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THE ROLE OF ATTENTION
IN SIMON EFFECT ASYMMETRIES

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INTRODUCTION

The Simon effect belongs to the category of stimulus-response compatibility effects. These effects, first noted in the 19th century by Donders (1868/1969), have received much attention, in both basic and applied research in psychology, in recent decades. The purpose of this work is to investigate the relation between left-right Simon effect asymmetries and the attentional asymmetries, in both right- and left-handers.

Chapter 1 offers a brief introduction to the topic of visual attention, and gives explanations of some basic aspects of this cognitive mechanism. The focus will be on distinctions that are crucial to understand the experimental chapters: the distinctions between endogenous and exogenous orienting of attention, between facilitatory and inhibitory effects, and between early and late selection theories of attention. At the end of the chapter the Simon effect will be introduced and explained on the basis of one of the currently most accredited theories. Finally, the focus of the current work, namely, Simon effect asymmetries, will be highlighted.

In Chapter 2 the cerebral lateralization of visual attention will be addressed. We will review the most important research, involving both neuropsychological patient data and neuroimaging data obtained from neurologically intact individuals, that indicate that the visual attention is localized – in right-handers – in the right cerebral hemisphere. Some papers highlighting asymmetries in behavioural research will be reported, and finally, lateralization of this mechanism in left-handers will be examined on the basis of the literature.

Chapters 3 and 4 are the two experimental chapters. Chapter 3 is the crucial one, in which four experiments that directly compare asymmetries in
visual attention and in the Simon effect are reported. For each experiment two samples of participants are tested, one of right-handers and one of left-handers. As hypothesized, asymmetries in the Simon effect are related to attentional asymmetries, and we demonstrate that handedness alone cannot give an exhaustive explanation of Simon effect asymmetries. Chapter 4 contains one control experiment that was conducted in order to exclude potential confounding variables in previous experiments, and one new experiment. Both experiments in this chapter tested only right-handed participants while manipulating the response requested. The results demonstrate the strong relation between visual attention and other mechanisms, for example, response selection mechanisms. Thus, it is difficult to analyze visual attention with respect to response selection separately.

Chapter 5 is the conclusive chapter, in which, on the basis of the experimental results, conclusions will be drawn.
THEORETICAL SECTION

CHAPTER 1: VISUAL ATTENTION AND SIMON EFFECT

More than one hundred years ago, William James (1890) wrote that “everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought” (p. 261).

Attention is the cognitive process of selecting one aspect of the environment while ignoring others. For example, it is possible to listen carefully to what a person is saying while ignoring other conversations in the same room. This popular phenomenon is known as the “cocktail party effect”, and was first reported by Cherry (1953). Researchers have systematically examined different aspects of attention, with one of the most studied being visual attention.

This chapter will introduce visual attention and provide explanations of some basic aspects of this cognitive mechanism. Some distinctions that are crucial to understand the following chapters will be given; for example, the distinction between endogenous and exogenous orienting of attention, between facilitatory and inhibitory effects, and between early and late selection theories of attention. At the end of the chapter the Simon effect will be introduced and interpreted on the basis of one of the currently most accredited theories. Finally, the focus of the current work, namely, Simon effect asymmetries, will be highlighted.

1.1 VISUAL ATTENTION

Attention can move in visual space overtly (together with eye movements) or covertly (without eye movements). Evidence that attention can be oriented
covertly was first reported by Posner (1980), by using a spatial cueing paradigm. Before the imperative stimulus, a cue is presented. If the cue does not signal a specific location in the space, the trial is neutral. If the cue signals a location, the trial can be valid (if the stimulus appears in the cued – attended – location) or invalid (if the stimulus appears in the un-cued – non-attended – location). Attention orienting effects manifest themselves as benefits and costs. Reaction Times (RTs) in the valid condition are faster than RTs in the neutral condition (about 10-15 ms), whereas RTs in the invalid condition are slower than RTs in the neutral condition (about 20-30 ms).

Posner, Walker, Friedrich and Rafal (1984) proposed that these effects happen because the act of shifting attention is composed of three mental operations: disengagement of attention from its current focus, moving attention to the target and engagement of the target. When cue and target do not appear in the same position (invalid trial), RTs are slower than when cue and target appear in the same position. This is due to a requirement to disengage attention from the cue, re-orient it to the target and engage it to the target in the first case, whereas in the second case these operations are not needed, so RTs are faster.

1.1.1 Endogenous versus exogenous orienting

James (1890) distinguished between active and passive attention. Active is also referred to as endogenous, voluntary, top-down or goal-directed, whereas passive is also referred to as exogenous, automatic, bottom-up or stimulus-driven. According to Jonides (1981), the two mechanisms differ from each other in capacity, resistance to suppression and expectancy. Endogenous orienting is impaired by a concurrent task, is not difficult to suppress and is influenced by the participant’s expectation. Exogenous orienting is not influenced by a concurrent task, is difficult to suppress and does not depend on the expectancy of the
participant. Moreover, the two mechanisms have different time courses. Benefits produced by endogenous orienting become evident later (they need 300 ms to reach optimum), and those produced by exogenous orienting start early (they can be observed between 100 and 300 ms after the cue onset) but they are transitory (see, for example, Müller & Rabbitt, 1989).

In the Posner paradigm discussed above, the cue can be peripheral (Figure 1a) or central (Figure 1b). According to Jonides (1981, see also Müller & Rabbitt, 1989) a peripheral cue (Posner & Cohen, 1984; Posner, Rafal, Choate & Vaughan, 1985) elicits the exogenous component of attention, whereas a central cue (Posner, Nissen & Ogden, 1978; Posner, Snyder & Davidson, 1980) elicits the endogenous component.

![Figure 1](image.png)

**Figure 1.** Example of a trial with peripheral (a) and central (b) cue. On the left the cue and on the right the subsequent stimulus (in the valid position) are represented (from Fernandez-Duque & Posner, 2001).

1.1.2 Facilitatory and inhibitory effects

In the previous paragraph we mentioned the fact that the effects of the exogenous component of the attention are transitory. Indeed, it is only when exogenous orienting is involved that we can observe a dissociation between an early facilitation (RTs faster in the valid trials) followed by a later inhibition.
This was first described by Posner and Cohen (1984) and was termed “Inhibition of Return” by Posner et al. (1985). Therefore, the effects of peripheral cues depend on the interval between cue and target (*Stimulus Onset Asynchrony*, SOA). The facilitatory effect occurs when the SOA is within about 300 ms, and as the SOA becomes longer, Inhibition of Return (IoR) appears.

1.1.3 Early or late selection?

One of the earliest theories of selective attention is Broadbent’s (1958) filter theory, usually referred to as early selection theory. The basic hypothesis was that all stimuli reaching the sensory system – whether or not they are attended – are analyzed on the basis of some physical attributes (for example, pitch or location), but only attended stimuli are processed further, to the level of identification. Therefore, a selective filter is responsible to determine which stimuli are to be further processed.

An alternative to Broadbent’s early selection theory is what is usually referred to as late selection theory. Deutsch and Deutsch (1963) proposed that the selective filter operates only after the analysis of all characteristics of the stimuli. This theory claims that people elaborate all the information they run into, irrespectively of what they choose to attend or to ignore. Several effects, very popular in cognitive psychology, support this theory, by showing that unattended information are elaborated and then could interfere with performance. Three of the most popular psychological effects are the Stroop effect, the Flanker effect and, finally, the object of this study: the Simon effect.

In a Stroop task (Stroop, 1935) participants have to name the colour of the ink in which a word is printed. When the word spells out the name of an incongruent colour (e.g. “green” printed in red ink) participants are slower to
respond “red” than in a neutral condition (e.g. “chair” printed in red ink) or in a congruent condition (e.g. “red” printed in red ink).

In a Flanker task (Eriksen & Eriksen, 1974) participants have to press one key if a central target – surrounding by flanking items – is a letter (e.g. H or K) and another key if the target is another letter (e.g. S or C). When the central target and the flanking items are from different response sets (e.g. H-target with S-flankers) participants are slower to respond than in a neutral condition (e.g. H-target with A-flankers) or in a compatible condition (e.g. H-target with K-flankers).

In the next paragraph the Simon effect will be introduced.

1.2 THE SIMON EFFECT

Simon and Rudell (1967) first observed that when participants had to press a left- or right-key in response to the word “left” and “right” presented to the left or right ear, they were faster when the content of the command corresponded with the ear stimulated than when it did not.

Simon and Small (1969) observed the same effect by using acoustic but not verbal stimuli. They reported that when participants had to press a left- or right-key in response to low and high tones presented to the left or right ear, they were faster when the tone was presented in the ear spatially corresponding with the key they had to press than when it was presented in the ear spatially non-corresponding with the key they had to press.

Craft and Simon (1970) first described this effect in the visual modality. Typically, participants have to press one left- or right-key in response, for example, to a circle or a square, which could appear on the left or on the right. They are faster (and more accurate) when the stimulus appears in the position spatially corresponding to the response position than when it appears in the
position spatially non-corresponding to the response position, even though the stimulus position is not relevant for the task. The four conditions are represented in Figure 2, whereas theoretical RTs in the four conditions are represented in Figure 3.

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Figure 2. In the upper panel the two non corresponding conditions (on the left: right stimulus – left response; on the right: left stimulus – right response, see respectively conditions “b” and “c” in Figure 3) are represented. In the lower panel the two corresponding conditions (on the left: left stimulus – left response; on the right: right stimulus – right response, see respectively conditions “a” and “d” in Figure 3) are represented.

The difference between the mean of the two non-corresponding conditions (“b” and “c” in Figure 3) and the mean of the two corresponding conditions (“a” and “d” in Figure 3) is typically between 20 and 30 ms (Lu & Proctor, 1995) and is referred to as the “Simon effect”, terms first used by Hedge and Marsh (1975).
To summarize, the Simon effect, as well as the Stroop and the Flanker effects, corroborates the late selection theory because it shows that the irrelevant information is automatically elaborated, so as to interfere with the performance of participants.

1.2.1 Attentional shift hypothesis of the Simon effect

In the first theoretical explanation of the Simon effect, Simon (1969; 1990) invoked a “natural tendency to react toward the source of stimulation”. According to this explanation, the stimulus position would trigger an orienting reaction, that tends to automatically elicit a response on the same side of the space. When the side of the stimulus differs from the side of the response, responses are slower because this tendency, being inappropriate, must be inhibited.
A second hypothesis (the *coding hypothesis*, proposed by Hasbroucq & Guiard, 1991, and by Kornblum, Hasbrouq & Osman, 1990) maintains that the irrelevant spatial code of the stimulus causes an interference at either the stimulus categorization stage or the response selection stage.

The *attentional shift hypothesis*, proposed by Nicoletti and Umiltà (1994), Stoffer (1991), Stoffer and Umiltà (1997) and Umiltà and Nicoletti (1992), integrated these two hypotheses. The model claims that stimulus position is automatically coded because of the need to shift the attention toward the stimulus. The spatial stimulus code is formed in relation to the position in which attention is focused when the stimulus appears, therefore a response on the side of space corresponding to the side where attention is directed is facilitated.

1.2.2 Simon effect asymmetries

Tagliabue, Vidotto, Umiltà, Altoè, Treccani and Spera (2007) showed that the Simon effect is often asymmetric, being greater in the right than in the left side of space in strong right-handers and greater in the left than in the right side of space in strong left-handers. They distinguished between the *stimulus Simon effect* (*stSE*), that is the Simon effect measured by comparing the two responses to the same stimulus (for example, the right stSE is measured by comparing the right-side and left-side responses to the right-side stimulus) and the *response Simon effect* (*reSE*), that is the Simon effect measured by comparing the same response to the two stimuli (for example, the right reSE is measured by comparing the right-side response to the right-side and left-side stimuli). Referring to the a, b c and d letters in Figure 3, the right stSE is the difference between b and d and the left stSE is the difference between c and a, whereas the right reSE is the difference between c and d and the left reSE is the difference between b and d.
Therefore, there can be two types of asymmetries, which originate by comparing the right stSE with the left stSE (i.e., the *stSE asymmetry*) and by comparing the right reSE with the left reSE (i.e., the *reSE asymmetry*). Figure 4 represents the results of Experiment 2 of Tagliabue et al. (2007), who showed that both stSE and reSE were greater on the right in strong right-handers and greater on the left in strong left-handers.

