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Dissociation between Awareness and Spatial Coding: Evidence from Unilateral Neglect

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and Sergio Della Sala³

Abstract

■ Prevalent theories about consciousness propose a causal relation between lack of spatial coding and absence of conscious experience: The failure to code the position of an object is assumed to prevent this object from entering consciousness. This is consistent with influential theories of unilateral neglect following brain damage, according to which spatial coding of neglected stimuli is defective, and this would keep their processing at the nonconscious level. Contrary to this view, we report evidence showing that spatial coding and consciousness can

dissociate. A patient with left neglect, who was not aware of contralesional stimuli, was able to process their color and position. However, in contrast to (ipsilesional) consciously perceived stimuli, color and position of neglected stimuli were processed separately. We propose that individual object features, including position, can be processed without attention and consciousness and that conscious perception of an object depends on the binding of its features into an integrated percept. ■

INTRODUCTION

Awareness of a stimulus can be defined as the explicit knowledge of its physical and semantic properties or simply of its existence. This knowledge can be demonstrated by direct reports of the perception of the stimulus; for example, by naming it, categorizing it, or just by signaling its presence. Contrary to common sense, several studies have demonstrated that stimulus perception can occur without awareness. Perception without awareness has been shown in many studies with healthy participants by means of procedures ensuring that the critical stimuli were presented below the awareness threshold (see Merikle, Smilek, & Eastwood, 2001, for a review). However, the clearest evidence of unconscious perception comes from a number of brain-damaged patients who are impaired in the conscious processing of certain stimuli but are able to process them unconsciously. Striking examples of this dissociation between preserved implicit (i.e., non-conscious) and impaired explicit (i.e., conscious) processing can be observed in unilateral neglect (UN).

UN is a neuropsychological disorder that usually follows right parietal damage and results in the patient's failure to orient attention toward the side of space contralateral to the lesion (Mesulam, 1999; Heilman, Watson, & Valenstein, 1993). Although UN patients are unaware of contralesional stimuli, implicit processing of several properties of these stimuli has been shown with indirect measures (Berti, 2002; Driver & Vuilleumier, 2001), that is, by evaluating

the effects of processing of neglected stimuli on responses to stimuli presented in the intact hemispace. Properties that can be processed implicitly include color and shape, identity of alphanumeric symbols, and even the meaning of words and pictures (Della Sala, van der Meulen, Bestelmeyer, & Logie, 2010; Làdavas, Paladini, & Cubelli, 1993; Berti & Rizzolatti, 1992; Marshall & Halligan, 1988). For example, word-nonword judgments of letter strings presented in the intact hemispace of UN patients were found to be faster when these strings were semantically related to words presented in the neglected hemispace (Làdavas et al., 1993).

Studies that used indirect tasks provided compelling evidence that, in UN, high-level stimulus processing can occur in the absence of awareness. To account for this counterintuitive dissociation, it has been proposed that the lack of awareness for neglected stimuli reflects selective impairment in processing a critical stimulus feature, that is, stimulus position. Indeed, one of the best-known UN accounts considers it as a deficit of spatial representation and only secondarily as an attentional deficit (Bisiach, 1993): Patients would not try to attend to locations that they are not able to represent. According to this account, UN derives from damage to parietal areas involved in the coding of space (the so-called dorsal or "where" system; Milner & Goodale, 1995). In contrast, cortical areas concerned with the recognition of objects through the analysis of their constituent features (the ventral or "what" system) would be relatively preserved (Berti, 2002). Several authors have proposed that the impaired spatial processing of contralesional stimuli by the dorsal system is what prevents

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object representations produced in the ventral system from entering consciousness (Berti, 2002; Berti & Rizzolatti, 1992).

This proposal implies that the encoding of stimulus location is a necessary condition for conscious awareness (Deouell, 2002; Driver & Vuilleumier, 2001): Without spatial coding, a stimulus might be processed up to the semantic level, but it is precluded from entering consciousness. The proposal of a direct causal relationship between lack of spatial coding and lack of conscious awareness of neglected stimuli (i.e., the idea of the spatial processing deficit as the only reason why otherwise well-coded stimuli do not reach awareness) further implies that spatial coding might be sufficient for constituent stimulus features, when properly processed by the ventral system, to access consciousness.

The fact that spatial processing *per se* (i.e., without constituent feature processing) is not sufficient to bring objects to awareness is suggested both by studies with normal participants (e.g., Treccani, Umiltà, & Tagliabue, 2006) and by studies on other neuropsychological disorders. For example, some patients with damage to the primary visual cortex (V1) demonstrate a preserved ability to localize visual stimuli that they deny seeing (the so-called “blindsight”; Cowey, 2010). Blindsight has often been described as the converse of UN (e.g., Làdavas, Berti, & Farnè, 2000). UN would result from the impairment of the localization system in the face of a relatively intact analysis of the constituent features of objects, whereas blindsight would result from relatively intact functioning of the localization system, in spite of a damage to the system analyzing object features, because of lesions of V1. In this latter case, stimulus awareness would not arise because only objects can access consciousness: Mere spatial codes (i.e., locations without content; Paillard, Michel, & Stelmach, 1983) would not give rise to conscious experiences.

Thus, to have a conscious experience of an event, one would need to activate both space and object representations (e.g., Làdavas et al., 2000). However, losing the ability to process a nonspatial stimulus feature, say stimulus color, does not lead to the loss of stimulus awareness. In contrast, when the representation of stimulus location is lost or degraded, then awareness of other stimulus properties and of the stimulus itself would also be lost. Our internal representation of space would provide the basic medium for conscious perceptual experience (Driver & Vuilleumier, 2001), and when the representation of constituent properties of stimuli is intact, as apparently happens to be the case with contralesional stimuli in UN, the “where” might enable the awareness of the “what” (Berti, 2002; see also the discussion about allochiria below).

These considerations are in line with the prevalent idea of a close relation between space and consciousness (Campbell, 2002). Indeed, contents of consciousness have often been described as laid out in space (Descartes, 1641/1993) or as having a spatial structure (Bisiach, 1997); space

is considered to be an *a priori* representation, necessary to know consciously the external world (Kant, 1781/1990).

Consistent with this idea and with the spatial coding account of UN, behavioral, electrophysiological, and neuroimaging measures have shown that processing of stimulus position is considerably more impaired in the contralesional than ipsilesional hemispace of UN patients (Deouell, 2002). Results of studies using these measures also suggest that spatial feature processing of contralesional stimuli is more impaired than the processing of other features: Even when a stimulus is seen or heard on the neglected side, its location often remains uncertain (Robertson, 2004). For example, studies using auditory stimuli (e.g., syllables or tones) have shown that UN patients fail to localize left-side stimuli (i.e., they are not able to report where the presented sound comes from) even when they are able to identify these stimuli (e.g., they are able to report whether a high- or low-pitch tone has been presented; Pavani, Làdavas, & Driver, 2002). However, given that, in these studies, spatial coding has been tested with direct tasks explicitly requiring patients to report stimulus position (Pavani et al., 2002; Deouell & Soroker, 2000), preserved implicit spatial processing cannot be ruled out. There is indeed evidence that explicit and implicit spatial perception can dissociate in brain-damaged patients (i.e., the same patients who show an impairment in conscious spatial processing can be able to process objects’ spatial features without being aware of them; Robertson, 2004; Kim & Robertson, 2001), just as it happens with explicit and implicit perception of objects’ constituent (i.e., nonspatial) features.

