Spatial hemineglect refers to the defective ability of patients with unilateral brain damage to explore the side of space contralateral to the lesion (contralateral), and to report stimuli presented in that portion of space. The ‘hemi’ prefix denotes a main feature of the disorder, which distinguishes hemineglect from global deficits of spatial exploration and perception. The patients’ performance is comparatively poor for objects and parts that are contralateral to the lesion (contralesional), and to report stimuli presented in the side ipsilateral to the lesion (ipsilesional), or a lateral gradient may be present. In the more widely used diagnostic tasks, such as line bisection (Fig. 1), target cancellation, copying and drawing (Fig. 2), patients are free to move their head and eye. A defective performance, therefore, cannot be attributed to primary sensory or motor deficits, which, in turn, may occur in the absence of hemineglect. These patients may also show ipsilesional displacement of the egocentric frames of reference, such as the perceived mid-sagittal plane (Fig. 3).

In the last 30 years, a number of general interpretations have been put forward, to account for the manifold manifestations of hemineglect, making use of constructs such as ‘representation’, ‘attention’, and ‘reference frames’.

(i) Conscious representations of contralateral space may be more or less completely lost.

(ii) Orientation of spatial attention...
Vallar – Spatial hemineglect

Fig. 1 Line bisection in hemineglect. (A) Right-brain-damaged patients with left hemineglect set the subjective midpoint (short vertical bar) of a horizontal segment, located outside their trunk’s mid-sagittal plane (in, dashed vertical line), to the right of the objective midpoint (the intersection between m and the centre of the segment). This rightward error may be reduced by cueing patients to attend the left side (e.g. by requiring them to read a digit located at the left end of the line (Ref. 71), or by placing their hand on the left end of the line (Ref. 72). Data of this sort suggest that the defective orientation of attention towards the contralesional side may be a pathological factor of hemineglect (see Ref. 73). The rightward directional error can be reduced when patients are required to set the mid-point of the empty space between two dots (B). When required to set the endpoints of the previously bisected segment, patients may relatively underestimate the right endpoint, and overestimate the left endpoint (C). (Data from patient A.F., Refs 74, 75 for related data.)

Fig. 2 Copying, drawing and identification in hemineglect. Right-brain-damaged patients with left hemineglect typically omit left-sided details in copying tasks (A). For example, this ‘cat-lion’ chimera was identified by patient F.G. as a ‘lion’, on the basis of the right side of the drawing. F.G.’s copy is shown below the original drawing. Presented with pairs of line-drawn figures that differ on their left side (e.g. ‘crocodile–whale/whale’) (B), patient B.R. judged such pairs as ‘same’, and identified the two figures on the basis of their right halves (i.e. as two ‘whale’). When required to trace the contours of the two drawings, patient B.R. showed an erroneous performance on both sides, in some trials (C), but persisted in his erroneous judgement (‘same’) and identification (‘whale’). The dissociation between preserved tracing and defective identification indicates that, at least in some patients, a preserved visuo-motor exploration does not ensure an adequate perceptual processing of objects in the neglected side of space, and provide an example of the multifaceted nature of hemineglect. (Modified from Ref. 76.)

Towards the contralesional side may be defective, with a sharp boundary between neglected and attended regions. A pathological orientational bias of attention may be present, with a continuous gradient of neglect along the axis running from the contralesional to the ipsilesional side. In the framework of a ‘premotor theory of attention’, hemineglect has been interpreted as an imbalance of spatial representations that control motor programs, producing an attentional deficit. The egocentric frame of spatial reference may be rounded, or translated (see Fig. 3) towards the ipsilesional side, or a more complex dimension may be present. Reviews of the syndrome of spatial hemineglect can be found in Refs 1, 7.

These general explanations share the view that hemineglect is produced by a higher-order spatial impairment, and differ in this respect from earlier accounts at a low-level of integration, such as disordered processing of sensory inputs, or defective peripheral motor mechanisms. Research in brain-damaged patients with hemineglect has produced a great deal of empirical data, which have been interpreted in the context of, and are compatible with, ‘representational’, ‘attentional’, or ‘frame of reference’ accounts. Indeed, it is likely to be the case that these general interpretations, rather than being alternative, incompatible, models may, on the one hand, refer to different aspects of hemineglect, and, on the other, prove to be difficult to distinguish (for a discussion concerning attentional vs. representational interpretations of hemineglect see Refs 1, 9, 15). An important lesson to be learnt from the recent investigations of hemineglect is that the disorder, as other neuropsychological and neurological deficits, fractionates into a variety of discrete patterns of impairment.

The compass of spatial hemineglect

The clinical term ‘spatial hemineglect’ should be conceived as the label of a ‘syndrome’ in which a number of symptoms and signs of disordered function are related to one another by a spatial peculiarity. The deficit concerns the contralesional side, with reference to specific spatial co-ordinate systems and processing domains. So far, a number of specific varieties of hemineglect have been reported, which may be distinguished along different, although related, cleavage dimensions (see Box 2). Neglect is frequently associated with the phenomenon of extinction to double simultaneous stimulation (see Box 2).

Within an egocentric frame (e.g. with reference to the mid-sagittal plane of the trunk, a main primitive of spatial orientation, see Fig. 3A), the deficit may concern different sectors of space. Visual and auditory objects in extra-personal space (the better known and more extensively investigated form of hemineglect) or personal space (the subject’s body) may be selectively disrupted. Hemineglect may be confined to either internally generated representations of visual images or objects in extrapersonal space.

