to be consistently observed (see Table 1). As stated above, measuring facilitation in detection tasks is not as usual as one might think, requiring special conditions, such as long cues or cues that temporally overlap with the target. Some authors believe that facilitation and IOR emerge simultaneously with cue onset (Klein, 2000; Lupiáñez, 2010). Because IOR is very robust in detection tasks, it might mask the facilitatory effect, even if cues are spatially predictive of the target location. At long SOAs, IOR instead of facilitation is observed in detection tasks, and a negligible facilitatory effect is observed in discrimination tasks, requiring an extremely high number of participants. In more perceptually demanding discrimination tasks, facilitatory effects can be observed in discrimination tasks, even at long SOAs (see for example Chica et al., 2012; Funes et al., 2007).

6.2. Number of trials per condition

When using the Spatial Orienting paradigm, it is recommended to have at least 20 trials per condition. In general, it is important to have as much observations as possible for each experimental condition, but with one key constriction: facilitation and IOR produced by non-predictive peripheral cues can decrease with practice (Lupiáñez et al., 2001b; Weaver et al., 1998). It is also important to design tasks that last no longer than ∼50 min, as the task is repetitive and participants get bored and start to report troubles to maintain fixation.

7. Comparing endogenous and exogenous orienting, a big dilemma

Some researchers are interested in comparing the effects of endogenous and exogenous attention on perceptual, decisional, or motor processes. Traditionally, this comparison has been made by using spatially predictive central symbolic cues for endogenous orienting, and spatially non-predictive peripheral cues for exogenous orienting. However, the differences between the consequences of the exogenous versus endogenous orienting of spatial attention observed in these studies could either be due to: (1) the type of cue (peripheral vs. central symbolic) and the underlying mechanism orienting spatial attention (i.e., endogenous or exogenous); (2) to the predictive value of the cue (spatially predictive vs. non-predictive); (3) to other perceptual factors: in exogenous orienting studies an object (the cue) is presented at approximately the same position as the target on a proportion of trials (i.e., on cued trials), while under conditions of central cuing, there is absolutely no spatial correspondence between the cue and target stimuli (Chica

and Lupiáñez, 2004, 2009; Chica et al., 2006, 2007; Gibson and Kingstone, 2006).

To overcome this problem, some authors have compared the effects of spatially predictive and non-predictive peripheral cues. It is important to note that in this case attention is always exogenously summoned to the cued location, but only in the case of spatially predictive cues there is an incentive to endogenously maintain attention at the cued location (Briand and Klein, 1987). Other studies have compared spatially predictive and non-predictive central arrow cues (Doricchi et al., 2010; Lasaponara et al., 2011). Note that, as stated above, in this case benefits were independent of cue predictivity, but costs were only observed with predictive cues.

Therefore, when using central and peripheral cues we can manipulate how spatial attention is triggered, either endogenously (using central symbolic cues) or exogenously (using peripheral cues); and we can also manipulate maintenance or removal of attention from the cued location. Contrary to what some authors have argued (Prinzmetal et al., 2009), peripheral predictive cues involve a mixture of endogenous and exogenous attention. When attention is oriented using spatially predictive central symbolic cues, attention is endogenously triggered and maintained. When peripheral cues are spatially non-predictive, attention is exogenously triggered and no endogenous maintenance or removal occurs, although there might be an endogenous effort to avoid capture or disengage following capture. When peripheral cues are spatially predictive of target appearance at the same location, attention is exogenously triggered and endogenously maintained. And finally, when peripheral cues are spatially predictive of target appearance at the opposite location (i.e., counter-predictive cues), attention is exogenously triggered and there is an endogenous removal of attention from the cued location (see e.g., Chica et al., 2011b).