![Figure 4](image_url)  
*Figure 4. Results of Experiment 2 of Tagliabue et al. (2007), showing that both stSE and reSE are greater on the right in right-handers and greater on the left in left-handers.*

The authors proposed that asymmetries were caused by cerebral lateralization of the mechanisms of attention orienting and response selection, both involved in the Simon task. Spironelli, Tagliabue and Umiltà (2009) corroborated this hypothesis by implementing a connectionist model that yielded Simon effect asymmetries.

More specifically, we reasoned that the stSE asymmetry might depend on the lateralization of attention orienting mechanisms, because it manifests itself
through the comparison between the Simon effect observed when the stimulus appears on the left, and the Simon effect observed when the stimulus appears on the right. The only difference between these two conditions is the stimulus position; thus differences should depend on different speed in attention orienting toward the left and the right side. Analogously, reSE asymmetry is likely to depend on the lateralization of response selection mechanisms, because it manifests itself through the comparison between the Simon effect when the response is executed on the left, and the Simon effect when the response is executed on the right. The only difference between these two conditions is the response position, and differences between the two hands should depend on different speed in selecting the left or right hand response. In the present work we tried to investigate asymmetries related to the lateralization of attentional mechanisms.

The role of attentional processes in the Simon task has been demonstrated in several studies, as we pointed out in the previous paragraph. In the next chapter the issue of the lateralization of attention will be addressed.
CHAPTER 2: NEUROPSYCHOLOGY OF ATTENTION

The purpose of this chapter is to review the most relevant research investigating the cerebral lateralization of visual attention.

Since Mesulam (1981; 1999; 2002) elaborated his model of the lateralization of visual attention, several research papers – conducted with both patients and neurologically intact participants – has been published, corroborating this model. In the next paragraphs some of the most relevant results will be reported, as well as some data that seems to show that this cerebral lateralization is evident in behavioural tasks too. At the end of the chapter the cerebral lateralization of spatial abilities in left-handers will be discussed.

2.1 MESULAM’S MODEL

Attention is often considered to depend on mechanisms predominantly localized, in right-handers, in the right hemisphere of the brain. In particular, Mesulam (1981; 1999; 2002) proposed a model according to which the right hemisphere would control attention shifts toward both the right and the left visual hemi-field (VHF), whereas the left hemisphere would control attention shifts only toward the right VHF.

This model (represented in Figure 5) was first elaborated on the basis of observation of visuo-spatial deficits (usually called Unilateral Spatial Neglect) often caused by lesions of the right hemisphere, and subsequently supported by research on neurologically intact participants, especially conducted with neuroimaging techniques.
2.2 UNILATERAL SPATIAL NEGLECT

Unilateral Spatial Neglect (USN) is one of the most studied disorders of attention, and is usually defined as the failure to report, respond, or orient to stimuli presented to the side opposite to a brain lesion, when this failure cannot be attributed to either sensory or motor deficits (for a review, see Heilman, Watson & Valenstein, 2002; 2003).

USN can occur after a unilateral lesion to a wide range of neural structures, but its cognitive consequences have most often been investigated in patients with a unilateral lesion of the parietal lobe. A patient with this syndrome can shave and dress only one side of the body, and eat only food placed on one side of the plate.
Patients usually read only one half of a sentence or a word and fail to copy one side of a drawing. A classical test which shows this deficit is the clock test: Asked to copy a drawing of a clock, the patient typically produces the drawing represented in Figure 6. On the basis of double dissociations observed in brain-damaged patients, Posner and his colleagues (Fernandez-Duque & Posner, 2001; Posner et al. 1984; Posner, Inhoff, Friedrich & Cohen, 1987) suggested that the three operations involved in attention shift mentioned in the previous chapter (disengagement, movement and engagement) are subserved by separate neural systems, and that, in particular, the parietal lobe is involved in the disengage operation. Therefore, the basic idea is that patients with a parietal damage fail to move attention on the VHF contralateral to the lesion because they do not disengage attention from the VHF ipsilateral to the lesion.

A patient with USN ignores stimuli located in the half side of space contralateral to the lesion, but space can be defined in either egocentric (also called body-centered) or allocentric (also called object-centered) coordinates. In the former case patients neglect the half with respect to their body midline, or visual field, or head; in the latter the patient can see all the objects in a room but neglect half of each individual object. A further distinction is between the sector of the space, which can be personal (the space occupied by the patient’s body), peripersonal (near, within grasping distance) or extrapersonal (far from the patient). These forms of USN are not mutually exclusive and a patient may have
one or more forms of neglect (see, for a review, Heilman et al., 2002; 2003; Rizzolatti & Camarda, 1987).

Other syndromes consequent to parietal lesion are *extinction* and *allesthesia* (Heilman et al., 2003). Patients with extinction are able to correctly detect unilateral stimuli both contralateral and ipsilateral to the lesion but when presented with bilateral simultaneous stimuli they often fail to report stimuli contralateral to the lesion. Patients with allesthesia are able to detect a stimulus contralateral to the lesion, but report that it was in the position ipsilateral to the lesion.

### 2.2.1 USN after right and left parietal lesions

Brain’s (1941) paper, apart from being an important milestone in the conceptualisation of USN as a distinct neurological condition (Halligan & Marshall, 1993), was the first to submit that USN is preferentially associated with right brain damage.

At this moment, it is a well-established fact that lesions to the right parietal lobe cause visuo-spatial deficits that are more frequent, more severe and more enduring than deficits caused by lesions to the left parietal lobe (see, for example, Heilman et al., 2002; 2003; Mesulam 1981, Rafal 1998).

In comparison with USN following right brain damage (RBD), USN following left brain damage (LBD) is actually less often studied, less frequently reported, and “therefore inadequately characterized” (Kleinman, Newhart, Davis, Heidler-Gary, Gottesman & Hillis, 2007; p.50). Fewer LBD patients are typically studied because they are often aphasic and may have problems in understanding the assessment instructions (Bowen, McKenna & Tallis, 1999), but a few papers compare directly USN after RBD and LBD.
Gainotti, Messerli and Tissot (1972) tested two samples of patients with USN in two different studies, with 114 patients with RBD and 108 with LBD in the first study, and 79 patients with RBD and 112 with LBD in the second study. They showed that USN differed both quantitatively and qualitatively after RBD and LBD.

Bowen et al. (1999) published a systematic review of 30 studies, 17 of them comparing RBD and LBD. As they reported, their review supported the belief that USN occurs more often after RBD than after LBD. The frequency of USN in the considered studies ranged from 12% to 100% after RBD, and from 0% to 76% after LBD. They stressed the fact that fewer patients with LBD are typically studied because they are often aphasic and have difficulty to understand the instructions. However, neither this fact nor other factors like tasks used, timing of the assessment, scoring and criteria used to both select patients and determine USN can affect the difference in the frequency of this syndrome after RBD or LBD.

Beis et al. (2004) used a comprehensive test battery and a large sample of patients with USN after LBD, and agreed with the conclusions of previous studies that USN is less frequent and less severe after LBD than after RBD.

Recently, some evidence (Kleinman et al., 2007, who studied 47 LBD patients 48-hours after the onset of stroke symptoms) seems to suggest that only allocentric USN is more frequent after LBD than after RBD.

Finally, the frequency of USN and that of extinction seems to be very similar (Becker & Karnath, 2007), with extinction also being more frequent after RBD than after LBD.
2.3 BEYOND USN: EVIDENCE FROM NEUROLOGICALLY INTACT INDIVIDUALS

Evidence supporting Mesulam’s (1981; 1999; 2002) model comes from studies using neurologically intact individuals, usually right-handed, as participants. Mostly, this research involves neuroimaging techniques, but there is some evidence coming from the observation of the phenomenon knows as pseudoneglect, and from some RT studies.

2.3.1 Neuroimaging studies

Corbetta, Miezin, Shulman and Petersen (1993) and Nobre, Sebestyen, Gitelman, Mesulam, Frackowiak and Frith (1997), by using PET (Positron Emission Tomography) demonstrated that, when a covert shift of attention takes place toward the left VHF, the right superior parietal cortex is activated, whereas when the shift is toward the right VHF, both left and right superior parietal cortex are activated.

Kim, Gitelman, Nobre, Parrish, LaBar and Mesulam (1999) and Gitelman, Nobre, Parrish, LaBar, Kim, Meyer and Mesulam (1999) corroborated these results by using fMRI (functional Magnetic Resonance Imaging) studies. Moreover, Kim et al. (1999) showed that this functional asymmetry is more prominent in a task in which exogenous rather than endogenous shifts of attention are involved (for a review see Corbetta & Shulman, 2002).

2.3.2 Pseudoneglect

Bowers and Heilman (1980), by using a tactile line bisection task in which participants were asked to estimate the midpoint of a line, first reported a systematic bias toward the left, i.e. participants often err toward the left respect to the real midline. They called this phenomenon “pseudoneglect” because this bias
is opposite in direction to that of patients with USN (for a review, see Jewell & McCourt, 2000).

2.3.3 Behavioral studies

Heilman and Van Der Abell (1979) reported that warning stimuli projected to the right hemisphere (i.e. presented in the left VHF) reduced RTs to a central target stimulus more than warning stimuli projected to the left hemisphere (i.e. presented in the right VHF).

Pollmann (1996; 2000) presented simultaneously a target in one VHF and a pop-out distractor in the other VHF, and observed an extinction-like effect, i.e. an increase of RTs in this condition respect to the one in which no distractor was presented. This increase was greater when the distractor was presented in the right VHF then when it was presented in the left VHF.

More interestingly, Downing and Pinker (1985) and Gawryszewski, Riggio, Rizzolatti and Umiltà (1987) demonstrated some attentional asymmetries by using different versions of a Posner-like task in conjunction with a three-dimensional display.

Downing and Pinker (1985) reported two experiments. In their Experiment 1 they used a three-dimensional display, in order to investigate if attentional costs vary depending on horizontal distance or on depth between the positions in which cue and stimulus appeared. They used a central cue (a digit) and SOAs varying between 400 and 800 ms, but did not report either handedness of the participants or the hand participants used to give the response. They found that costs were greater when stimuli were presented in the left VHF, and attributed this asymmetry to the cerebral lateralization of visual attention, even thought they pointed out that this could be simply due to the fact that participants viewed the display only with the left eye (the right one was indeed covered).
Gawryszewski et al. (1987) reported six experiments, in which stimuli were presented in depth (Experiments 1 and 4), along the horizontal meridian (Experiments 2 and 5), and along the vertical meridian (Experiments 3 and 6). They used an endogenous cue (a central arrow) and SOAs varying between 800 and 1200 ms. Participants had to respond as soon as possible with their right thumb. The authors, in Experiment 2, found that costs were greater when the stimulus appeared in the left VHF than when it appeared in the right VHF. They argued that this could be a consequence of the cerebral lateralization of visual attention, which makes the stimulus in the right VHF more salient.