Kristjánsson, Vuilleumier, Malhotra, Husain, and Driver (2005) were the first to compare the processing of spatial and nonspatial attributes of contralesional stimuli by means of an indirect task. In Kristjánsson et al.’s study, two UN patients performed a task in which, on each trial, they had to find a uniquely colored target among a set of three stimuli (i.e., three diamonds) and report whether it had a notch cutoff. In the first experiment of this study, Kristjánsson et al. used long target display times and found that both patients showed considerable color and location repetition priming effects: Responses were faster when either target color or location was repeated across successive trials. For both types of priming effect (i.e., repeated target location or color), the effects observed for ipsilesional and contralesional targets were comparable.

These findings suggest that, when tested with indirect measures, UN patients may show considerable effects of both spatial and nonspatial attributes of contralesional stimuli and that spatial processing can also occur for these stimuli. However, these results do not imply that neglected stimuli are spatially processed. With long target display times, indeed, the patients tested by Kristjánsson et al. (2005) in Experiment 1 never failed to detect contralesional targets, that is, contralesional targets were not actually neglected but were consciously processed.

Kristjánsson et al. (2005) also tested the same two patients in another experiment in which shorter display

times were used. In this condition, patients often missed contralesional targets. Results of this experiment revealed a dissociation between color and location repetition priming in the contralesional hemispace: Color priming occurred regardless of whether the preceding target had been consciously detected or escaped awareness, whereas location priming only arose from preceding targets that had been consciously detected (i.e., location of neglected stimuli did not prime the response to subsequent stimuli). Thus, results of this second experiment point to the existence of an association between location priming and awareness.

Kristjánsson et al. (2005) used a task in which unseen objects might affect patients' judgments of objects presented afterward. However, to assess the possible indirect effects (i.e., priming effects) of the neglected contralesional stimulus presented in one trial, participants needed to consciously detect the contralesional stimulus presented in the following trial and emit an explicit response to it. Priming effects were estimated on the basis of this response. As in previous studies, therefore, in this case too, patients were required to emit direct responses to contralesional stimuli. Responses to these stimuli were obviously defective (e.g., they were slower than responses to ipsilesional stimuli) and might not be the optimal measure to evaluate implicit processing of stimulus spatial information. Nevertheless, the results of this study represent the most convincing evidence in support of the hypothesis of mutual dependence between stimulus location processing and stimulus awareness (i.e., one cannot spatially process a stimulus without being or becoming aware of it), which, in turn, is fully consistent with the idea of a relation between impairment of spatial processing and lack of stimulus awareness in UN.

Other studies have compared spatial and nonspatial feature processing in the two hemispaces by using non-behavioral measures (i.e., electrophysiological measures), which do not require the patient to emit overt responses to the critical stimuli, thus being free from the problems connected with the use of direct behavioral measures as an index of implicit processing. For example, Deouell, Bentin, and Soroker (2000) recorded the EEG responses of a group of UN patients to the occurrence of auditory stimuli (i.e., tones) that differed from the stimuli presented before with reference to either a spatial dimension (i.e., the stimulus location) or a nonspatial dimension (i.e., the pitch or duration of the stimulus). Changes of stimulus location elicited larger responses when the deviant stimulus was presented on the ipsilesional side than when it was presented on the contralesional side. Differences between the two hemispaces were either smaller or absent when the change concerned the tone pitch or duration, thus indicating a greater impairment of contralesional stimulus processing when stimulus location was involved compared with when nonspatial dimensions were concerned. Although Deouell et al. did not test awareness of the presented stimuli, these data are in agreement with

behavioral results obtained with UN patients in auditory tasks (e.g., Pavani et al., 2002) in suggesting a link between impairment of spatial processing of contralesional stimuli and lack of awareness of these stimuli.

Evidence in favor of this hypothesis also comes from studies that used event-related EEG potentials and fMRI to investigate the neural basis of conscious and unconscious stimulus processing. These studies showed that visual areas in the ventral system can still be activated, to some extent, by neglected stimuli. In contrast, activation of cortical areas in the dorsal pathway was observed only for consciously perceived stimuli (e.g., Rees et al., 2002; Vuilleumier et al., 2002; Driver, Vuilleumier, Eimer, & Rees, 2001). Yet, results of these studies are just suggestive of some link between dorsal stimulus processing and stimulus awareness, but they do not provide direct evidence of a spatial coding deficit in UN that selectively involves neglect stimuli and underlies the lack of stimulus awareness.

Another phenomenon that has been interpreted as evidence of the spatial coding accounts of both consciousness and UN is *allochiria* (Obersteiner, 1882), that is, the tendency of some UN patients to report stimuli on the neglected side as being perceived on the ipsilesional side: The patient may declare that a tap on his or her left hand was actually on his or her right, the voice of a person may be reported as being heard on the opposite side to that on which the person is speaking, and objects presented on the left side of the visual scene may be reported as having been presented on the right side.

Allochiria would indicate that nonspatial features of neglected stimuli are processed, whereas location is not, and that spatial coding enables conscious perception (Deouell, 2002; Deouell & Soroker, 2000; Làdavas et al., 2000). Only when a spatial code, even if inaccurate, is attributed to the (implicitly processed) neglected stimuli (i.e., contralesional stimuli are coded as presented on the ipsilesional side) can they access consciousness. Yet, not even *allochiria* rules out the possibility that the actual position of the contralesional (misplaced) stimuli is implicitly processed. Indeed, the fact that the displacement of contralesional stimuli toward the ipsilesional side usually occurs to homologous (symmetrical) locations (Bisiach, 1993; Halligan, Marshall, & Wade, 1992; Obersteiner, 1882) suggests that the position of these stimuli in the contralesional hemispace is actually coded. However, such a code (i.e., the veridical position of contralesional stimuli) is apparently discarded, and these stimuli are attributed to contralateral positions in the ipsilesional hemispace.

The symmetrical stimulus displacement shown by some UN patients with *allochiria* may indeed seem inconsistent with the idea of spatial coding deficits in UN: Clearly, these patients correctly identify the stimulus position within the contralesional hemispace. However, this phenomenon is reconcilable with spatial coding accounts if one considers that space is not a unitary whole, that is, there exist multiple spatial maps (cf. Robertson, 2004). Spatial coding deficits in UN would not necessarily affect all the spatial maps.

In the case of the typical manifestation of UN (with or without allochiria), such spatial deficits would specifically involve the horizontal plane, that is, the coding of stimulus position on the left–right axis with reference to the body midline (rather than the stimulus spatial coding within one hemispace). Following right cerebral lesions, what would be impaired is the attribution of a “left” spatial code to contralesional stimuli.