8. Adapting the Spatial Orienting paradigm to different populations and techniques

8.1. Patients: an example of adaptation of the paradigm for brain damaged patients suffering from neglect

In this section, we will describe an example of adaptation of the Spatial Orienting paradigm to patients with right fronto-parietal damage suffering from neglect. These patients' attention is highly biased to right (ipsilesional) targets, which makes interesting the use of the Spatial Orienting paradigm to explore their attentional imbalance. Let's first envision the design of an experiment in which we would like to potentiate the observation of exogenous attentional facilitation. First of all, we have to take into account that neglect patients present serious deficits in conscious perception of left-sided events when right-sided stimuli compete for their spatial attention (Bartolomeo and Chokron, 2002; Posner et al., 1985; Rastelli et al., 2008). It is for this reason that stimuli are generally presented for a longer period of time when testing right fronto-parietal damaged participants than healthy volunteers. Therefore, if peripheral cues are usually presented for ~50 ms in the healthy population, they are presented for ~300 ms in patients with right fronto-parietal damage. Note that this long cue duration might increase the presence of facilitation, as compared with shorter cue durations (Collie et al., 2000; Rastelli et al., 2008). Targets are also presented for a longer duration in right fronto-parietal damaged participants than healthy controls, to decrease the rate of missed responses. Therefore, if targets are usually presented for ~50 ms in healthy participants, they are presented for ~100 ms (or sometimes until response) in patients with right fronto-parietal damage. Long target durations

might also increase the presence of facilitation (Martín-Arévalo et al., 2013a).

As exposed above, the cue–target SOA is one of the variables that critically determines whether exogenous cuing effects would be facilitatory or inhibitory (IOR). Again, very short SOAs can increase the rate of missed responses in neglect patients, and therefore, SOA duration is usually not shorter than ~300 ms. In order to increase facilitation, cues and targets could temporally, but not spatially, overlap. Finally, it is important to think about the task to be performed with the target (which is another crucial variable determining exogenous cuing effects). As exposed above, discrimination tasks and Go–No go tasks produce larger facilitatory effects than detection or localization tasks. There are however important constrains to perform discrimination and localization tasks in brain-damaged patients. Damage to any level of the cortico-spinal tract produces deficits in fine voluntary motor control (Purves et al., 2001). Many patients therefore present difficulties in using two response keys (controlled with two fingers of the same hand) to perform a discrimination or localization task. One possibility could be to press a key with the left hand, and the other key with the right hand. Unfortunately, many neglect patients suffer from hemiplegia, due to associated lesions of the primary motor cortex. One possibility is to use a joystick to perform responses (Chica et al., 2011c). However, we have to be cautions in demanding left–right directional responses, because patients could present directional neglect, an impairment to program and perform left-directed movements (Husain et al., 2000). It is for all these reasons that the most used tasks in neglect are simple detection tasks, although in principle, Go–No go tasks can also be used to enhance facilitatory effects.

If we were interested in IOR effects rather than facilitation in right fronto-parietal damaged patients, following the same logic than above, the best task conditions seem to be: detection tasks, and cues and targets that do not temporally overlap. This time, spatial overlap between the cues and targets could increase the IOR effect. The SOA is also recommended to be long for observing IOR effects: a 1000 ms SOA is a quite standard one producing strong effects. Given that long target durations are used for improving perceptual performance on neglect patients, a fixation cue is recommended to increase the magnitude of IOR (Martín-Arévalo et al., 2013a). Fixation cues are also recommended in some special populations (in the elderly and Alzheimer disorder, Faust and Balota, 1997; in children, MacPherson et al., 2003; in schizophrenic patients, Mushquash et al., 2012). Target–target paradigms have been proved very useful to observe IOR in right fronto-parietal damaged patients. These paradigms are easier to perform (participants respond to each stimulus, without having to refrain responding to the cues) than cue-target paradigms, and allow a rapid evaluation of neglect (see Bartolomeo et al., 1999; Bourgeois et al., 2012).

A final consideration when evaluating different populations is that some participants (brain damaged and psychiatric patients, as well as very young or old populations) cannot be evaluated for long periods of time. They get tired, bored, unmotivated, lose concentration, etc. For most of these populations, if the task is longer than 15 min, it is recommended to perform different sessions. This should not be a problem, since spatial cueing effects with peripheral cues, if any, tend to be reduced with practice (Lupiáñez et al., 2001b). Therefore, effects should be robust in short sessions.

8.2. Spatial Orienting paradigm and Event Related Potentials (ERPs)

The Spatial Orienting paradigm has extensively been used in combination with electroencephalographic recordings. Here, we will present an example of adaptation of the paradigm to analyze event related potentials (ERPs). One of the most important

considerations to take into account is that when an event can be temporally predicted (i.e., the event is always presented after the same temporal window), a component known as the "Contingent Negative Variation" (CNV) appears. The CNV is a long-latency negative potential observed during response or stimulus anticipation. The appearance of this component can alter the attentional modulations expected when comparing cued, uncued, and neutral trials. To avoid its appearance, the time interval before each stimulus is usually randomly jittered, so that temporal predictivity is reduced. The fixation display duration can be for example randomly jittered between 1000 and 1500 ms, and the SOA between the cue and target can be jittered within a 300 ms interval (i.e., instead of using a fixed, 1000 ms SOA, its duration can be randomly jittered between 700 and 1000 ms). It is important to pre-test these conditions, as it has been shown that temporal predictability affects facilitation and IOR with non-predictive peripheral cues in discriminations tasks (Gabay and Henik, 2010; Milliken et al., 2003).