While we were conducting the present research, Castro-Barros, Righi, Grechi and Ribeiro-do-Valle (2008) published a paper in which attentional asymmetries in behavioural data were shown. They used a “location discrimination” task and a “location and shape discrimination task”. In both tasks two boxes, one on the right and one on the left of a central fixation point, were presented. A prime stimulus (they called it S1, and it consists in the darkening of one of the two boxes, i.e. a non-informative cue) occurred first, and subsequently a target stimulus (S2) was presented. In the “location discrimination” task a stimulus was presented, and participants were asked to press one key with the hand corresponding to the position of S2. In the “location and shape discrimination task” two target stimuli (S2+ and S2-, differing in shape) were presented and participants were asked to press one key (again, with the hand corresponding to the position of S2) when S2+ was presented and not to respond to S2-. They found an effect of S1 (i.e. a facilitation effect) on RTs at S2, and this effect was modulated by the VHF in which S1 was presented, with the facilitation effect being greater when S1 appeared in the right box than when it appeared in the left box, in particular when both location and shape discrimination were required.
2.4 THE LEFT HANDEDNESS PROBLEM

De Renzi (1982) claimed, on the basis of a brief review on some studies on the topic, that pathological data do not support the view that spatial abilities are differently organized in right-handers and left-handers, but pointed out that several factors (for example, familiarity or lateralization of language) can interfere with the lateralization of these abilities. For these reasons he concluded that, at that moment, he had to defer any conclusion until new data had been collected. Until now, more than 25 years after De Renzi’s (1982) book, further data have been collected, but the point is not very clear yet.

Considering the clinical studies mentioned in the previous paragraphs, it is clear that left-handers are usually under-represented in most studies. Gainotti et al. (1972) and Kleinman et al. (2007) excluded all left-handers. Bowen et al. (1999) reported that one of the reasons why participants are excluded by the studies they reviewed is left-handedness, but they do not discuss this point further. Beis et al. (2004) specified that 83.2% of their 78 patients were right-handers (but they did not discuss this point later) and Becker and Karnath (2007) did not specify handedness of patients.

In addition, the fact that it is difficult to find USN in left-handed patients confirms the notion that attention in left-handers has a more bilateral distribution across the hemispheres (e.g., Dronkers & Knight, 1988). Only a few papers reported unilateral neglect in left-handed patients: to our knowledge there are only the single-case studies of Dronkers and Knight (1988); Caramazza and Hillis (1990); Padovani, Pantano, Frontoni, Iacoboni, Di Piero and Lenzi (1992); and DeLuca (1993). All these studies reported left-handed patients showing USN on the right VHF after LBD.

Less recently, Hècaen and de Ajuriaguerra (1964, as cited in Wang, 1980), Hécaen and Sauguet (1971, as cited in Annett, 1985) and Hécaen, De Agostini
and Monzon-Montes (1981, as cited in Annett, 1985) all reported a greater percentage of USN in left-handers after RBD than after LBD.

Bryden (1982) and Bradshaw (1989), based on studies which used unilateral ECT (*Electro-Convulsive Therapy*) or amobarbital and studies on patients with USN, reported the estimated distributions of visuospatial abilities in right- and left-handers (see Table 1).

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<td><strong>RIGHT-HANDERS</strong></td>
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<tr>
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<td>-</td>
</tr>
<tr>
<td>Right</td>
<td>69</td>
<td>68</td>
</tr>
</tbody>
</table>

*Table 1. Localization of spatial abilities in left- and right-handers from Bryden (1982) and Bradshaw (1989).*

Both of them, as well as Annett (1985), pointed out that the lateralization of visuo-spatial abilities is much less clear than that of language, especially in left-handers.

Concerning the pseudoneglect phenomenon, Jewell and McCourt (2000) reported that very few studies have addressed the effects of handedness in a line bisection task, but they failed to find a significant difference in the direction of the bias in the two groups.

To our knowledge there are no studies, except for that of Tagliabue et al. (2007) concerning the Simon effect, investigating specifically the asymmetries of visual attention in left-handed participants. The purpose of this work is to compare asymmetries in visual attention with Simon effect asymmetries, in both right- and left-handers.
EXPERIMENTAL SECTION

CHAPTER 3: INVESTIGATING ASYMMETRIES

The purpose of the present chapter is to demonstrate that Simon effect asymmetries observed by Tagliabue et al. (2007) – in particular, stSE asymmetries – are caused by the lateralization of the attention orienting mechanism.

According to the Mesulam’s (1981; 1999; 2002) model introduced in the previous chapter, the right hemisphere would control attention shifts toward both the right and the left VHF, whereas the left hemisphere would control attention shifts only toward the right VHF. In other words, both hemispheres orient attention to the right and only one orients attention to the left. For this reason we hypothesized that, in a Simon task, attention is more strongly allocated on the stimulus when it appears on the right than on the left.

We thought that the best way to confirm this hypothesis was by using a variant of the Posner paradigm. The Posner paradigm is the most suitable paradigm to investigate attentional movements, because it indexes explicitly spatial attention and because, being based on a simple RT task, it does not involve the response selection mechanism.

We hypothesized that, in a Posner task, we should observe a difference between trials in which the cue appears on the right and trials in which the cue appears on the left. Indeed, if it is true that an event on the right attracts more attention than the same event on the left, then the effects of the cue should be stronger when it appears on the right. Therefore, we expect to observe greater benefits (in valid trials) and greater costs (in invalid trials) when the cue appears on the right than when it appears on the left. In a Simon task the shift of the
attention is automatically driven by the appearance of the peripheral stimulus, thus we investigated costs and benefits produced by exogenous orienting of attention.

We considered the experiments of Downing and Pinker (1985) and Gawryszewski et al. (1987) as starting points, with some adjustments in order to better investigate facilitatory and inhibitory mechanisms.

The main differences concerned SOA and informativeness of the cue. In Experiment 1 and Experiment 2 we used short SOAs (100 and 200 ms) to investigate facilitation, and in Experiment 3 and Experiment 4 we used long SOAs (800 and 1200 ms, the same used by Gawryszewski et al., 1987), to investigate IoR. In addition, we always employed peripheral cues. The cue was informative (which triggered attentional shift both exogenous and endogenous) in Experiments 1 and 3, and non-informative (which triggered purely exogenous attentional shifts) in Experiments 2 and 4. All the participants were randomly assigned to one of the four experiments, and took part, one week later, in a typical Simon task. We did not counterbalance the sequence of the tasks because an influence of one task on the other was not plausible, as the two tasks are very different. However, Experiment 5 (reported in the next chapter) was run to make sure that this assumption was indeed true.

Other adjustments to the Posner task were made in order to make it similar to the Simon task. In particular, we used only two boxes, one on the right and one on the left of the central fixation cross, and did not eliminate trials in which participants moved their eyes (as is customarily in a Simon task, trials with eye movements are not eliminated, although participants are instructed to maintain fixation).

We tested a group of right-handers and a group of left-handers in each experiment. As it has been shown in the previous chapter, the lateralization of
attentional mechanisms in the two populations is different, with left-handers being a more heterogeneous group.

Participants in Experiment 2 of Tagliabue et al. (2007) were strong right- or left-handed: The criterion used for inclusion in the group was a score of 90% with the Edinburgh Handedness Inventory (Oldfield, 1971), that is right-handed participants had a score between 90 and 100, and left-handed participants had a score between 0 and 10. In the present experiments we used a less restrictive criterion: Right-handers had a score between 70 and 100, and left-handers had a score between 0 and 30. We changed the criterion in order to verify if Simon effect asymmetries observed in the study of Tagliabue et al. (2007) with strong right- and left-handers are present in less lateralized right- and left-handers.

We hypothesized that Simon effect asymmetries in right-handers should be in the same direction as those of Tagliabue et al. (2007; Simon effect on the right greater than on the left) but that these asymmetries should be different in left-handers. In particular, we expected to find either the same asymmetries observed in strong left-handed participants (Simon effect on the left greater than on the right) or a symmetric Simon effect. We reasoned that, if attention shifts are involved in the Simon task, and if it is true that the cerebral lateralization of attention causes Simon effect asymmetries, participants with different handedness should show different patterns of asymmetries, in both Posner and Simon tasks, and that, regardless of handedness, participants with strong asymmetries in one direction in the Posner task should show strong asymmetries in the same direction in the Simon task. We expected to observe a greater facilitation and a smaller IoR in the Posner task when the cue appears on the right, as well as a greater right Simon effect, in right-handers, and all the asymmetries in the other direction or no asymmetries in left-handers.
For each experiment, we first report results for the Posner and Simon task separately. In the last paragraph of the chapter we will investigate the relation between asymmetries in the two tasks.

3.1 EXPERIMENT 1

The purpose of Experiment 1 is to investigate if some asymmetries are present in the facilitation effect, when both exogenous and endogenous orienting of attention are involved. For this reason we employed an informative peripheral cue at short SOAs.

3.1.1 Method

PARTICIPANTS. Sixty students of the University of Padua participated in the experiment. Thirty were right-handed (score between 70 and 100 at the Edinburgh Handedness Inventory), and thirty were left-handed (score between 0 and 30). All had normal or corrected-to-normal vision, and were not aware of the purpose of the experiment.

APPARATUS AND STIMULI. Participants were seated approximately 50 cm in front of an IBM-compatible computer with a processor AMD Athlon XP2100+. The computer was connected to a 17" Samsung 710N LCD monitor with resolution 1280 x 1024 and to a keyboard. A program developed with the E-Prime software (version 1.1.4.1) generated the stimuli and recorded the responses.

Posner task. A central 0.5° x 0.5° cross was presented at fixation. Two 3° x 4° empty boxes were presented approximately 8° to the left and to the right of fixation. Stimuli, consisting in 1.5° x 1.5° white squares, appeared in the center of one of the two boxes. The peripheral cue was a 0.9° arrow that could appear above one or both boxes. In trials in which only one cue was shown, the
probability that the stimulus appeared in the cued box was 70%, while when two arrows were shown, the stimulus had the same probability to appear in the left or in the right box.

**Simon task.** A central 0.5° x 0.5° cross was presented at fixation, and stimuli were two 1.5° x 1.5° squares (green or red), which could appear 8° to the left or to the right of the fixation cross.

### 3.1.2 Procedure

All the participants performed the Posner task first and the Simon task one week later.

**Posner task.** At the beginning of each trial, the fixation cross and the boxes appeared, accompanied by a 440 Hz warning tone lasting for 300 ms. The boxes stayed on the screen for the duration of the trial; the fixation cross, at the beginning of each trial, flashed for 500 ms. After 1800 ms the cue appeared, and remained visible for 100 ms. In the case of the 100-ms SOA the stimulus appeared straight after the offset of the cue; in the case of the 200-ms SOA the stimulus appeared 100 ms after the offset of the cue. We used two different SOAs in order to reduce the probability of anticipations. The maximum allowed response time was 1000 ms. After 200 ms, a new trial began. Trials could be valid (the stimulus appeared in the box indicated by the arrow), invalid (the stimulus appeared in the opposite box), neutral (the cue indicated both boxes) or catch (the stimulus did not appear). Participants were instructed to shift attention toward the box indicated by the arrow, without eye movements, and to press the spacebar of the keyboard, as quickly as possible, as soon as the stimulus appeared. The experimenter sat at the back of the participant checking for eyes movement through a mirror located in front of her/him on the top of monitor. Trials were 440: For every SOA, there were 112 valid trials (56 with the stimulus
on the right and 56 with the stimulus on the left), 48 invalid trials (24 with the stimulus on the right and 24 with the stimulus on the left), 40 neutral trials (20 with the stimulus on the right and 20 with the stimulus on the left) and 20 catch trials. Experimental trials were preceded by 18 practice trials. All the participants responded with their dominant hand, right for right-handers and left for left-handers.

**Simon task.** At the beginning of each trial, the fixation cross and the boxes appeared, accompanied by a 440 Hz warning tone lasting for 300 ms, and remained visible for 1800 ms. At the offset of fixation, the imperative stimulus appeared for 100 ms. The maximum allowed response time was 1500 ms. After 200 ms, a new trial began. Participants had to press with their left and right index finger one of two keys of the computer keyboard, depending on the colour of the stimulus: the “F” and “K” keys, respectively to the left and to the right of the body midline. Half of the participants were instructed to respond with the left key to red stimuli and with the right key to green stimuli, whereas the other half had the opposite mapping. There were 144 stimuli in total: 36 red stimuli and 36 green stimuli presented to the left of fixation, and 36 red stimuli and 36 green stimuli presented to the right of fixation. Experimental trials were preceded by as many practice trials as were needed to execute a sequence of 10 correct trials.