Thus, there is no definitive evidence for a selective deficit of stimulus spatial coding of neglected stimuli, at least as far as implicit spatial processing is concerned, and for a causal link between this deficit and lack of awareness. There are several indications of the existence of this link, but all of them can be interpreted otherwise. The aim of our study was to examine the relation between space processing and conscious awareness by testing a UN patient with an indirect task that has been shown to be diagnostic of the spatial nature of representations, regardless of whether they are explicitly or implicitly processed (i.e., a Simon-like task; Treccani et al., 2006). As in Kristjánsson et al.’s (2005) study, the very same task tested the effect of the processing of both spatial and nonspatial stimulus attributes (i.e., stimulus position and color). The task thus provided us with an independent measure of implicit stimulus processing other than the critical one and allowed possible dissociations between the two types of processing (i.e., spatial and nonspatial) to emerge. In contrast with previous studies, however, task performance could be only indirectly affected by processing of stimuli presented in either the intact or neglected hemispaces, thus providing a highly sensitive measure of implicit stimulus processing. No direct responses to either contralesional or ipsilesional stimuli were indeed required: The patient was asked to judge the color of a centrally presented square. This square was flanked by another square that was task-irrelevant and was of the same color as the target square (color-congruent condition), of the alternative target color (color-incongruent condition), or of a color different from that of the possible targets (color-neutral condition). The patient responded by pressing a left- or right-side button: the button on the same side as the flanker (spatially corresponding condition) or the button on the opposite side (spatially noncorresponding condition).

We tested the effects of both flanker position and color on the speed and accuracy of target-color judgments. These two effects are commonly observed with normal participants in tasks that analyze these effects in isolation: tasks in which the lateralized irrelevant stimulus accompanying the central target (i.e., the flanker) is of task-neutral color (Treccani et al., 2006) or tasks in which the central target is flanked by two symmetrical stimuli (i.e., left and right sides) of a task-relevant color (Cohen & Shoup, 1997). In the former type of tasks, responses are usually faster in flanker–response spatially corresponding trials (e.g., when a right button press is required in the presence of a right-side flanker) than in noncorresponding

trials (i.e., the so-called accessory stimulus Simon effect; Simon & Small, 1969). In the latter type of tasks, responses are faster in the target–flanker color-congruent trials (e.g., when a red target is accompanied by red flankers) than in color-incongruent trials (i.e., the so-called Eriksen flanker effect; Eriksen & Eriksen, 1974). These two effects are attributed to either attribute (i.e., color or position) of the flanker(s) being coded, although task-irrelevant, and automatically activating the associated response. In the accessory stimulus Simon tasks, the flanker activates the spatially corresponding response (e.g., the right button press if the flanker is on the right). In the Eriksen flanker tasks, the flankers activate the response associated to their color on the basis of the task instructions (e.g., if red targets required right button presses, red flankers also activate the response on the right). When the response activated by the flanker (irrelevant) attribute is the correct one, it is quickly selected. In contrast, when the response signaled by the flanker attribute is the wrong response, the competition between this response and the required one slows RTs.

The joint effect of flanker position and color had been previously investigated with normal participants in a study using the same task as that administered here (Treccani, Cubelli, Della Sala, & Umiltà, 2009). Consistent with the most widely accepted theories of compatibility phenomena, this study showed an interactive effect of target–flanker color congruency and flanker–response spatial correspondence: What mattered most for performance was not whether the response signaled by either flanker attribute was the required response but rather whether the responses signaled by the two flanker attributes corresponded or did not correspond. This task, therefore, would allow us not only to test whether flankers were spatially coded but also to examine the interaction of the possible spatial and color codes (i.e., the combined effect of the two flanker features) in either the neglected or intact hemispace.

The evaluation of the way in which different stimulus features interact in the neglected hemispace was interesting in itself. Indeed, it has been suggested that feature binding might be defective in the neglected hemispace and the effects of conjunction of contralesional stimulus features might not be observed even when individual features are properly processed (Van Vleet & Robertson, 2009). Accordingly, the lack of contralesional stimulus awareness in UN might result, not so much from a spatial processing impairment, as from binding deficits: It might be difficult or even impossible for unbound object features to access consciousness, as people may only become aware of integrated and unitary objects (Treisman & Gelade, 1980).

In fact, stimulus spatial coding and feature binding are usually seen as inseparable processes, and the distinction between them might seem immaterial: Individual stimulus features would be bound together because they share the same position, and the lack of spatial coding would also prevent feature binding (e.g., Deouell, 2002). Yet,

there is evidence that these processes can dissociate in some brain-damaged patients, that is, patients with Balint's syndrome (Robertson, 2004). Balint's syndrome is a severe neuropsychological disorder that usually results from a bilateral damage to the parietal cortex. Patients with this condition can perceive only one object in the visual scene at any given moment. In addition, they are unable to report the location of the perceived object. Despite these explicit spatial problems, there is evidence of intact implicit spatial processing in Balint patients (Kim & Robertson, 2001). This spared implicit spatial representation, however, does not seem to be sufficient to sustain appropriate binding of the different features and items in the visual scene. Features such as color, shape, motion, and size seem to be randomly combined in the objects perceived by Balint patients, and these patients frequently misattribute the features of one object to another (i.e., they form false feature conjunctions; e.g., they may report a red X and a blue O as a red O and a blue X).

In Balint patients, improper binding (rather than a complete lack of it) is observed for objects that are consciously perceived (although only one at a time). The possible indirect effects of the feature binding of objects, when the observer is completely unaware of the presence of these objects, have not yet been investigated. The task administered here might then be the optimal tool to investigate this issue.

Our patient also performed a direct task that allowed us to test her awareness of flankers: a flanker detection task. In each trial of this task, the patient was required to report whether the flanker stimulus had been presented. The absence of explicit perception of contralesional flankers shown in this task (i.e., the "zero-awareness" criterion; Merikle et al., 2001) allowed us to attribute unequivocally their effects on target-color judgment to the implicit processing of their attributes.

METHODS

Participants

Six patients were selected from a pool of right-brain-damaged patients whom we examined during the period from October 2008 to May 2009. Patients were selected if their lesions were confined to the right hemisphere

and if they were able to perform the experimental tasks (e.g., they understood the instructions and were able to perform the required responses). All patients were given the conventional subtests of the Behavioral Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987). To be selected, patients also needed to show signs of space-based neglect—as opposed to object-based neglect—in the BIT copying and drawing tasks: When requested to copy multiple figures (i.e., the three horizontally aligned geometrical shapes in the BIT shape copying subtest), the selected patients copied only the central and right-side (contralesional) figures and neglected the figure on the left, rather than neglecting the contralesional side of the individual figures. Spontaneous drawings also suggested that the frame of reference of their deficit was centered on their body midline rather than on external objects.

Only one patient (V.M.) met an additional critical criterion, that is, an ipsilesional/contralesional detection ratio greater than 10:1 in a version of the flanker detection task administered before the experimental sessions. This task was identical to the control task of the experimental phase (see below) and was administered immediately after the patient's neuropsychological examination (i.e., 1 day before the first experimental session). In this task, the patient showed a clear-cut dissociation between the flanker detection performances in the two hemispheres: V.M. detected the 94% of right flankers and none of left flankers.

V.M. is a right-handed woman, with 15 years of education, who, at the time of testing, was 58 years old. She suffered from an ischemic stroke (documented by CT scan; see Figure 1) confined to part of the territory of the right middle cerebral artery centered on the superior temporal gyrus and encroaching upon the right BG, resulting in a severe left UN, left hemiparesis, and inferior limb hypertonia.