Another important constrain when using the Spatial Orienting paradigm with ERPs is that stimuli cannot easily be presented at very short SOAs. The Adjacent Response (Adjar) technique is used to remove overlapping activity by convolving the initial estimates of the waveforms for the cues and targets with previous and subsequent event distributions (Woldorff, 1993). This procedure has previously been shown to be an effective way of estimating and removing overlapping responses from the waveforms of interest (e.g., Hopfinger and Mangun, 1998, 2001; Woldorff, 1993). When implemented correctly, the estimates of overlap for the cue and target waveforms should converge to a stable solution after a number of iterations.

Some studies also use targets and non-targets (also called "standards") for the main task, requiring participants to respond to targets and to refrain responding to non-targets. ERP components are usually analyzed for "standards" only, in order to avoid the ERP modulations associated to motor responses. Although this is a good technique to improve the ERP waveform, it is important to consider that adding the "standards" automatically converts the task in a Go–No go task, which can affect the expected behavioral and neural results.

Although in behavioral paradigms the response window can offset after a response is detected, in ERP designs, it is important to keep the target and response window for a fixed amount of time, even if a response is detected. This will allow the ERP recording for comparable windows in all conditions. Finally, participants are always required to not move or blink during the experimental trials in electroencephalographical recordings, to reduce artifacts. However, it is impossible to not blink for the whole duration of the experiment. Therefore, it is recommended to add a display after each trial, in which participants are allowed to blink if necessary. They could for example be required to blink during the inter-trial interval, which should last for at least 2 s. Periodical rests within the task are essential to improve participants' comfort.

8.3. Spatial Orienting paradigm and functional Magnetic Resonance Imaging

Compared to electroencephalographical recordings, functional Magnetic Resonance Imaging (fMRI) has a better spatial resolution, but a much lower temporal resolution. The use of fMRI is highly appropriate to explore the neural circuits underlying attentional orienting, although its low temporal resolution constrains the use of short SOAs. This is the reason why fMRI studies of attentional orienting have principally focused on endogenous facilitation produced by spatially predictive central symbolic cues, which is observed at longer SOAs than exogenous facilitation produced by spatially non-predictive peripheral cues. Even if IOR is observed at long SOAs, with temporal characteristics that might fit the

timing required to observe hemodynamic responses, cued minus uncued fMRI contrasts have not been successful in showing the fronto-parietal brain network underlying exogenous cuing effects (Mayer et al., 2007). It is therefore recommended to focus on endogenous attentional effects when using the Spatial Orienting paradigm in combination with fMRI.

The first fMRI attentional orienting studies used blocked designs, in which cue- and target-related activity could not be teased apart (Corbetta et al., 1993; Gitelman et al., 1999; Kim et al., 1999; Mayer et al., 2004; Nobre et al., 1997; Peelen et al., 2004; Rosen et al., 1999). More recent event-related fMRI studies have used a different approach and analyzed the cue-related activation separately from target-related activation. For example, Hopfinger et al. (2000) piloted a cue sensory-control session, where the cues used in the main experiment were flashed every 750 ms (duration, 500 ms) for 22 s, alternating with 22 s no-stimulus blocks. A synthetic hemodynamic response function was convolved with the box-car function that represented the periodic alternation in the experimental conditions to yield the model response function that included a temporal derivative. In another cue control, the cue and target stimuli were identical to that used in the main attention study except that the cues were not spatially predictive. Target stimuli (250 ms) were presented on only 22% of trials with an inter-stimulus-interval of 300 ms, whereas the other 78% of trials (catch trials) consisted only of the cue stimuli; only these catch trials were analyzed, using event-related methods. During data analyses, the responses of interest in the event-related design were modeled by convolving a vector containing the onset times of the cues and targets with a synthetic hemodynamic response function composed of the sum of two gamma functions and its temporal derivative (accounting for the hemodynamic response and subsequent undershoot and for slight variations in timing). As a result, the analysis emphasized transient hemodynamic activity temporally adjacent to the cue and target events.