### 3.1.3 Results and discussion

**Posner task.** Correct RTs (with the exclusion of neutral and catch trials, omissions and anticipations, i.e. RTs faster than 100 ms) were submitted to an Analysis of Variance (ANOVA). Newman-Keuls post-hoc test was used to explore the significant interactions, and planned comparisons (criterion: p<0.05, one-tailed) were used to test the effects of interest. Trials in which eye movements occurred were not eliminated from the analyses. Overall, eye
movements were less than 1%. The ANOVA had handedness (left-handers vs. right-handers) as the between-participants factor and cue validity (invalid vs. valid) and cue position (left vs. right) as the within-participants factors. The cue validity factor was significant with F(1,58)=67.18 p<0.001, showing a 17-ms facilitation effect. The interaction between handedness and cue position was significant with F(1,58)=4.18 p<0.05, and a Newman-Keuls post-hoc test showed that right-handers were faster when the cue was on the right than when it was on the left (318 vs. 322 ms), whereas left-handers showed no difference (331 vs. 330 ms). The interaction among handedness, cue validity and cue position was significant too, with F(1,58)=13.79, p<0.001 (see Figure 7).

Asymmetries in the facilitatory effect were present, and their directions were different in left- and right-handed participants. The effect was greater (p<0.05) when the cue was on the left (23 ms, p<0.001, Cohen’s d=0.99) than

![Figure 7: Results of Posner task of Experiment 1.](image-url)
when it was on the right (15 ms, \(p<0.001\), Cohen’s \(d=0.92\)) in left-handers, and it was greater (\(p<0.01\)) when the cue was on the right (21 ms, \(p<0.001\), Cohen’s \(d=1.13\)) than when it was on the left (7 ms, \(p<0.05\), Cohen’s \(d=0.39\)) in right-handers. Omissions were 1.27% in the invalid and 1.14% in the valid condition.

**Simon task.** Correct RTs (with the exclusion of errors and anticipations, i.e. RTs faster than 150 ms) were submitted to an ANOVA with handedness (left-handers vs. right-handers) as the between-participants factor and stimulus position (left vs. right) and response position (left vs. right) as the within-participants factors. As for the Posner task, Newman-Keuls post-hoc test was used to explore the significant interactions, and planned comparisons (criterion: \(p<0.05\), one-tailed) were used to test the effects of interest. Response position was significant with \(F(1,58)=13.10\) \(p<0.001\), showing that participants were faster with the right response than with the left response (491 ms vs. 504 ms). However, this effect was modulated by handedness, the interaction between handedness and response position being significant with \(F(1,58)=4.45\) \(p<0.05\), and a Newman-Keuls post-hoc test showed that right-handers were faster with the right response (497 vs. 516 ms) and left-handers did not show any difference between the two responses (486 vs. 492 ms). The interaction between stimulus position and response position was significant with \(F(1,58)=35.57\) \(p<0.001\), showing a 22-ms overall Simon effect. Left and right stSE and reSE were tested separately for the two groups (see Figure 8 for mean RTs), as in Tagliabue et al. (2007).

Planned comparisons showed that in left-handers the stSE did not significantly differ between the left side and the right side but it was significant on the right (20 ms, \(p<0.001\), Cohen’s \(d=0.50\)) and not on the left (10 ms, \(n.s\), Cohen’s \(d=0.24\)); the reSE on the right (11 ms, \(p<0.05\), Cohen’s \(d=0.35\)) and on the left (19 ms, \(p<0.01\), Cohen’s \(d=0.49\)) did not differ. In right-handers the stSE
was greater (p<0.001) on the right (48 ms, p<0.001, Cohen’s d=1.36) than on the left (8 ms, ns, Cohen’s d=0.19); the reSE did not differ between the right side (31 ms, p<0.001, Cohen’s d=0.88) and the left side (25 ms, p<0.001, Cohen’s d=0.74).

![Figure 8: Results of Simon task of Experiment 1.](image)

The same ANOVA was conducted on accuracy. The interaction between stimulus position and response position was significant with F(1,58)=23.84 p<0.001, showing that when stimulus position and response position corresponded errors were fewer than when they did not correspond (2.5% and 2.36% in corresponding trials, for left and right responses vs. 4.58% and 5.19% in non-corresponding trials, for left and right responses). Clearly, there was no speed-accuracy trade-off.

To summarize, right-handers showed both a greater facilitation in the Posner task and a greater Simon effect on the right than on the left; left-handers
showed a greater facilitation on the left in the Posner task, but a symmetric Simon effect. Therefore, the results of the Posner task, with a peripheral informative cue, which triggers both exogenous and endogenous attentional shifts, are in agreement with those of Downing and Pinker (1985) and of Gawryszewski et al. (1987), and with our hypothesis about a difference in benefits and costs, depending on both stimulus side and participants’ handedness. With regard to the Simon task, right-handers showed asymmetries that replicated the results of Tagliabue et al. (2007), and left-handers showed no asymmetries. This result is in line with our hypothesis of the lack of asymmetries in left-handers because of a great variability in the lateralization of visuo-spatial abilities in this population.

In the second experiment we investigated whether asymmetries in the facilitation effect are still present when only the exogenous component of attention operates.

3.2 EXPERIMENT 2

The purpose of Experiment 2 was to investigate if the asymmetries of the facilitation effect observed in Experiment 1, where both endogenous and exogenous components of attention were involved, could be observed even when only the exogenous component is involved. For this reason we employed a non-informative peripheral cue at short SOAs.

3.2.1 Method

PARTICIPANTS. Sixty students of the University of Padua, selected as before, participated in the experiment. They had not taken part in Experiment 1.

APPARATUS AND STIMULI. Apparatus and stimuli, of both Posner and Simon tasks, were identical to those of Experiment 1.
3.2.2 Procedure

**Posner task.** The procedure was identical to that of Experiment 1, except for one difference. The cue was non-informative, therefore participants did not receive the instruction to move attention to the box indicated by the cue. The cue was non-informative as to the location of the stimulus, the probability of valid and invalid trials being the same (50%). There were 440 trials: For every SOA, there were 80 valid trials (40 with the stimulus on the right and 40 with the stimulus on the left), 80 invalid trials (40 with the stimulus on the right and 40 with the stimulus on the left), 40 neutral trials (20 with the stimulus on the right and 20 with the stimulus on the left) and 20 catch trials. Experimental trials were preceded by 18 practice trials.

**Simon task.** The procedure was identical to that of Experiment 1.

3.2.3 Results and discussion

**Posner task.** Correct RTs (with the exclusion of neutral and catch trials, omissions and anticipations, i.e. RTs faster than 100 ms) were submitted to the same analyses (ANOVA and planned comparisons) as in Experiment 1. Trials with eye movements were less than 1%. The handedness factor was significant with F(1,58)=4.13 p<0.05, showing that right-handed participants responded faster than left-handed participants (296 vs. 321 ms). Cue validity was significant with F(1,58)=60.80 p<0.001, showing a 10-ms facilitation effect. Note that the validity effect was smaller than in Experiment 1 (there it was 17-ms), perhaps because now the endogenous orienting of attention was no longer involved. The interaction among handedness, cue validity and cue position was significant with F(1,58)=12.10 p<0.001 (see Figure 9).
The results of Experiment 2 were not different from those of Experiment 1. Again, planned comparisons showed that in left-handers the facilitatory effect was greater (p<0.01) when the cue was on the left (16 ms, p<0.001, Cohen’s d=1.07) than when it was on the right (5 ms, p<0.05, Cohen’s d=0.35), and in right-handers the facilitatory effect was greater (p<0.05) when the cue was on the right (13 ms, p<0.001, Cohen’s d=1.06) than when it was on the left (5 ms, p<0.05, Cohen’s d=0.36). Omissions were 2.05% in the invalid and 1.91% in the valid condition.

Simon task. Correct RTs (with the exclusion of errors and anticipations, i.e. RTs faster than 150 ms) were submitted to the same analyses (ANOVA and planned comparisons) as in Experiment 1. Handedness was significant with F(1,58)=7.29 p<0.01, showing that right-handers responded faster than left-handers (452 vs. 493 ms). The interaction between stimulus position and response position was significant with F(1,58)=57.93 p<0.001, showing a 28-ms
overall Simon effect. As before, left and right stSE and reSE (see Figure 10 for mean RTs) were tested separately for the two groups.

Figure 10: Results of Simon task of Experiment 2.

Planned comparison showed that in left-handers the stSE did not significantly differ in the two hemi-fields, being present both on the left (27 ms, p<0.001, Cohen’s d=0.58) and on the right (14 ms, p<0.05, Cohen’s d=0.31); reSE was symmetric too, being present both on the left (20 ms, p<0.001, Cohen’s d=0.50) and on the right (21 ms, p<0.001, Cohen’s d=0.54). In right-handers, both stSE and reSE were symmetric, being respectively 41 ms (p<0.001, Cohen’s d=1.16) and 38 ms (p<0.001, Cohen’s d=1.40) on the right, and 29 ms (p<0.001, Cohen’s d=0.78) and 32 ms (p<0.001, Cohen’s d=1.26) on the left.

The same ANOVA was conducted on accuracy. The interaction between handedness and stimulus position was significant with F(1,58)=4.21 p<0.05, showing that right-handers made more errors when the stimulus was on the left.
than on the right (5.93% vs. 4.54%), whereas left-handers did not show any
difference (3.94% vs. 4.49%). The interaction between stimulus position and
response position was significant too, with F(1,58)=20.19 p<0.001, showing that,
when stimulus position and response position corresponded, errors were fewer
than when they did not correspond (3.38% and 3.29% in corresponding trials, for
left and right responses, vs. 5.74% and 6.48% in non-corresponding trials, for left
and right responses). Clearly, there was no speed-accuracy trade-off.

The results of the Posner task in the present experiment confirmed the
results of Experiment 1: Asymmetries in the facilitatory effect were reliable also
when only the exogenous component of attention was involved. In addition, the
direction of these asymmetries was modulated by handedness: Left-handers
showed a greater facilitation on the left, whereas right-handers showed a greater
facilitation on the right. In the present experiment no asymmetries in the Simon
effect were observed: This result seems to indicate, as we suggested in the
introduction, that the fact that we did not test strong left- and right-handers could
be the reason of a greater variability between participants and a consequent lack
of statistical significance. We will return on this point later on.

Taken together, the data of Experiments 1 and 2 seem to confirm our
hypothesis that also attentional facilitation, besides the Simon effect, is
asymmetric, and that both asymmetries are modulated by handedness. In the next
two experiments we investigated the other attentional effect we are interested in,
that is IoR.

3.3 EXPERIMENT 3

The purpose of Experiment 3 was to investigate if the asymmetries
observed in the facilitation effect in Experiments 1 and 2, are present in the IoR
effect too. For this reason we employed an informative peripheral cue at long
SOAs.

3.3.1 Method

PARTICIPANTS. Sixty students of the University of Padua, selected as
before, participated in the experiment. They had not taken part in previous
experiments.

APPARATUS AND STIMULI. Apparatus and stimuli, of both Posner
task and Simon task, were identical to those of previous experiments.

3.3.2 Procedure

Posner task. The procedure was identical to that of Experiment 1, except
that SOAs were 800- and 1200-ms instead of 100- and 200-ms. The cue
remained visible for 400 ms instead of 100 ms; then, the stimulus appeared 400
ms after the offset of the cue in the case of the 800-ms SOA, and 800 ms after the
offset of the cue in the case of the 1200-ms SOA.