No impairment of her visual field was detected with a neurological examination at the time of testing. V.M.'s visual field integrity was assessed clinically with the visual confrontation technique proposed by Bisiach, Cappa, and Vallar (1983) for the examination of UN patients. The patient was sitting on a chair against a wall of the testing room (i.e., the patient's shoulder contralateral to the to-be-examined hemifield faced the wall). When testing the left hemifield, this procedure prevented attention from

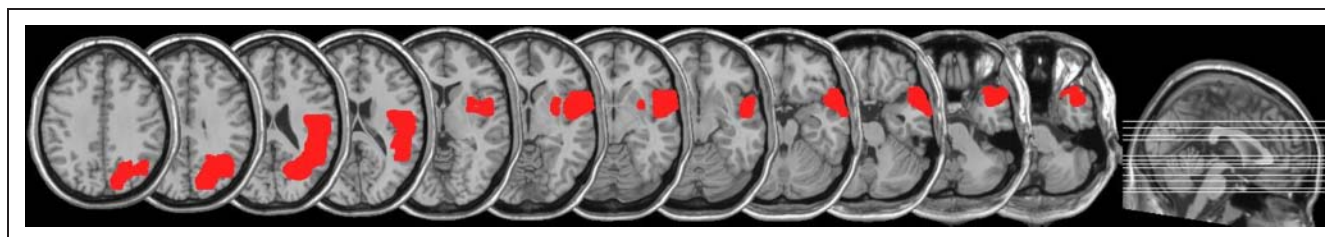


Figure 1. Axial slices showing in red the extent of V.M.'s lesion (lesion reconstruction based on CT scan). Note that right in the figure indicates the right side of the brain.

remaining anchored to objects on the right and forced the patient to orient attention to the left. The examiner was in front of the patient who was asked to stare at the examiner's nose. The patient's task was to detect movements of the examiner's index finger. Ten stimuli (i.e., movements of either the left or right index) were given briefly by the examiner, in each of the two visual hemifields. V.M.'s performance was at ceiling (10/10 detections) in the right visual field, and she missed only two stimuli on the left (8/10).

Therefore, V.M. did not show clinical signs of hemianopia, whereas her behavior, as well as the neuropsychological assessment, revealed a severe UN. Neuropsychological evaluation, as well as the first session of the experimental investigation, was carried out 43 days from the onset of the lesion. The Verbal Judgements Test (Spinnler & Tognoni, 1987) was used to evaluate V.M.'s global cognitive level. This is a verbal intelligence test consisting four subtests: differences, proverbs, nonsensical stories, and classifications. In it, the patient scored within normal limits. V.M. also obtained normal scores in the Mini-Mental State Examination (Measso et al., 1993) as well as in tests of executive functions, language, and verbal memory. In contrast, she showed pathological scores in almost all the subtests of the BIT. The patient also scored below the cutoff in a visuospatial memory test (i.e., Corsi Span, Spinnler & Tognoni, 1987). Her impaired performance in this test was attributable to the severe UN. V.M.'s scores in all the administered neuropsychological tests are presented in Table 1.

Materials and Procedure

V.M. underwent two experimental sessions that were run on 2 days, with an interval of 2 weeks between them, using E-Prime (Version 1.1.4.1) software (Schneider, Eschman, & Zuccolotto, 2002). Each experimental session constituted two tasks.

Target-color Judgment Task

The stimuli and sequence of the events of each trial are depicted in Figure 2.

Trials began with the presentation of a central $0.8^\circ \times 0.8^\circ$ white fixation cross. The patient was instructed to keep her eyes on it. An acoustic 800-Hz warning tone was delivered at the onset of fixation. At the offset of fixation, the target and flanker stimuli (i.e., $1.9^\circ \times 1.9^\circ$ colored squares) appeared. The target was shown at the center of the screen and could be either green or red. The flanker was presented on either the left or right of the target (the center of the flanker was vertically aligned with fixation, 5.7° to the left or right) and could be red, green, or blue (Session 1) or only blue (Session 2). The target and flanker remained on the screen until the response was made or for a maximum of 350 msec. Offset of target and flanker was followed by a blank interval, which lasted until the response or the time granted for responding (1500 msec)

elapsed. The patient was instructed to press one of the two buttons of the mouse according to the target color (i.e., the button on the left in response to the red targets and the button on the right in response to the green targets). Both responses with the wrong button and the lack of a response within the 1500 msec given for responding were counted as errors. In either case, a 400-Hz auditory error feedback was given during the blank, immediately after the response or after the response time was elapsed. Afterwards, a prompt to begin the next trial was presented. As soon as the patient declared that she was ready to continue, the next trial began.

Color-neutral (blue) flankers served as filler stimuli in Session 1 and were not included in the analyses. In contrast, all the flankers were blue in Session 2, which was aimed at investigating the effect of flanker-response spatial correspondence in isolation (i.e., without this effect being confounded with that of the target-flanker color congruency). Previous studies conducted with normal participants (e.g., Treccani et al., 2009) suggest that spatial correspondence effects do not show up in trials wherein the flanker color is neutral in terms of response assignment when they are intermixed with trials in which the flanker is of a task-relevant color (congruent and incongruent).

The patient responded by pressing the two buttons of a computer mouse with the index and middle fingers of her right hand. The mouse was placed inside a wooden box, which was located on the right of the patient and oriented so that the mouse was secured either to the "floor" of the box, in the standard position (i.e., its buttons were upward), or to the "ceiling" of the box, upside down (i.e., buttons were downward). In this latter case, the mouse buttons were pressed with upward movements of the fingers, instead of the usual downward movements (see Figure 3). When the mouse was in the standard position, the index finger was on the left of the middle finger, whereas when the mouse was upside down, it was operating by placing the hand so that the palm faced the box's ceiling, and the index finger was on the right of the middle finger. Eye movements were monitored by an experimenter's assistant (e.g., Van Vleet & Robertson, 2009) using a mirror. Trials during which eye movements were detected were excluded from the analyses (5.8% and 3.4% in Sessions 1 and 2, respectively).

In both sessions, there were 384 randomly mixed trials. They were divided into four blocks and equally distributed across the possible types of trial: 12 (2 target colors \times 3 flanker colors \times 2 flanker positions) in Session 1 and 4 (2 target colors \times 2 flanker positions) in Session 2. In each session, the patient performed the first two blocks with the mouse in the standard position and the remaining blocks with the mouse in the upside-down position, thus pressing the left and right mouse buttons first with the index and middle fingers and then with the middle and index fingers. Therefore, both left and right responses (i.e., responses to red and green targets) were made by using (in an equal number of trials) the two fingers, that

Table 1. Neuropsychological Evaluation of V.M.