Ollinger et al. (2001) have developed and tested a method to separate processes within a trial in event-related functional MRI. When the time interval between the two events (in our case between the cue and target) cannot be jittered with long intervals (which can be as long as 12 s, which is not an ideal timing for cueing experiments), two main recommendations are made to optimize the estimation of the hemodynamic response associated to each event: (1) the inter-trial interval should be jittered, with a minimum range of one to two repetition times and a maximum range of three to four repetition times; (2) around 30% of the trials should be partial trials, in which only the cue stimulus is presented. These partial trials should be randomly inserted so that participants cannot anticipate its appearance.

8.4. Spatial Orienting paradigm and Transcranial Magnetic Stimulation

The Spatial Orienting paradigm is also easily adaptable to be used with offline and online Transcranial Magnetic Stimulation (TMS) studies. In offline designs, repetitive pulses of TMS are applied to a targeted brain region for a period of time. This stimulation produces effects lasting for a delimited amount of time, depending on the stimulation protocol. For example, repetitive TMS patterns of 1200 TMS pulses applied at 1 Hz with an inter-pulse interval of 1 s (for a total of 20 min) 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-Cabre et al., 2007). Therefore, the time window of reduced excitability is estimated in about 10–15 min. The behavioral paradigm is run before and after the TMS stimulation, in order to test specific effects of TMS over cognitive

functions. The only required adaptation of the paradigm is related to the lasting effects of TMS. In the above-described example, our task should run for no more than 10–15 min (Bourgeois et al., 2013).

Attentional effects can also change with practice in the task (Lupiáñez et al., 2001b), therefore, control experiments should be run to determine which pre-post TMS modulations are due to the TMS stimulation protocol, and which ones are expected for practice and task repetition. Ideally, the control experiments should be identical to the main manipulation, while actively stimulating a region that produces no attentional effects. However, attentional functions are so much distributed in the brain that finding this control region is a hard and risky decision. Attention is implemented in different regions of the frontal and parietal cortex, but also produces effects in occipital, temporal, and frontal brain regions in preparation for perception and/or action (see Corbetta and Shulman, 2002, for a review). It is for this reason that, although not ideal, some researchers use a vertex stimulation or a sham control. In sham control, the coil is placed at the same location than the stimulated site, but positioned at 90° with its surface pointing away from the skull. This procedure can be effective in mimicking the clicking noise associated with the delivery of TMS pulses, while effectively preventing the magnetic field from significantly reaching and stimulating the brain. New sham techniques that better mimic real TMS (in qualitative sensations of pain, tingling, sharpness, piercing, electric, tugging, pinching) are being developed (Borckardt et al., 2008; Mennemeier et al., 2009).

TMS can also be applied online, while participants are performing the task. This online procedure is used when researchers are interested in testing the effects of TMS in a specific time window (for example between the onset of the cue and that of the target). I.e., online designs are used when specific hypothesis are made in restricted time windows. TMS has a temporal resolution of the order of milliseconds, making it a good technique to test the temporal dynamics of brain function. However, more considerations about how to adapt the Spatial Orienting paradigm are necessary in online than offline designs. Let's imagine a situation in which TMS pulses are applied during the cue–target SOA, in order to test the causal contribution of a given region to attentional orienting (Chica et al., 2011a). When applying the pulses to one of the cerebral hemispheres, there is a lateralized noise and tapping sensation between the cue and target presentation. This noise and tapping sensation may act as a fixation cue or intervening event (also called cue-back), which might favor the appearance of IOR (see Martín-Arévalo et al., 2013a). As in offline designs, control experiments need to be performed, ideally using an active control (which is extremely difficult to find, see above). Unfortunately, to the best of our knowledge, no new sham technology trying to mimic real TMS associated sensations allows to rapidly switch between real and sham TMS from trial to trial. Until these new methods are fully developed, a vertex or sham control is highly recommended to disentangle any potential confounding factor associated to TMS stimulation.

Finally, an important decision is whether the TMS control is interleaved within the experimental trials or presented in a different block of trials. Generally speaking, interleaved TMS control pulses might be a better option than running a control TMS block. However, there would be situations in which adding an interleaved control can make the task longer than desirable. For example, an experimental manipulation consisting of two blocks of trials (stimulating IPS and TPJ) will require a TMS control. Running an interleaved TMS control requires duplicating the duration of both blocks of trials, while running a TMS control block only adds one third of the trials, because the same control block could be used for both IPS and TPJ blocks.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neubiorev.2014.01.002.

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