Simon task. The procedure was identical to that of Experiment 1.

3.3.3 Results and discussion

Posner task. Correct RTs (with the exclusion of neutral and catch trials,
omissions and anticipations, i.e. RTs faster than 100 ms) were submitted to the
same analyses (ANOVA and planned comparisons) as in the previous
experiments. Trials with eye movements were less than 1%. Cue position was
significant with F(1,58)=4.77 p<0.05, showing that RTs were faster when the cue
was on the right than when it was on the left (337 vs. 339 ms). The interaction
among handedness, cue validity and cue position was significant with
F(1,58)=5.40 p<0.05 (Figure 5).
In left-handers the difference between valid and invalid trials (IoR) was not significant in either VHF (-1 ms on the left and 6 ms on the right, Cohen’s d respectively = -0.04 and 0.20). In right-handers the IoR effect was present on the left (9 ms, p<0.05, Cohen’s d=0.44) but not on the right (-2 ms, ns, Cohen’s d=-0.12). Omissions were 1.16% in the invalid and 1.19% in the valid condition.

Note that the main effect of cue validity was not significant, showing that a global IoR was not present. The absence of this effect with an informative cue is a well-established fact (e.g. Umiltà, 2000), attributable to the involvement of endogenous component of the attention.

However, we observed IoR in right-handers, when the cue appeared on the left, which supports our hypothesis that the cue is more salient when it appears on the right than on the left. With long SOAs this advantage manifested itself through the disappearance of IoR when the cue appeared on the right. Moreover, it is important to note that IoR was absent in either VHF in left-handers. This

Figure 11: Results of Posner task of Experiment 3.

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<td>327</td>
</tr>
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</table>
result is, once more, in line with the hypothesis that asymmetries are less reliable in left-handers because of the great variability in the lateralization of visuo-spatial abilities in this population.

**Simon task.** Correct RTs (with the exclusion of errors and anticipations, i.e. RTs faster than 150 ms) were submitted to the same analyses (ANOVA and planned comparisons) as in the previous experiments. Response position was significant with $F(1,58)=7.71$ $p<0.01$, showing that right responses were faster than left responses (452 vs. 460 ms). However, this effect was modulated by handedness, the interaction between handedness and response position being significant with $F(1,58)=5.95$ $p<0.05$ and a Newman-Keuls post-hoc test showed that right-handers were faster with right-response (440 vs. 456 ms), whereas left-handers did not show any difference (463 vs. 464 ms). The interaction between stimulus position and response position was significant too, with $F(1,58)=33.21$ $p<0.001$, showing a 25-ms overall Simon effect.

As before, left and right stSE and reSE were tested separately for the two groups (see Figure 12 for mean RTs). In left-handers both stSE and reSE are symmetrical, being respectively 16 ms ($p<0.05$, Cohen’s $d=0.38$) and 19 ms ($p<0.01$, Cohen’s $d=0.40$) on the left, and 18 ms ($p<0.01$, Cohen’s $d=0.44$) and 15 ms ($p<0.01$, Cohen’s $d=0.50$) on the right. In right-handers, stSE was greater ($p<0.001$) on the right (47 ms, $p<0.001$, Cohen’s $d=1.17$) than on the left (16 ms, $p<0.05$, Cohen’s $d=0.43$) and reSE showed a tendency ($p=0.06$) to be greater on the right (37 ms, $p<0.001$, Cohen’s $d=1.03$) than on the left (26 ms, $p<0.01$, Cohen’s $d=0.75$).
The same ANOVA was conducted on accuracy. The interaction between handedness and stimulus position was significant with F(1,58)=6.13 p<0.05, showing that left-handers made more errors when the stimulus was on the left than when it was on the right (5.37% vs. 3.98%), whereas left-handers did not show any difference (3.14% vs. 3.66%) The interaction between stimulus position and response position was significant too, with F(1,58)=15.15 p<0.001, showing that when stimulus position and response position corresponded errors were fewer than when they did not correspond (2.64% and 3.01% in corresponding trials, for the left and the right response vs. 5.51% and 5% in non-corresponding trials, for the left and right response). Clearly, there was no speed-accuracy trade-off.

To summarize, asymmetries in right-handers are still present in the Posner task with long SOAs and support our hypothesis of an advantage of the right
VHF. Again, Simon effect asymmetries are present in right-handers but not in left-handers.

In the next experiment we investigated whether asymmetries in IoR are still present when only the exogenous component of attention is involved.

3.4 EXPERIMENT 4

The purpose of Experiment 4 was to investigate if the asymmetries of IoR observed in Experiment 3, where both endogenous and exogenous components of attention are involved, could be observed even when only the exogenous component is involved. For this reason, we employed a non-informative peripheral cue at long SOAs.

3.4.1 Method

PARTICIPANTS. Sixty students of the University of Padua, selected as before, participated in the experiment. They had not taken part in previous experiments.

APPARATUS AND STIMULI. Apparatus and stimuli, of both Posner and Simon tasks, were identical to those of previous experiments.

3.4.2 Procedure

Posner task. The procedure was identical to that of Experiment 3, except for one difference. The cue was non-informative, therefore participants did not receive the instruction to move attention to the box indicated by the cue, and the probability of valid and invalid trials was the same (50%).

Simon task. The procedure was identical to that of Experiment 1.
3.4.3 Results and discussion

**Posner task.** Correct RTs (with the exclusion of neutral and catch trials, omissions and anticipations, i.e. RTs faster than 100 ms) were submitted to the same analyses (ANOVA and planned comparisons) as the previous experiments. Trials with eye movements were less than 1%. The cue validity factor was significant, with $F(1,58)=74.71 \ p<0.001$, showing a 15-ms overall IoR. No other factors or interactions were significant.

As can be seen in Figure 13, both groups showed a symmetrical IoR. The effect did not differ between VHFs either in left-handers (16 ms, $p<0.001$, both on the left and on the right, Cohen’s $d$ respectively 0.70 and 0.73) or in right-handers (15 ms, $p<0.001$, Cohen’s $d=0.89$, on the left, and 12 ms, $p<0.001$, Cohen’s $d=0.67$, on the right). Interestingly, this is the only experiment in which we did not observe any asymmetry in the Posner task, either in left-handers or in right-handers. Omissions were 0.66% both in the invalid and in the valid condition.

![Figure 13: Results of Posner task of Experiment 4.](image-url)
Simon task. Correct RTs (with the exclusion of errors and anticipations, i.e. RTs faster than 150 ms) were submitted to the same analyses (ANOVA and planned comparisons) as in the previous experiments. Response position was significant with *F*(1,58)=9.81 *p*<0.01, showing that the right response was faster than the left response (514 vs. 527 ms). However, this effect was modulated by handedness, the interaction between handedness and response position being significant with *F*(1,58)=6.72 *p*<0.05, and a Newman-Keuls post-hoc test showed that right-handers were faster with the right hand than with the left hand (505 vs. 530 ms), while left-handers showed no difference (523 vs. 525 ms). The interaction between stimulus position and response position was significant with *F*(1,58)=33.28 *p*<0.001, showing a 20-ms overall Simon effect. As before, left and right stSE and reSE were tested separately for the two groups (Figure 14).

In left-handers both stSE and reSE were symmetric – the differences were not significant – on the left and on the right (15 ms, *p*<0.05, Cohen’s *d*=0.38 for the left stSE and 20 ms, *p*<0.05, Cohen’s *d*=0.39 for the right stSE; 18 ms, *p*=0.055, Cohen’s *d*=0.50 for the left reSE and 17 ms, *p*<0.05, Cohen’s *d*=0.40 for the right reSE). In right-handers both stSE and reSE were greater (*p*<0.001 and *p*<0.01) on the right than on the left (46 ms, *p*<0.001, Cohen’s *d*=1.38 vs. -4 ms, *ns*, Cohen’s *d*=-0.09 for the stSE and 32 ms, *p*<0.001, Cohen’s *d*=1.18 vs. 10 ms, *p*=0.055, Cohen’s *d*=0.32 for the reSE). Again, this is in line with our hypothesis.
The same ANOVA was conducted on accuracy. Only the interaction between stimulus position and response position was significant with $F(1,58)=9.54$ $p<0.001$, showing that when stimulus position and response position corresponded errors were fewer than when they did not correspond (2.31% and 2.59% in corresponding trials, for left and right responses vs. 3.43% and 4.21% in non-corresponding trials, for left and right responses). Clearly, there was no speed-accuracy trade-off.

To summarize, no asymmetries were observed in the Posner task in this experiment. Taken together, data of Experiments 3 and 4 suggest that the exogenous orienting alone cannot cause asymmetries. This could be true only when long SOAs are employed and IoR occurs: Remember that asymmetries were reliable when short SOAs were employed, and facilitation occurred. We will discuss this point later on.
3.5 COMPARING POSNER AND SIMON ASYMMETRIES

Our hypotheses were that participants with different handedness should show different patterns of asymmetries, in both the Posner and the Simon task, and that, regardless of handedness, participants with strong asymmetries in one direction in the Posner task should show strong asymmetries in the same direction in the Simon task.

We have already discussed asymmetries in the Posner task in the two groups of participants: Concerning facilitation, the right VHF shows an advantage in right-handers and the left VHF shows an advantage in left-handers. In the case of IoR, results are not easy to interpret, due to a lack of asymmetries in the task with a non-informative cue (Experiment 4), i.e. when only the exogenous component of orienting operates. However, in the task with the informative cue (Experiment 3) they are clear enough: We observed an asymmetry only in right-handers, which showed an advantage for the right VHF. Taken together, our results seem to confirm a general advantage, in right-handers, for the right VHF.

Concerning the Simon task, our results – apart from those of Experiment 2 – show that the Simon effect is symmetric in left-handers and greater on the right side in right-handers. We then analyzed RTs – and accuracy – in the Simon task of the 240 participants (120 left-handers and 120 right-handers all together). The ANOVA had handedness (left-handers vs. right-handers) as the between-participants factor and stimulus position (left vs. right) and response position (left vs. right) as the within-participants factors. Response position was significant with $F(1,238)=21.39 \ p<0.001$, showing that RTs were faster when participants responded with the right hand than with the left hand (482 vs. 491 ms). The interaction between handedness and stimulus position was significant with $F(1,238)=7.55 \ p<0.01$, and a Newman-Keuls post-hoc test showed that right-
handers were faster when the stimulus appeared on the right than on the left (478 vs. 484 ms), whereas left-handers showed no difference (493 vs. 492 ms). The interaction between handedness and response position was significant with $F(1,238)=18.93 \ p<0.001$, and a Newman-Keuls post-hoc test showed that right-handers were faster when they responded with the right hand than with the left hand (473 vs. 489 ms), whereas left-handers showed no difference (492 vs. 493 ms). The interaction between stimulus position and response position was also significant, with $F(1,238)=156.94 \ p<0.001$, showing a 23-ms overall Simon effect.

Finally, the interaction among handedness, stimulus position and response position was significant with $F(1,238)=8.95 \ p<0.01$. As can be seen in Figure 15, stSE and reSE asymmetries depend on handedness. In left-handers, both stSE and reSE are symmetrical, being respectively 17 ms ($p<0.001$, Cohen’s $d=0.40$) and 19 ms ($p<0.001$, Cohen’s $d=0.47$) on the left and 18 ms ($p<0.001$, Cohen’s $d=0.41$) and 16 ms ($p<0.001$, Cohen’s $d=0.44$) on the right. In right-handers, stSE was greater ($p<0.001$) on the right (46 ms, $p<0.001$, Cohen’s $d=1.27$) than on the left (12 ms, $p<0.001$, Cohen’s $d=0.30$), and reSE was greater ($p<0.001$) on the right (35 ms, $p<0.001$, Cohen’s $d=1.10$) than on the left (23 ms, $p<0.001$, Cohen’s $d=0.73$). These results confirm what we had found by analyzing the Simon effect in each experiment: Left-handers showed a symmetric Simon effect, whereas the effect is asymmetric, being greater on the right, in right-handers.
When conducting the present study, we chose to test mild left- and right-handed participants (with a score, respectively, between 0 and 30 and between 70 and 100). We hypothesized that right-handers should have shown the same pattern of asymmetries as those showed by Tagliabue et al. (2007), i.e. a greater Simon effect on the right, whereas left-handers should have shown either the same pattern as the left-handers of Tagliabue et al. (2007) or no asymmetries. Indeed, this is what we found by analyzing together the data of the four experiments, even though the results of the individual experiments were not totally consistent (in particular, because right-handers did not show any asymmetry in Experiment 2).