<i>Neuropsychological Test</i>	<i>V.M.'s Score</i>	<i>Range</i>	<i>Cutoff^a</i>
<i>Global Cognitive Level</i>			
Verbal Judgments Test (Spinnler & Tognoni, 1987)	44.25	0–60	>32
Mini-Mental State Examination (Measso et al., 1993)	26.31	0–30	>24
<i>Executive Functions</i>			
Weigl Sorting Test (Laiacona, Inzaghi, De Tanti, & Capitani, 2000)	11.82	0–15	>8
Cognitive Estimation Task (Della Sala, MacPherson, Phillips, Sacco, & Spinnler, 2003)	13.20	0–21	<18
<i>Language</i>			
Semantic Verbal Fluency (Spinnler & Tognoni, 1987)	53	0–∞	>7
Letter Verbal Fluency (Novelli, Papagno, Capitani, Laiacona, Vallar, et al., 1986)	31	0–∞	>16
Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983)	48	0–60	>34
<i>Memory</i>			
Spatial Span (Corsi Test; Spinnler & Tognoni, 1987)	3^a	0–10	>3.5
Verbal Span (Digit Span; Orsini et al., 1987)	7	0–9	>3.5
Paired-associate Learning (Novelli, Papagno, Capitani, Laiacona, Cappa, et al., 1986)	20.5	0–22.5	>6
<i>Neglect</i>			
BIT (Wilson et al., 1987)			
Conventional subtests			
Total	79^a	0–146	>129
Line crossing	35	0–36	>34
Letter cancellation	15^a	0–40	>32
Star cancellation	26^a	0–54	>51
Shape and figure copying	0^a	0–4	>3
Line bisection	0^a	0–9	>7
Behavioral subtests			
Total	31^a	0–81	>67
Picture scanning	6^a	0–9	>6
Telephone dialing	4^a	0–9	>8
Menu reading	6^a	0–9	>6
Article reading	5^a	0–9	>6
Telling and setting the time	3^a	0–9	>7
Coin sorting	0^a	0–9	>7
Address and sentence copying	3^a	0–9	>7
Map navigation	3^a	0–9	>6
Card sorting	1^a	0–9	>7

Scores are corrected for age and level of education, when appropriate.

^aPathological scores (i.e., scores under or above the cutoff point).

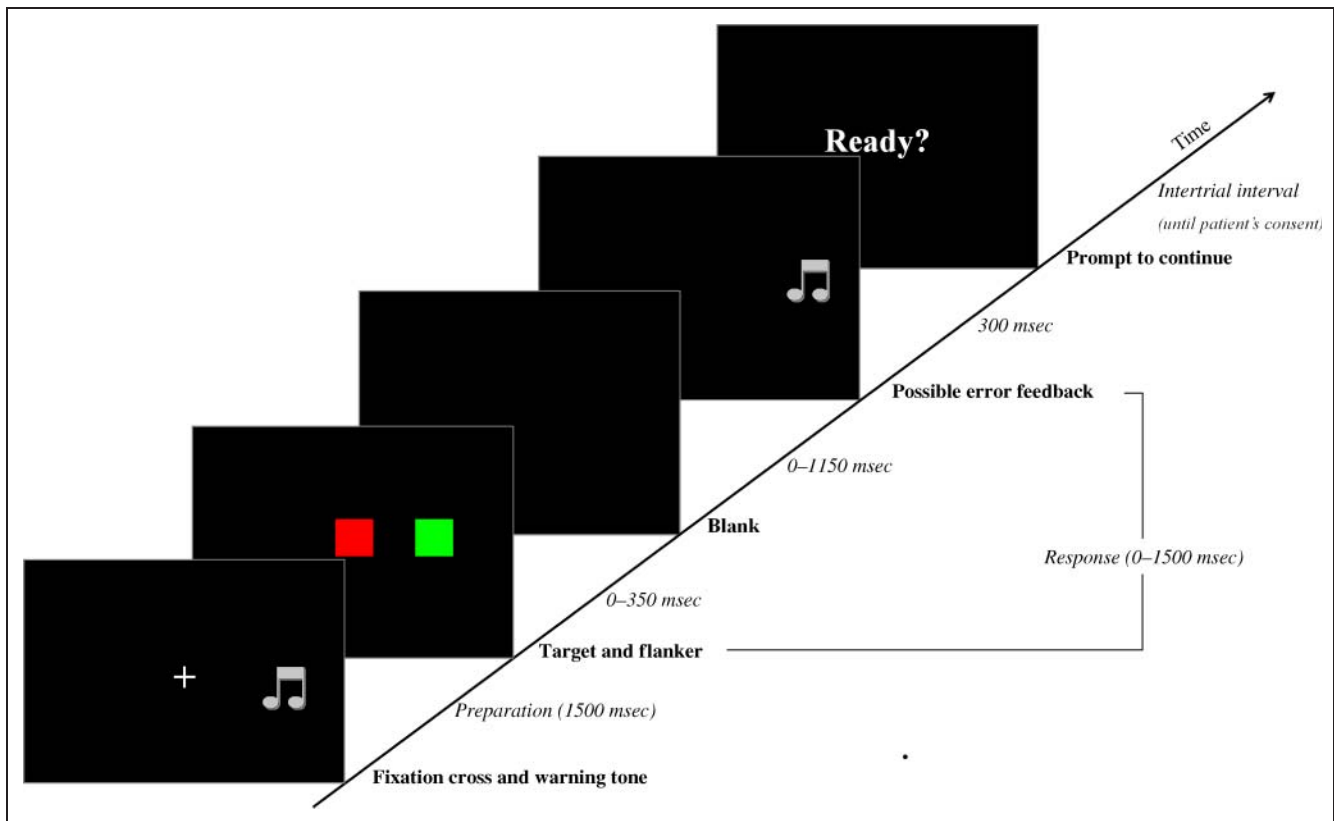


Figure 2. Target-color judgment task. Schematic representation of the stimuli and sequence of the events of each trial.

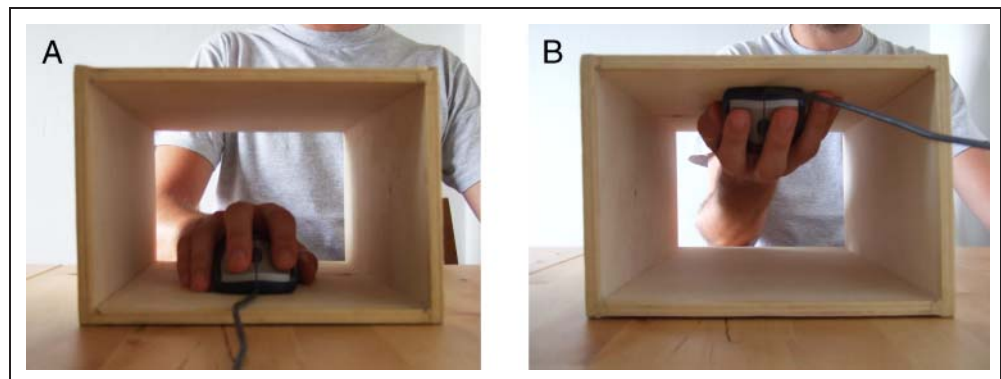
is, the finger used for responding was balanced within each response-position condition. Thus, response position did not coincide (was not confounded) with the identity of the response finger, and possible differences in response speed between the two fingers could not mask the effects under investigation (i.e., the spatial correspondence effect in the two hemispaces).

Flanker Detection Task

This task was performed immediately after the color judgment task in both sessions. Stimuli and procedure were

the same as in the previous task, but the flanker was not always presented, and V.M. had to say whether one or two stimuli were displayed. Patient's responses were entered by the experimenter. V.M. was allowed to correct herself, giving another response when she felt the first one was wrong. The next trial began only when she was sure about her response. There were 162 randomly mixed trials divided into three blocks. Among these, 108 presented both target and flanker stimuli and were equally distributed across the possible types of target + flanker trials (12 in Session 1 and 4 in Session 2), whereas 54 presented the target alone (27 trials for each target color condition).

Figure 3. Target-color judgment task. Standard (A) and upside-down (B) arrangements of the response device. When the computer mouse was upside down (B), the back of the hand rested on a small cushion that was placed on the box's floor. The cushion was removed before taking this photograph to better show the mouse and hand placements.