In the accuracy analysis, only two interactions reached significance. The first was the interaction between handedness and stimulus position with F(1, 238)=5.34 p<0.05: Left-handers made 3.6% errors when the stimulus was on the left and 3.97% errors when it was on the right, whereas right-handers made
4.32% errors when the stimulus was on the left and 3.66% errors when it was on the right. The second significant interaction was between stimulus position and response position with F(1,238)=66.23 p<0.001, showing that when stimulus position and response position corresponded errors were fewer than when they did not correspond (2.71% and 2.81% in corresponding trials, for the left and the right response vs. 4.82% and 5.22% in non-corresponding trials, for the left and right response). Clearly, there was no speed-accuracy trade-off.

Therefore, by considering together Posner and Simon tasks, our first hypothesis seems to be confirmed: Participants with different handedness show different patterns of asymmetries, in either task. Our second hypothesis was that, regardless of handedness, participants with strong asymmetries in one direction in the Posner task should show strong asymmetries in the same direction in the Simon task. Therefore, the next step was to investigate the relation between the asymmetries in the two tasks.

First of all, we calculated for each participant the difference between the attentional effect – the effect found in the Posner task – with the right cue and with the left cue. A positive value of this difference indicates a greater effect on the left (left VHF advantage), and a negative value indicates a greater effect on the right (right VHF advantage). We then selected two groups of participants with a clear cut\(^1\) left VHF advantage and with a clear cut right VHF advantage in the Posner task. In the group with a left VHF advantage there were 68 participants (18 right-handers and 50 left-handers), whereas in the group with a right VHF advantage there were 77 participants (49 right-handers and 28 left-handers).

A new ANOVA on the RTs of the Simon task was conducted with handedness (left-handers vs. right-handers) and VHF advantage (left vs. right) as

\(^1\) We chose a cut-off of 10 ms because this is often the size of the validity effect in the Posner task.
the between-participants factors, and stimulus position and response position as the within-participants factors. The response position was significant with F(1,141)=18.42 p<0.001 and showed that the right response was faster than the left response (486 vs. 497 ms). However, this effect was modulated by handedness, the interaction between handedness and response position being significant with F(1,141)=9.93 p<0.01, and a Newman-Keuls post-hoc test showed that right-handers were faster with the right hand (477 vs. 497) and left-handers showed no difference (495 vs. 498 ms). The interaction between stimulus position and response position was significant too, with F(1,141)=64.90 p<0.001, showing a 22-ms overall Simon effect. The interaction among handedness, stimulus position and response position was significant with F(1,141)=8.12 p<0.01, indicating a greater Simon effect in right-handers (29 ms) compared with left-handers (14 ms). The interaction among VHF advantage, stimulus position ad response position was significant with (1,141)=4.48 p<0.05, showing that participants with a left VHF advantage have a greater Simon effect than participants with a right VHF advantage (27 ms vs. 15 ms).

Finally, the interaction among handedness, VHF advantage and response position was significant with F(1,141)=9.54 p<0.01. Tagliabue et al. (2007) showed that the significance of the response position factor indexes the presence of a significant asymmetry in the stSE. Therefore, the interaction among handedness, VHF advantage and response position shows modulation of the stSE asymmetry by the other two factors. For this reason, we then carried out planned comparisons contrasting asymmetries in the stSE in the different groups. (Figure 16 shows the stSE in the four groups of participants).
Results of these planned comparisons showed that in right-handers with a right VHF advantage the stSE asymmetry was significant (p<0.01) and significantly different (p<0.01) from the stSE asymmetry of left-handers with a left VHF advantage. Despite the fact that this latter asymmetry failed to reach significance (i.e. the 30-ms, Cohen’s d=0.97, left stSE is not significantly greater than the 20-ms, Cohen’s d=0.50, right stSE), our hypothesis of a greater SE for right stimuli in right-handers and, at least, of a symmetric stSE in left-handers, was confirmed when the preferred hand and the VHF advantage benefited the same side of space. In contrast, when the preferred hand and the VHF advantage benefited different sides of space, left- and right-handers do not differ in the direction of the stSE asymmetry, indicating that a conflict between the preferred hand and the VHF advantage produces a disappearance of the Simon effect for left stimuli. In addition, if we compare the stSE of left- and right-handers, when both groups show a left VHF advantage, the asymmetry is reversed (p<0.001).
being the left stSE present in left-handers (30 ms, $p<0.001$, Cohen’s $d=0.97$) and absent in right-handers (3 ms, $ns$, Cohen’s $d=0.06$). Finally, the comparison between the two groups of left-handers again shows different stSE asymmetries ($p<0.01$), with the stSE being significant only when there is a left VHF advantage (30 ms, $p<0.001$, Cohen’s $d=0.97$ on the left, and 20 ms, $p<0.01$, Cohen’s $d=0.50$ on the right).

These results show that neither handedness nor the VHF advantage independently determine asymmetries in the Simon task. Rather, these two factors exert their influence jointly. Results are congruent with the notion that the asymmetries observed in the Simon task are due to the lateralization of both mechanisms involved, i.e. attention orienting and response selection. Therefore, the analyses just reported confirm our hypothesis of a relation between attentional asymmetries and Simon effect asymmetries in the comparison between participants with right and left VHF advantage.

At this point, one wonders if the fact that, in the Posner task, participants always used their dominant hand, which, of course, was the right hand for right-handers and the left hand for left-handers, was a confounding variable. Moreover, a second confound was possible in the previous experiments. This was controlled for in the next experiment. The Posner task was always conducted first and the Simon task was always conducted second. Although unlikely, there is the possibility that execution of the Posner task influenced performance in the Simon task. We ran Experiment 5 to explore these two possible confounds. On the basis of results of this Experiment, we ran Experiment 6 to further investigate the role of the hand used to give the response.
CHAPTER 4: CONFOUNDING VARIABLES

As we demonstrated in the previous chapter, Simon effect asymmetries are related to the asymmetries in visual attention, i.e. the asymmetries showed in the previously performed Posner task, in both right- and left-handers.

However, one may wonder if the asymmetries in the Posner task observed in previous experiments were due to the correspondence between cue position (right or left) and anatomical nature of the effector (right hand or left hand). The reason why we asked our participants to use their dominant hand is that, in planning the previous experiments, we aimed at replicating conditions that maximised attentional asymmetries, which, in turn, might be related to Simon effect asymmetries. In the literature, these conditions were present only in Downing and Pinker (1985) and in Gawryszewski et al. (1987), even though, in the former, handedness of participants and hand used to perform the task were not reported. In Gawryszewski et al. (1987) the Posner task was performed with the preferred hand by right-handed participants. Our rationale was that, if Simon effect asymmetries are, at least in part, caused by attentional asymmetries, then we expected differences in Simon effect asymmetries, depending on attentional asymmetries. For our rationale, it did not matter if, in other conditions of the Posner task, these asymmetries were absent. For this reason we instructed our participants to perform the Posner task with their preferred hand.

Considering there was a confound between handedness of participants and hand used for responding, we ran Experiment 5 to explore this possible confound. Therefore, in Experiment 5, right-handed participants were asked to perform the Posner task by using, in half blocks, their dominant hand, and in the other half, the other hand.
Finally, in Experiment 6, right-handed participants were asked to perform the Posner task by giving a bimanual response, to further investigated the role of hand used to give the response.

4.1 EXPERIMENT 5

The purpose of this experiment was to investigate the relation between the asymmetry in the cue validity effect observed in the Posner task and the hand with which the Posner task was performed. In other words, we investigated what happens when the Posner task is performed with the non-dominant hand.

Moreover, in previous experiments there was also a possible second confound, which we controlled in this experiment: The Posner task was always conducted first and the Simon task was always conducted second. As we argued in the previous chapter, there is the possibility that the execution of the Posner task influenced performance in the Simon task. Therefore, in this experiment, we tested four groups of 15 right-handed participants each. Responding hand (right or left) was counterbalanced within participants, while order of tasks (Posner task first or Simon task first) was counterbalanced between participants.

4.1.1 Method

PARTICIPANTS. Sixty students of the University of Glasgow, selected as before, except for the fact the they were all right-handed, participated in the experiment. They had not taken part in previous experiments.

APPARATUS AND STIMULI. Apparatus and stimuli, for both the Posner and the Simon task, were identical to those of previous experiments.
4.1.2 Procedure

Half of the participants performed the Posner task first and, one week later, the Simon task (as in the previous experiments), whereas the other half performed the Simon task first and, one week later, the Posner task.

**Posner task.** The procedure was identical to that of the Experiment 1, except for one difference. Half of the participants were requested to press the spacebar with the right hand in the first two blocks and with the left hand in the second two. The other half received the opposite assignment.

**Simon task.** The procedure was identical to that of Experiment 1.

4.1.3 Results and discussion

**Posner task.** Correct RTs (with the exclusion of neutral and catch trials, omissions and anticipations, i.e. RTs faster than 100 ms) were submitted to the same analyses (ANOVA and planned comparisons) as in the previous experiments. Trials in which eye movements occurred were not eliminated from the analyses. Overall, eye movements were less than 1%.

The ANOVA had order (Posner task first vs. Simon task first) as the between-participants factor, and hand (left vs. right), cue validity (invalid vs. valid) and cue position (left vs. right) as the within-participants factors. Order was significant with F(1,58)=10.86 p<0.01, showing that participants who performed the Posner task first were faster than participants who performed the Posner task second (317 vs. 354 ms). Cue validity was significant with F(1,58)=65.20 p<0.001, showing a 15-ms validity effect. The interaction between order and hand was significant with F(1,58)=6.99 p<0.05, and a Newman-Keuls post-hoc test showed that the right hand was faster than the left hand when the Posner task was performed second (349 vs. 360 ms) and there was no difference when the Posner task was performed first (322 vs. 313 ms). So, it would seem
that, if carry-over effects were at all possible, they could manifest themselves only when the Posner task was performed second. That justifies our decision to make participants perform always the Posner task first. We will return to this point when we analyze the Simon task results.

The interaction among hand, cue validity and cue position was significant with F(1,58)=9.78 p<0.01 (Figure 17).

![Figure 17: Results of Posner task of Experiment 5.](image_url)

As can be seen in Figure 17, attentional asymmetries were affected by the hand participants used to respond. Asymmetries were evident only when participants performed the task with their right (dominant) hand. That is, the facilitation effect was greater (p<0.01) when the cue appeared on the right (21 ms, p<0.001, Cohen’s d=0.76) than on the left (8 ms, p<0.01, Cohen’s d=0.40) when the participants performed the task with their right hand. In contrast, the facilitation effect did not differ between the two sides (being 14 ms – p<0.001,
Cohen’s d=0.68 – on the right and 18 ms – p<0.001, Cohen’s d=0.76 – on the left) when participants performed the task with the left hand. Omissions were 0.95% in the invalid and 1.23% in the valid condition.

Concerning the interaction among hand, cue validity and cue position, three considerations are in order: The first is that the asymmetry in attentional effects is partially determined by the hand employed for responding. The second is that when participants perform the Posner task with their non-preferred hand, attentional asymmetries disappear. Importantly, however, they do not reverse. The third consideration is that the explanation we put forward for attentional asymmetries in the Posner task seems to hold only when the task is performed with the dominant hand.