RESULTS

In the flanker detection tasks, the patient detected 93% and 94% of right flankers (in Sessions 1 and 2, respectively) and none of left flankers (in either session). Her performance in the left-flanker condition was comparable to that observed in the no-flanker condition: In both cases, she always reported that only the central square had been presented. In spite of her lack of awareness of the contralesional flankers, these flankers, like the right ones, had an effect in the target-color judgment tasks of both sessions (see Figure 4 and Table 2).

Distributions of correct RTs in the target-color judgment task of Session 1 were calculated for each level of the three independent variables: Flanker Side (left and right), Congruency between the target and flanker colors (congruent and incongruent), and Spatial Correspondence between position of the flanker and position of the required response (corresponding and noncorresponding). These distributions were divided into five 20% bins (De Jong, Liang, & Lauber, 1994) and submitted to an ANCOVA with these variables as between-item factors. Bin (1st–5th) was included in the ANCOVA as covariate to control for the possible variation in time of the Color Congruency and Spatial Correspondence effects (Treccani et al., 2009). The analysis revealed main effects of both Color Congruency, $F(1, 202) = 4.34, p < .05$, and Spatial Correspondence, $F(1, 202) = 7.25, p < .01$: Responses were faster in color-congruent (695 msec) than color-incongruent (725 msec)

Table 2. Target-color Judgment Task: Session 2

Flanker Side	Spatial Correspondence	RT	PE
Left	Corresponding trials	681 (19.3)	1.1%
	Noncorresponding trials	709 (19.9)	5.6%
Right	Corresponding trials	665 (18.8)	1.0%
	Noncorresponding trials	688 (19.4)	5.3%

Means (and SEMs) of correct RTs and percentages of errors (PEs) as a function of flanker side and flanker–response spatial correspondence.

trials and in spatially corresponding (689 msec) than noncorresponding (730 msec) trials.

The interaction between Spatial Correspondence and Flanker Side was also significant, $F(1, 202) = 10.16, p < .01$: Spatially corresponding versus noncorresponding RTs were 668 versus 750 msec with left flankers and 710 versus 712 msec with right flankers (i.e., a spatially corresponding trial advantage of 82 msec was found with left flankers, whereas the difference between corresponding and noncorresponding RTs was only of 2 msec with right flankers). In contrast, the Color Congruency effect was not modulated by the flanker position (i.e., the color-congruent trial advantage in the left and right hemispaces was of 25 and 37 msec, respectively). Finally, there was a significant interaction between Color Congruency, Spatial Correspondence, and Flanker Side, $F(1, 202) = 8.79, p < .005$. Additional comparisons showed that Color Congruency modulated the

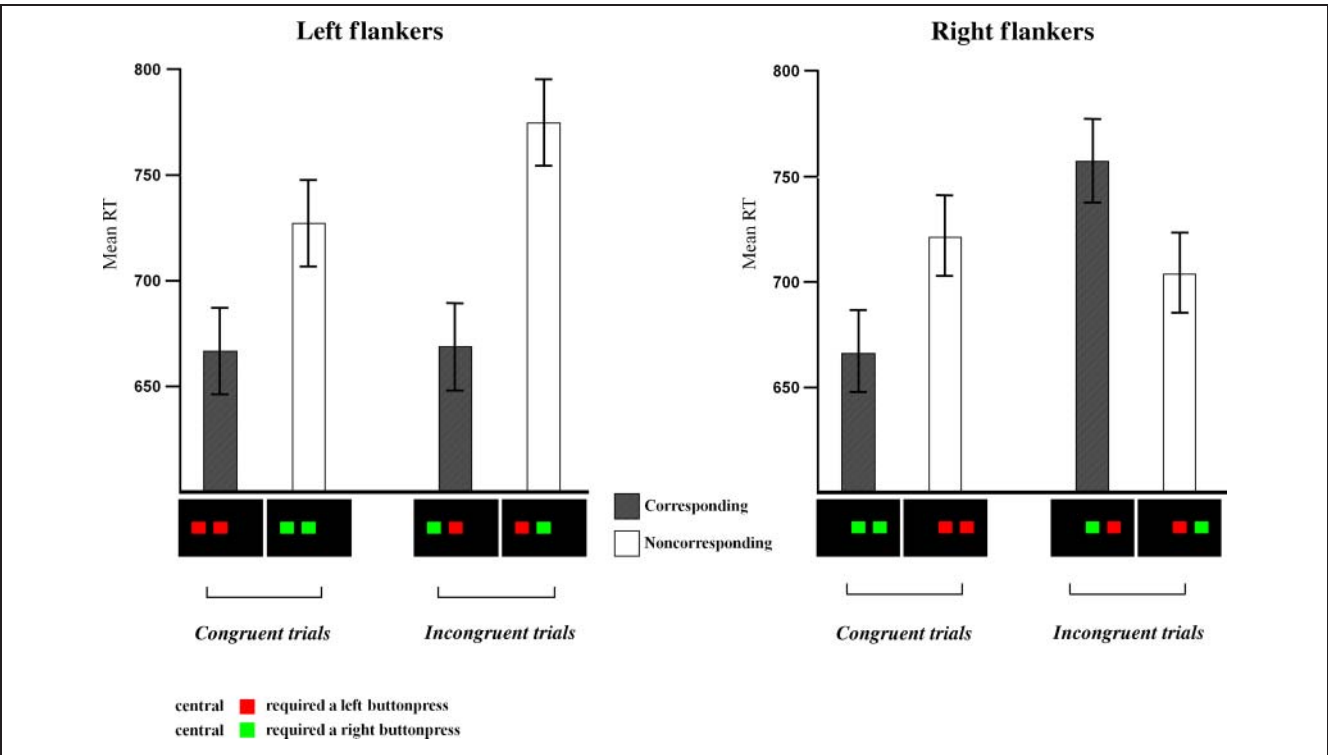


Figure 4. Target-color judgment task: Session 1. Means (\pm SEMs) of correct RTs as a function of flanker side (left and right), target–flanker color congruency (congruent and incongruent), and flanker–response spatial correspondence (corresponding and noncorresponding). Below the x axes of the two graphs, schematic representations of the stimulus display are presented for every condition.

Spatial Correspondence effect (i.e., spatially corresponding responses were faster than spatially noncorresponding responses when the target and flanker colors were congruent, whereas the reverse occurred when the target and flanker colors were incongruent) but only with right flankers, $F(1, 202) = 9.87, p < .005$. The Color Congruency \times Spatial Correspondence interactive contrast performed on left-flanker trials was not significant, $F(1, 202) = 1.22, p = .27$. Spatially corresponding versus noncorresponding differences were significant for both color-congruent, $F(1, 202) = 4.35, p < .05$, and color-incongruent trials, $F(1, 202) = 13.32, p < .001$, of left-flanker conditions, as well as for color-congruent, $F(1, 202) = 3.91, p < .05$, and color-incongruent trials, $F(1, 202) = 6.06, p < .05$, of right-flanker conditions. Overall, the error rate was 11.7%. Seventy-one percent (71%) of the errors were wrong button presses, and the remaining 29% were omissions (i.e., the lack of a response during the 1500 msec granted for responding). Spatially corresponding versus noncorresponding error percentages were 13.8% versus 13.8% and 7.4% versus 16.7% in the color-congruent and -incongruent trials of left-flanker conditions, whereas they were 12.5% versus 6.7% and 13.3% versus 0% in the color-congruent and -incongruent trials of right-flanker conditions. None of these corresponding versus noncorresponding differences were significant (Yates-corrected chi-squares, all $ps \geq .13$).