We believe, however, that the results of the present experiment do not disprove the conclusions we have drawn on the basis of the first four experiments. In contrast, the results of the present experiment make it evident that the explanation we had offered before needs to be complemented by adding a further mechanism.

The lack of an asymmetry with the left hand can indeed be explained by invoking an automatic shift of attention toward the effector operating in a given moment, as demonstrated by Eimer, Forster, Van Velzen and Prabhu (2005) and by Forster and Eimer (2007). When the participant has to give a unimanual response, two different shifts of attention take place: one toward the VHF where cue and stimulus appear and one toward the effector (the hand used to give the response). Consider the case in which the cue appears on the right: When the participant responds with the right hand, the right side is favoured by both shifts. In contrast, when the participant responds with the left hand, the shift toward the VHF favours the right side and the shift toward the effector favours the left side, so that the two shifts tend to cancel each other out. Consider the case in which
the cue appears on the left: When the participant responds with the left hand, the left side is favoured by both shifts, whereas when the participant responds with the right hand, the shift toward the VHF favours the left side and the shift toward the effector favours the right side.

If the asymmetries in the Posner task were due only to the anatomical nature of the hand used to perform the task, we would expect a greater facilitation on the left when the participant has to respond with the left hand. The fact that we do not observe this asymmetry confirms that the anatomical nature of the hand with which participants respond affects the asymmetries in the Posner task, but it is not the reason of the greater facilitation on the right side we observed in all previous experiments of the present study, where participants performed the task with their dominant hand. Moreover, the fact that the facilitation effect is symmetric when participants perform the task with their left hand, shows that the only way to investigate the relation between Posner and Simon asymmetries is by making participants perform the Posner task with their dominant hand, as we did in the previous experiments. In fact, if we had asked our participants to use their non dominant hand there would have been no asymmetries in the Posner task to be compared with the asymmetries in the Simon task.

**Simon task.** Correct RTs (with the exclusion of errors and anticipations, i.e. RTs faster than 150 ms) were submitted to the same analyses (ANOVA and planned comparisons) as in the previous experiments. The ANOVA had order (Posner task first vs. Simon task first) as the between-participants factor and stimulus position (left vs. right) and response position (left vs. right) as the within-participants factors. The stimulus position factor was significant with F(1,58)=5.26 p<0.05, showing that participants responded faster to the right stimulus than to the left stimulus (489 vs. 497 ms). The response position factor
was significant with $F(1,58)=12.01$, $p<0.01$, showing that the right response was faster than the left response (487 vs. 500 ms). The interaction between stimulus position and response position was significant with $F(1,58)=58.33$, $p<0.001$, showing a 31-ms overall Simon effect (Figure 18).

![Figure 18: Results of Simon task of Experiment 5.](image)

Planned comparisons showed that the stSE was greater ($p<0.001$) on the right (44 ms, $p<0.001$, Cohen’s $d=1.13$) than on the left (18 ms, $p<0.001$, Cohen’s $d=0.39$), and that the reSE was greater ($p<0.05$) on the right (39 ms, $p<0.001$, Cohen’s $d=0.88$) than on the left (23, $p<0.001$, Cohen’s $d=0.65$) too. No other sources of variance reached significance. Overall, results replicated those of Experiment 1 and are in agreement with those of the other previous experiments.

To exclude effects of task order on Simon effect asymmetries, we carried out separate planned comparisons for the two order groups: The comparison between the stSE asymmetry of the two groups did not show any difference. The
absence of any effect of order on Simon task asymmetries in the present experiment allows us to exclude that the results of the previous experiments were attributable to carry-over effects between the two tasks.

The same ANOVA was run on accuracy. Stimulus position was significant with F(1,58)=5.96 p<0.05, showing that participants made 3.84% errors when the stimulus appeared on the left and 2.96% when the stimulus appeared on the right. Response position was significant with F(1,58)=7.26 p<0.01, showing that participants made 2.85% errors with the left hand and 2.96% with the right hand. The interaction between stimulus position and response position was also significant, with F(1,58)=6.23 p<0.05, showing that, when stimulus position and response position corresponded, errors were fewer than when they did not correspond (2.73% and 2.96% in corresponding trials, for the left and the right response vs. 2.96% and 4.95% in non-corresponding trials, for the left and right response). Clearly, there was no speed-accuracy trade-off.

4.2 EXPERIMENT 6

As we showed in Experiment 5, the hand used to perform the Posner task interferes with the asymmetries, these being present only when participants perform the task with their dominant hand.

At this point we wondered what happens if participants have to press two keys simultaneously, one on the left and one on the right. Experiment 6 was run to test this for a Posner task only.

4.2.1 Method

PARTICIPANTS. Thirty students of the University of Glasgow, selected as before, except for the fact they were all right-handed, participated in the experiment. They had not taken part in previous experiments.
APPARATUS AND STIMULI. Apparatus and stimuli were identical to those of Experiment 1, except for the fact that a response-box was used, instead of the keyboard, to select the response.

4.2.2 Procedure

Participants only performed a Posner task that was identical to that of Experiment 2, except for two differences. The first difference was that, in the Posner task, participants were instructed to respond to the appearance of the stimulus by pressing two keys simultaneously, one on the right – with the right index finger – and one on the left – with the left index finger – of the response-box. The second difference concerned the SOAs, that were both short (200 ms) and long (800 ms), varying within blocks, to investigate both the facilitation effect and IoR. The cue employed was a non informative peripheral cue, as that used in Experiments 2 and 4.

4.2.3 Results and discussion

Correct RTs (with the exclusion of neutral and catch trials, omissions and anticipations, i.e. RTs faster than 100 ms) were submitted to two ANOVAs, both conducted on RTs of the first response participants gave. Once again, Newman-Keuls post-hoc test was used to explore the significant interactions, and planned comparisons (criterion: p<0.05, one-tailed) were used to test the effects of interest. Trials in which eye movements occurred were not eliminated from the analyses. Overall, eye movements were less than 1%.

The first ANOVA had SOA (short vs. long), cue validity (invalid vs. valid) and cue position (left vs. right) as the within-participants factors. SOA was significant with F(1,29)=37.31 p<0.001, showing that participants were faster when SOA was short than when it was long (329 vs. 348 ms). Cue validity was
significant with $F(1,29)=6.97$ $p<0.05$, showing that participants were faster when the cue was invalid than when the cue was valid (335 vs. 342 ms). The interaction between SOA and cue validity was also significant, with $F(1,29)=149.15$ $p<0.001$, showing that, when the SOA was short, the facilitation effect was present (6 ms, $p<0.05$), whereas when the SOA was long, IoR was present (18 ms, $p<0.001$). Planned comparisons showed that the facilitation effect was present only when the cue appeared on the right (7 ms, $p<0.05$, Cohen’s $d=0.39$) and not when it appeared on the left (6 ms, $ns$, Cohen’s $d=0.31$), even though the magnitude was very similar in the two VHF, whereas the IoR was symmetric, being present both when the cue appeared on the right (15 ms, $p<0.001$, Cohen’s $d=0.64$) and on the left (22 ms, $p<0.01$, Cohen’s $d=1.17$). Omissions were 0.98% in the invalid and 1.17% in the valid condition.

These results confirm what we pointed out in the previous chapter. First of all, we observed facilitation with short SOA and IoR with long SOA. The former effect is asymmetric, whereas the latter is symmetric, and these results replicated those of, respectively, Experiment 2 and Experiment 4 in which SOAs were manipulated between experiments.

In addition, these results showed that the asymmetry in the facilitation effect is still present when a bimanual response is requested. Therefore, they seem to support our idea that the asymmetries demonstrated in the Posner task in the first four experiments are not due only to the hand participants use to perform the task, because in this task participants use both hands.

At this point we wondered if there was a difference depending on whether the first key pressed by participant was the right one or the left one. It would be possible, for example, that participants, who were all right-handed, pressed more often the right key first, so the overall asymmetry which advantages the right VHF could be hidden by the fact that the asymmetry is present only when the
hand used to perform the task was the right one. In this case the results would provide the same information of previous experiments; otherwise, they could provide some further confirmation to our hypotheses. For this reason, we carried out the second ANOVA, by adding the hand factor.

In the second ANOVA the hand factor was added, in order to investigate if the asymmetries observed in the overall facilitation effect were present with both hands or, as suggested by data of Experiment 5, only when the hand used to perform the task was the dominant one. Therefore, the second ANOVA had hand (i.e. the first response participants gave, left vs. right), SOA (short vs. long), cue validity (invalid vs. valid) and cue position (left vs. right) as the within-participants factors. One participant was not considered in this analysis because of missing data in some conditions (due to a strong tendency of the participant to press the right key first). Only the two main factors of SOA and cue validity, and the interaction between SOA and cue validity, were significant, respectively with F(1,28)=27.41 p<0.001, with F(1,28)=7.97 p<0.01, and with F(1,28)=86.48 p<0.001, all confirming the results obtained with the first ANOVA.

Concerning facilitation, planned comparisons showed, that it was present only when the hand used to press the first key was the left one, being 8 ms (p<0.01) with the left hand and 4 ms (ns) with the right hand. No asymmetries were observed with respect to the position in which the cue appeared, the facilitation being present when the cue appeared on the left (7 ms, p<0.05, Cohen’s d=0.35) and on the right (9 ms, p<0.05, Cohen’s d=0.35) with the left hand, and absent when the cue appeared on the left (2 ms, ns, Cohen’s d=0.09) and on the right (5 ms, ns, Cohen’s d=0.19) with the right hand.

Concerning IoR, it was symmetric and present with both hands, being 17 ms (p<0.001) with the left hand and 22 ms (p<0.001) with the right hand. No asymmetries were observed respect to the position in which the cue appeared, the
IoR being present when the cue appeared on the left (20 ms, \( p<0.001 \), Cohen’s \( d=0.69 \)) and on the right (14 ms, \( p<0.01 \), Cohen’s \( d=0.55 \)) with the left hand and when the cue appeared on the left (25 ms, \( p<0.001 \), Cohen’s \( d=0.76 \)) and on the right (18 ms, \( p<0.01 \), Cohen’s \( d=0.62 \)) with the right hand.

Therefore, results showed that the hand participants use to respond, when the response is bimanual, did not affect the asymmetries in the facilitation effect, which were globally present. The fact that they disappeared when the two hands were analyzed separately could be simply due to the small size of the effect, but the fact that they did not depend on the hand added support to our hypothesis. To make sure that results were not simply due to the fact that participants responded more often with one hand respect to the other, we carried out a new ANOVA on the percentages of responses, that led us to an interesting observation.

4.2.4 A serendipitous observation

A new ANOVA was carried out on percentage of first responses. What we wanted to check was that the results observed in RTs were not due only to a difference in percentage of responses with the left and with the right hand. It would be possible, for example, that participants, who were all right-handed, pressed more often the right key first, so this could be a confounding variable.

The ANOVA had hand (i.e. the first response participants gave, left vs. right), SOA (short vs. long), cue validity (invalid vs. valid) and cue position (left vs. right) as the within participants factors. SOA was significant with \( F(1,29)=15.76 \ p<0.001 \), showing that participants responded more often when the SOA was short (49,8%) than when the SOA was long (49,1%). The interaction among SOA, cue validity and hand position was significant with \( F(1,29)=4.56 \ p<0.05 \) but Newman-Keuls post-hoc test did not show any significant difference.
An interesting interaction among cue validity, cue position and hand was found, with $F(1,29)=61.38$ $p<0.001$. When inspecting the means of this interaction, we realized that this was nothing else but a Simon effect (see Figure 19). In other words, the first key participants pressed to respond to the stimulus was more often the one in the position spatially corresponding to the stimulus position. When the stimulus appeared on the left, participants responded 54.7% of the times with the left key first and 44.2% with the right key first, whereas when it appeared on the right, participants responded 56.9% of the times with the right key first and 42% with the left key first).