Data from the target-color judgment task of Session 2 underwent the same analysis, with only the exclusion of the Color Congruency variable. The ANCOVA only revealed the significant main effect of Spatial Correspondence, $F(1, 354) = 6.50, p < .05$. Regardless of the side on which the flanker was presented, spatially corresponding responses were faster than noncorresponding responses (673 vs. 698 msec). The error percentage was also lower in corresponding than noncorresponding trials with both left and right flankers, but neither of these differences was significant (Yates-corrected chi-squares, both $ps \geq .20$). On the whole, the error rate was very low (2.4%), and all the errors were wrong button presses.

Results of ANCOVAs were confirmed by nonparametrical tests, that is, permutation analyses (Monte Carlo Constrained Synchronized Permutation Test [CSPT]: Basso, Chiarandini, & Salmaso, 2007). Given that only two variables can be introduced in each permutation analysis, RTs from Session 1 were first analyzed through separate CSPTs for the two flanker positions, with spatial correspondence and bin as factors (the same factors were considered in the subsequent analyses). In both analyses, for each factor, we computed the test statistic (T) from the observed data. This allowed us to test the main effect of each factor. We compared the observed value of T with its null distribution, which was obtained through (5000) synchronized permutations, that is, by exchanging the same (random) number of observations (RTs) between each pair of levels of the factor under testing, within the same level of the other factor. The exchanged observations were in the same original position. We then computed the p value for

each test statistic, that is, the probability, based on the T null distribution, to obtain a T value equal to or greater than the observed one. The spatial correspondence effect was significant for left flanker ($p < .0001$), whereas it was far from significance for right flankers ($p = .67$). Data obtained in right-flanker trials were then further analyzed through two separate CSPTs for the two color congruency conditions. Both the spatially corresponding response advantage in color-congruent trials and the noncorresponding response advantage in color-incongruent trials were significant (both $ps < .05$). RTs from Session 2 were analyzed through separate CSPTs for the two flanker positions. The spatial correspondence effect was significant in both left- and right-flanker trials (both $ps < .05$).

DISCUSSION

The results reported here indicate strong effects of both the flanker color and the flanker position on V.M.'s performance. In the target-color judgment task of Session 1, V.M. showed color congruency effects with both left and right flankers, confirming that the color (i.e., a nonspatial attribute) can be processed and engage response-related mechanisms in either neglected or intact hemispace (e.g., Kristjánsson et al., 2005; Danckert, Maruff, Kinsella, de Graaff, & Currie, 1999). Notably, a spatial correspondence effect was also observed in the neglected hemispace, which shows that the position of neglected stimuli can be processed as well. This is the first demonstration that, in UN, not only constituent features but also spatial attributes of contralesional (nonconsciously perceived) stimuli can be properly coded (cf. McIntosh et al., 2004¹). It undermines both the widely shared assumption that UN is essentially a deficit in the spatial representation of contralesional stimuli (Bisiach, 1993) and the idea that such a deficit causes the loss of awareness of these stimuli (Berti & Rizzolatti, 1992). V.M. showed a dramatic impairment in responding overtly to left flankers, yet her (covert) spatial coding of these stimuli was as effective as the coding of right flankers: The spatial correspondence effects observed with left flankers were comparable in size to both the standard and reverse correspondence effects observed with right flankers. This finding was confirmed in Session 2, where the spatial correspondence effect could not be modulated by color congruency, and a standard effect of about 25 msec was found in either hemispace. Therefore, the hypothesis that spatial representation of contralesional stimuli is partially preserved in UN patients but is not good enough to support conscious awareness (cf. Robertson, 2004) does not seem likely either: The coding of lateral stimuli with respect to the body position and/or with respect to the focus of attention (i.e., the spatial coding underlying the spatial correspondence effects observed in the target-color judgment task) seems to have been equally effective in both the left and right hemispaces of V.M.

In fact, these results cannot rule out that other types of (implicit) spatial coding or spatial representations serving

computational needs different from those involved in the tasks administered here (cf. Milner & Goodale, 1995) were defective in the neglected hemispace (e.g., a more finely tuned spatial representation entailing the coding of spatial relations between objects within this hemispace). However, the left versus right coding that V.M. was able to perform (cf. Treccani et al., 2009) is exactly the type of coding the lack of which is considered by the spatial account as underlying the lack of contralesional stimulus awareness in UN patients and the stimulus misallocation in those patients who show allochiria. As previously underlined, spatial deficits in UN are not supposed to affect necessarily all the spatial maps. For example, patients might still be able to code the position of an object within the contralesional hemispace, as shown by some patients with allochiria. The spatial deficit would specifically affect the representation of the stimulus on the left–right axis. This is not clearly the case with the UN patient evaluated in the present study. Therefore, V.M.’s performance is more consistent with an alternative account of UN, according to which contralesional space representation is intact, but attention-orienting mechanisms are not, so that attention cannot be allocated toward the contralesional side of space representation (Mesulam, 1999; Heilman et al., 1993).

These findings do not obviously rule out that some UN patients have an actual deficit in the left–right spatial coding of objects when they appear on the contralesional side: UN patients are indeed a heterogeneous group. However, these results clearly demonstrate that, at (the very) least, this problem does not concern all the patients showing UN and that the overt neglect of implicitly processed stimuli cannot be univocally attributed to the lack of spatial coding. It has been conjectured that at least some UN patients may encode the locations of the stimuli, the constituent features of which they show they can process implicitly (e.g., Robertson, 2004). The present results provide empirical evidence for this conjecture.

More generally, the present findings indicate that both spatial and nonspatial stimulus information can be encoded, and associated responses can be activated, without the stimulus entering consciousness and even when attention is oriented elsewhere. Therefore, contrary to widely accepted views (Berti, 2002; Campbell, 2002; Berti & Rizzolatti, 1992), the processing of either type of information (the one processed by the dorsal pathway and that processed by the ventral pathway) does not seem to be decisive in bringing a stimulus to consciousness. Even if spatial coding of visual stimuli might be necessary for conscious perception (Berti & Rizzolatti, 1992), it is certainly not sufficient. Furthermore, spatial coding of neglected (i.e., unattended) stimuli poses a serious challenge to theories maintaining that spatial codes of stimuli producing spatial correspondence effects derive from shifts of attention toward these stimuli (Umiltà & Nicoletti, 1992; Umiltà & Liotti, 1987). The present findings are better accounted for by hypotheses that do not posit a crucial role of attention movements for the generation of spatial correspondence effects: the accounts

postulating that the stimulus position (here, flanker position) is coded with respect to a salient reference object (here, the central target; e.g., Hommel, 1993) or those theories that keep the idea of attention as critical for the spatial code to be generated but do not maintain that attention has to be oriented toward a stimulus in order for this stimulus to be spatially coded (i.e., they simply state that the stimulus is spatially coded with respect to the position of the focus of attention at the time the stimulus is presented—here, again, the center of the screen, where the target appeared; e.g., Stoffer, 1991). This latter account, in particular, is also consistent with results obtained with other tasks providing for the presentation of lateralized accessory stimuli that accompanied central targets: Unlike with the study described here, attention has been shown to be critical for spatial correspondence effects to occur in previous studies with healthy participants that used accessory stimulus tasks, irrespective of whether the accessory stimulus was perceived with or without awareness (Treccani et al., 2006).

The dissociation between spatial coding and both attention and consciousness observed in the present study leaves open the questions of exactly when attention intervenes and what allows stimuli to be consciously perceived. A cue comes from the qualitatively different pattern of results we observed for right and left flankers in Session 1: interactive and additive effects of spatial correspondence and color congruency, respectively. On the one hand, this difference provides further evidence for the patient’s lack of awareness of left flankers. Indeed, according to several authors (McCormick, 1997; Greenwald, Draine, & Abrams, 1996; Dixon, 1971), the observation of effects of the critical stimulus feature in an indirect task (in our study, the target-color judgment task) and the failure to detect the stimulus in a forced-choice task (here, the flanker detection task) are not enough to demonstrate perception without awareness. An additional criterion is necessary, which consists in demonstrating qualitatively different behavioral effects under conditions of conscious and nonconscious perception. More importantly, the qualitative difference between the effects of flankers in the two hemispaces may shed light on the way stimuli are processed with and without attention.

The interactive effect of color congruency and spatial correspondence observed in the intact hemispace was the expected finding for attended and consciously perceived flankers: It replicates results obtained with normal participants (e.g., Treccani et al., 2009, Experiment 1). Previous studies suggest that spatially corresponding trials of color-congruent conditions and noncorresponding trials of the incongruent conditions are advantaged because, in both cases, the flanker color and position activate the same response, which is quickly selected when it is the correct response (i.e., in corresponding-congruent trials) or quickly aborted when it is the wrong one (i.e., in noncorresponding-incongruent trials). When the flanker color and position prime two different responses (i.e., in noncorresponding-congruent or corresponding-incongruent trials), a conflict takes place between the two responses that cannot be

rapidly solved, and this slows RTs. In contrast, when the flanker color does not belong to the target set (as in Session 2), the flanker would activate only the spatially corresponding response, speeding it up when it is the correct one. In this case, the spatial correspondence effect would not be masked by the effect of color congruency (see Treccani et al., 2009, Experiment 2). Thus, V.M.'s performance in the target-judgment task was comparable with that of normal participants and consistent with current hypotheses about the cognitive mechanisms underlying compatibility phenomena, either when the flanker varied with reference to only one attribute (i.e., its position in Session 2), irrespective of the hemisphere in which it was presented, or when the flanker varied with reference to two task-relevant attributes (i.e., color and position in Session 1), as long as it was presented in the intact hemisphere.

In other words, in the intact, attended hemisphere, V.M. showed regular trends of compatibility effects for (consciously perceived) flankers characterized by either one or two attributes, whereas in the neglect hemisphere, she showed a regular trend only when the (nonconsciously perceived) flankers varied according to one attribute. With two flanker attributes, we observed a different pattern from that found either in normal participants or in the intact hemisphere of the patient herself, that is, no modulation of the effect of one flanker attribute by the other attribute.

Previous studies suggest that the interaction between the effects of two flanker attributes critically depends on the fact that these attributes are perceived as belonging to the same object. Indeed, additive rather than interactive effects have been found when the integration of the spatial and nonspatial stimulus-irrelevant features was hampered, for example, because they were conveyed by two different objects (e.g., Stoffels & Van Der Molen, 1988). If the two attributes are perceived as belonging to two separate objects, there are just no prerequisites for the interaction between their effects: The agreement or disagreement between the responses signaled by two attributes can affect performance only when these two signals come from the same source. Indeed, only when two features are integrated, the consistency between them can emerge as a new feature of the stimulus display, which, in turn, reflects the way in which our brain segregates and binds stimulus features, building meaningful and unitary percepts in a coherent visual scene, starting from separate feature representations (cf. Treisman, 1998). Accordingly, no interaction should occur when flanker color is not bound to flanker position, that is, when they are processed separately. Thus, the additive effects observed in the contralesional (unattended) hemisphere, with faster corresponding responses in both congruent and incongruent conditions, suggest that feature binding does not occur in this hemisphere.

In summary, V.M.'s performance reveals that both spatial and nonspatial flanker features were processed in

either the intact or neglected hemisphere, but the type of processing was different in the two hemispheres: Color and position of ipsilesional (attended and consciously perceived) stimuli appear to have been processed jointly, whereas those of contralesional (neglected) stimuli seem to have been processed as separate features. These results suggest, therefore, that an important component of UN is a deficit in binding simple features of contralesional stimuli into objects (see Van Vleet & Robertson, 2009; Cohen, Ivry, Rafal, & Kohn, 1995), in particular, a deficit in integrating information concerning stimulus identity and stimulus location (i.e., features processed by the ventral and dorsal visual pathways; Robertson, 2004; Bailys, Gore, Rodriguez, & Shisler, 2001; see also Deouell, 2002). This proposal is based on the feature integration theory (Treisman & Gelade, 1980). According to this theory, single features of unattended stimuli may be processed and trigger responses in an automatic fashion. However, to consciously recognize and voluntarily respond to the stimuli, stimulus features need to be bound together and form integrated objects. Unbound object features cannot access awareness. The binding process is mediated by attention. When attention is either attracted away from an object or prevented from being oriented toward an object because of brain damage, object features are not bound together, and the observer does not become aware of them. Given that the representations of unattended objects are not tightly bound to the representation of their locations, wrong combinations of features of different objects into one object or allochiric misallocation of such objects toward the focus of attention can also occur in either normal or brain-damaged observers (e.g., false conjunctions in Balint patients or misallocation from the contralesional to the ipsilesional hemisphere in neglect patients; Marcel et al., 2004). In this case, constituent features of the unattended objects are bound to the attended locus, and even if erroneously perceived as being in a location different from that of their original sources, they can access consciousness.

However, some caution should be used in drawing such conclusions, as this account provides for a causal link between attention and consciousness, whereas there is evidence that conscious perception can occur without attention (cf. van Boxtel, Tsuchiya, & Koch, 2010; Koch & Tsuchiya, 2007). Further research is needed to disentangle the interaction between attentional processes, feature binding, and conscious awareness: They undoubtedly share an intimate relation, but the nature of this relation is still not fully understood.

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Note

1. McIntosh et al. (2004) found that the trajectory of the reaching movements of a right-brain-damaged patient was influenced by the presence of contralesional, nonconsciously perceived objects. These results suggest that the spatial locations of such objects were implicitly coded and used to guide actions. In McIntosh et al.'s study, however, the patient showed extinction rather than UN (i.e., the patient only failed to detect a stimulus in the contralesional hemispace when it was paired with a simultaneous bilateral stimulus), and the spatial representations subserving the patient's task (i.e., movement parameters to be specified in the motor system with reference to the arm and hand positions) were clearly different from the left-right spatial coding underlying the spatial correspondence effect observed in the present study. In addition, there was no evidence that stimulus features other than the spatial ones (i.e., constituent stimulus features) were processed by the patient in the contralesional hemispace. In this respect, McIntosh et al.'s findings resemble the results of studies with blindsight patients (cf. Cowey, 2010), except that, in McIntosh et al.'s study, the absence of contralesional stimulus awareness was the consequence of an attentional disorder rather than of the deprivation of cortical visual input.

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