![Figure 19. Percentage of responses in Experiment 6.](image)

What this result suggests to us is that the Simon effect is an effect so strong as to appear in a simple RT task, that in this case is a Posner task, i.e. even though neither the discrimination of a – spatially or not – characteristic of the stimulus nor selection of the response is needed. However, this effect is evident
only in the percentages of responses and not in RTs performance of participants. In any case, they demonstrated trend is in line with the results of our previous experiments and with our hypotheses.
GENERAL DISCUSSION AND CONCLUSIONS

The purpose of this work was to investigate the relation between the asymmetries of the Simon effect, one of the most studied phenomenon in the field of stimulus-response compatibility, and the asymmetries of the visual attention, in both right- and left-handers.

In Chapter 1 visual attention has been introduced, and the focus has been brought on some basic aspects, crucial to understand the experimental chapters, such as the distinction between endogenous and exogenous orienting (Jonides, 1981; Müller & Rabbitt, 1989), and between facilitatory and inhibitory effects (Posner & Cohen, 1984; Posner et al., 1985). In particular, covert attention, as well as the classic paradigm used to investigate it (Posner, 1980; Posner et al., 1984) has been illustrated. Early (Broadbent, 1958) and late (Deutsch & Deutsch, 1963) selection theory had been discussed, showing that the Simon effect (Craft & Simon; 1970; Hedge & Marsh, 1975; Lu & Proctor, 1995; Simon & Rudell, 1967; Simon & Small, 1969) is one of the most popular tasks that corroborate the late selection theory. In a Simon task, indeed, the spatial position of the stimulus is elaborated even though it is not relevant for the task, and interferes with the performance of participants. One of the currently most accredited theories (e.g., Nicoletti & Umiltà, 1994; Stoffer, 1991; Stoffer & Umiltà, 1997; Umiltà & Nicoletti, 1992), claims that the spatial code of the stimulus is extracted because of the need of attention to shift toward the stimulus.

Tagliabue et al. (2007) showed that the Simon effect is often asymmetric, being greater in the right than in the left side of space in strong right-handed participants and greater in the left than in the right side of space in strong left-handed participants. They also distinguished between the stimulus Simon effect (stSE) and the response Simon effect (reSE) and proposed that the asymmetries
are caused by cerebral lateralization of the mechanisms involved in the Simon effect, that is attention orienting and response selection.

In the present work we focused on the stSE asymmetry, and hypothesized that it would depend on the cerebral lateralization of attentional mechanisms. Two considerations led us to formulate this hypothesis: The first consideration was the fact that the role of attentional processes in the Simon effect is invoked by one of the currently most accredited theory of the Simon effect – the attentional shift hypothesis (Nicoletti & Umiltà, 1994; Stoffer, 1991; Stoffer & Umiltà, 1997; Umiltà & Nicoletti, 1992). The second consideration was that it is known that spatial attention depends on mechanisms predominantly localized, in right-handers, in the right hemisphere, as we demonstrated in the second chapter.

In Chapter 2 the model of Mesulam’s (1981; 1999; 2002) has been presented. It claims that the right hemisphere controls attention shifts toward the right and the left visual fields, whereas the left hemisphere controls attention shifts only toward the right visual field.

Evidence in support of this model has been discussed: They come from both brain-damaged patients (Fernandez-Duque & Posner, 2001; Heilman et al., 2002; 2003; Mesulam, 1981; Mesulam, 1999; Mesulam, 2002, Posner et al., 1984; Posner et al., 1987; Rafal, 1998) and neurologically intact individuals participating in neuroimaging studies (Corbetta et al., 1993; Corbetta & Shulman, 2002; Gitelman et al., 1999; Kim et al., 1999; Nobre et al., 1997).

Moreover, some asymmetries that have been observed in attentional shifts in RT tasks were reported. In particular, Downing and Pinker (1985) and Gawryszewski et al. (1987) observed, by using different versions of a Posner-like task (Posner et al. 1980) in conjunction with a three-dimensional display, a difference in the attentional effects in the two VHF.
Finally, in the last paragraph, we considered the fact that the lateralization of visual attention seems to be differently organized in left-handers, and we discussed the literature about this topic.

**Chapter 3** is the main experimental chapter. On the basis of what has been introduced in the first two chapters, the hypothesis of this work was that, in a Simon task, more attention is allocated on the stimulus when it appears on the right than on the left, and that this is the reason why the Simon effect is greater on the right (in right-handers).

To test our hypothesis we used a Posner paradigm. We expected to observe a difference when the cue appears on the right or on the left. That is because the cue on the right – if it is true that an event on the right catches more attention than the same event on the left – would be more salient than the same cue on the left. Thus, we expected to observe greater benefits and costs when the cue appears on the right.

In this chapter we ran four experiments, in which both left- and right-handers were tested in both a Posner and a Simon task. All the experiments involved a peripheral cue – informative in Experiments 1 and 3, and non-informative in Experiments 2 and 4 – because we were mainly interested in investigating the exogenous orienting of attention (Jonides, 1981), that is the type of orienting involved in a Simon task. In Experiments 1 and 2 we employed short SOAs to explore asymmetries in the facilitation effect, whereas in Experiments 3 and 4 we employed long SOAs to explore asymmetries in IoR.

Both right- and left-handed participants were tested, because of the different lateralization of attentional mechanisms in these two populations, as it has been showed in Chapter 2. Tagliaabue et al. (2007) indeed reported a Simon effect greater on the right side in strong right-handers and greater on the left side in strong left-handers. Here, mild/not strong right- and left-handers were tested to
investigate if asymmetries are still present in less laterized participants. We expected to find asymmetries in the same direction as in the previous study in right-handers and an asymmetry in the opposite direction of right-handers or no asymmetries in left-handers.

We had two main hypotheses: The first was that groups of participants with different handedness would show different patterns of asymmetries in both the Posner and the Simon tasks; the second was that, regardless of handedness, participants with strong asymmetries in one direction in the Posner task should show strong asymmetries in the same direction in the Simon task.

The results of the four Posner tasks showed that the facilitation effect was greater when the cue appeared on the right in right-handers and when the cue appeared on the left in left-handers. Therefore, asymmetries seem mainly to concern the facilitatory component of attention orienting (as it has been shown by Experiments 1 and 2), with a consistent advantage for the right VHF in right-handers and for the left VHF in left-handers. Concerning IoR, this effect was symmetrical when only the exogenous shift of the attention was involved (i.e., in Experiment 4), whereas an advantage of the right VHF in right-handers was evident when endogenously driven shift of attention took place too (i.e., in Experiment 3). This result suggests that the endogenous component of attention, which does not interact with asymmetries when short SOAs are employed, does modulate the asymmetries when the SOA increases. It is known that, usually, IoR is not observed when the endogenous component of attention is involved (e.g. Umiltà, 2000). Thus, we wondered why it is present, in our experiment, in right-handers, when the cue appears on the left. Again, we think that the explanation had to be found in the advantage of the right VHF, because holding voluntarily attention on the right side seems to take fewer resources than holding voluntarily attention on the left side.
An exogenous shift of attention toward the right would be easier than toward the left because in the former case both hemispheres are involved, whereas in the latter case only one hemisphere is involved, and the result is that attention is less efficient in the left VHF. When the endogenous component is also involved, like in our Experiment 3, the automatic shift is followed by an active effort of the participant to maintain attention in that position, which is harder when the cue is on the left for the reason just explained. In other words, data suggest that, when the cue appears on the right, engagement is easier (this is the reason why facilitation is greater) and disengagement is harder (this is the reason why IoR is not present) than when the cue appears on the left. We think it would be interesting to investigate, by using SOAs different from those used in the present research (for example, between 200 and 800 ms), the time-course of asymmetries, because it is possible that engagement is not easier on the right, but only faster, and that disengagement is not harder, but only slower.

With regard to the Simon task, data of right- and left-handers support the hypothesis that asymmetries in the Simon effect are due to the cooperation of the two mechanisms, attention orienting and response selection. The fact that right-handers showed a Simon effect greater on the right, and that left-handers did not show asymmetries, supports our hypothesis because, if the advantage of the dominant hand, alone, could determine asymmetries, we would have expected that left-handers showed a Simon effect greater on the left. Our findings, instead, suggest that both mechanisms, attention orienting and response selection, are involved in Simon effect asymmetries: Right-handers have a strong advantage on the right because both attention and response selection are more efficient on the right; left-handers do not show a similar advantage because of the great variability of the lateralization of spatial abilities in this population, which causes, globally, the absence of a strong advantage of one of the two VHF's.
On the basis of the Simon task only, we could not conclude that the variability of lateralization is the reason of the lack of asymmetries in left-handers. However further evidence comes from the comparison of the asymmetries in the two tasks, and from the finding that the direction of asymmetries, in this population, is predictable on the basis of the direction of the asymmetries in the Posner task, i.e. the direction of the asymmetries is determined by the attentional component. Indeed, left-handers who showed an advantage of the left VHF in the Posner task showed a greater stSE on the left, while left-handers who showed an advantage of the right VHF in the Posner task showed a symmetrical stSE. This finding supports our hypothesis: When left-handers, who have an advantage of the left hand, have an advantage of the left VHF, the left side is advantaged by both mechanisms, therefore the stSE is greater on the left; when they have an advantage of the right VHF, the response selection mechanism favours the left VHF but the attention mechanism favours the right VHF, therefore the asymmetry is in the same direction of those of right-handers.

In Chapter 4 two more experiments had been run.

Experiment 5 was run to make sure that results observed in Posner tasks in previous experiments were not due to the fact that participants always performed the task with their dominant hand.

In the first four experiments we always made participants use their dominant hand in the Posner task because we wanted to maximize the likelihood of finding attentional asymmetries to be compared with the asymmetries in the Simon task we expected to find. In Experiment 5 we had the confirmation that this was indeed the only way to compare asymmetries in Posner and Simon tasks, as asymmetries were not present when participants perform the task with the non-dominant hand.
In this experiment we observed that the asymmetry in attentional effects is partially related to the hand employed for responding, because when participants perform the task with their left (non-dominant) hand, attentional asymmetries disappear. However, they do not reverse, thus adding support our hypothesis, because if asymmetries were due only to the correspondence between cue position (right or left) and anatomical nature of the effector (right hand or left hand), we would have expected reversed asymmetries – a facilitation effect greater when the cue appears on the left – when participants responded with their left (non-dominant) hand. The disappearance of the asymmetry with the left hand has been explained by invoking an automatic shift of attention toward the effector operating in a given moment, as demonstrated by Eimer et al. (2005) and by Forster and Eimer (2007).

Therefore, the finding that attentional asymmetries in the Posner task were absent when participants responded with their non-dominant hand allowed us to expand the explanation of why, in right-handers responding with their right hand, attentional asymmetries favour the right VHF. This modified version of our explanation invokes two mechanisms. The first is a more effective orienting of spatial attention toward the right VHF (Mesulam, 1981; 1999; 2002), while the second is the tendency for spatial attention to be directed toward the effector (Eimer et al., 2005; Forster & Eimer, 2007). When participants respond with the right hand, the two mechanisms add their effects in favour of the right side of the space; when participants respond with their left hand, the effects of the two mechanisms are in opposite directions and tend to cancel each other out.

Experiment 6 was run to further investigate this point. In the last experiment participants were asked to perform a Posner task only, by giving a bimanual response. Results corroborated our hypotheses by showing that asymmetries are still present when a bimanual response was requested.
In conclusion, this work demonstrates that handedness – or general advantage of the dominant hand – could not, alone, give an exhaustive explanation of Simon effect asymmetries. Obviously, it is not easy to analyze separately the two mechanisms – attention orienting and response selection – but, on the basis of this work, we can conclude that the direction of attentional asymmetries, and not only handedness, explains Simon effect asymmetries.
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