This egocentric (location-based, with reference to the observer) forms of hemineglect have been distinguished from deficits related to disorders of allocentric frames of reference, where hemineglect concerns the contralesional side.
of objects, independent of their position relative to the egocentric frame (e.g. the patient’s mid-sagittal plane)\(^\text{22,23}\). Within neglect for objects, further distinctions have been drawn between an ‘object-based’ deficit, where the assignment of ‘left’ and ‘right’ sides is defined with respect to the observer’s viewing position, and an ‘object-centred’ deficit, which is viewer-independent\(^\text{24}\). In an object-based frame of reference, the neglected side of the object would be affected by rotation, or, in the case of words, by reversed or vertical print. In an object-centred frame, neglect (which has been described in the domain of dyslexia) is unaffected by reversed or vertical print, affecting the contralesional side of the word, in its canonical perspective\(^\text{25}\). Double dissociations between object-based versus spatial (egocentric) hemineglect have been reported\(^\text{26,27}\).

Along the input–output response chain, which relates perceptual processes to the organization of goal-directed motor responses, distinctions have been drawn between ‘peripersonal’ vs. ‘properson’ varieties of hemineglect for objects in extrapersonal space: defective awareness of sensory input vs. impairments of motor programming of movements of the unaffected ipsilesional limbs, towards targets located in contralateral sectors of extra-personal space (directional hypokinesia)\(^\text{28–32}\).

Within the more extensively investigated visuo-spatial domain, further dissociations have been described. Patients may be impaired in line bisection (see Fig. 1), but not in target cancellation tasks or vice versa\(^\text{33,34}\). Spatial exploration may be defective when visual control is allowed (open eyes), and preserved in a proprioceptive-somatosensory condition, with right-brain-damaged patients being blindfolded; in other patients the opposite dissociation has been found\(^\text{35}\). One patient with a bilateral lesion showed left-neglect dyslexia (paralexic errors affecting the beginning of words) and right visuo-spatial neglect in copying and bisection (see Figs 1 and 2A) tasks\(^\text{36}\) (see a similar case in Ref. \text{37}). In another right-brain-damaged patient left hemineglect was confined to faces\(^\text{38}\). One left-brain-damaged patient exhibited right-neglect dyslexia (paralexic errors that affected word endings) without other manifestations of visuo-spatial hemineglect\(^\text{39}\).

\textbf{Fig. 3 Egocentric spatial frames of reference in hemineglect.} (A) The midsagittal and other planes and axes of rotation of the body, related to its centre of gravity (c.g.). (Redrawn from Ref. \text{77}.) Patients with hemineglect may show a displacement of the subjective midsagittal plane towards the side ipsilateral to the lesion. Right-brain-damaged patients with (RN+) and without (RN-) left visuo-spatial hemineglect and normal subjects (C) were required to set the perceived auditory midline, localizing a free-field, pure tone to the left or to the right of the subjective midsagittal plane. ‘Right’ and ‘left’ refer to the starting position of the tone sequence, and 0 deg represents the midsagittal plane. Patients with hemineglect displaced the subjective midsagittal plane sideways in both the front (B) and the back (C) halves of space. Both normal subjects and patients without hemineglect did not make such errors. In a few individual patients the rightward displacement was confined to one (front or back) half of auditory space, suggesting the existence of discrete internal representations, along the anterio/posterior dimension, which might be selectively affected by brain damage. These findings have been taken as evidence in hemineglect for a pathological translation of spatial coordinates towards the side ipsilateral to the lesion, for an interpretation in terms of rotation, see Ref. \text{78}. (Data reproduced, with permission, from Ref. \text{79}.)

The interpretation of the precise mechanisms underlying some of these dissociations is debatable. These empirical observations suggest, however, that the ‘internal representation’ of space, the ‘spatial attention’, or the ‘spatial frame of reference’, far from being a single monolithic and supramodal system, should be conceived as having a highly multifaceted architecture, including multiple components or centres, which may be selectively affected by brain damage. Illustrative examples of this multiple-component approach to spatial cognition, from anatomical, neurophysiological, and neuropsychological perspectives, may be found in Refs 25,40–42.

These manifestations of hemineglect can be readily described, in general terms, as the impaired ability – which cannot be traced back to elementary sensory and motor deficits – to explore the side of space contralateral to the lesion, and to report stimuli presented in that portion of space. Hemineglect, however, may also affect the clinical manifestations of allegedly elementary neurological disorders, such as contralesional visual-half field (hemianopia), somatosensory (hemianesthesia), and motor (hemi-plegia) deficits associated with unilateral brain damage, adding to their primarily sensorimotor components (see Box 3).

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### Box 1. An interim taxonomy of the clinical syndrome of spatial hemineglect (HN)abcd

<table>
<thead>
<tr>
<th>Defective manifestations</th>
<th>Extra-personal space</th>
<th>Personal (bodily) space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions Input/output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perceptual HN*</td>
<td>Hemiasomatognosia*</td>
<td></td>
</tr>
<tr>
<td>Premotor/intentional HN, directional hypokinesia*</td>
<td>Anosognosia*</td>
<td></td>
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<tr>
<td>Sectors of space (with reference to the body, as in Fig. 3A)</td>
<td></td>
<td></td>
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<tr>
<td>External HN</td>
<td>Lateral</td>
<td></td>
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<tr>
<td>Lateral (along a left-right axis) near, far</td>
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<td></td>
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<tr>
<td>Altitudinal (along a vertical axis) upper, lower</td>
<td></td>
<td></td>
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<tr>
<td>Internal (imaginal) HN Lateral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames of reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egocentric hn head, trunk, arm, etc.</td>
<td>Somatosensory HN*</td>
<td></td>
</tr>
<tr>
<td>Allocentric/object-centred HN</td>
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<tr>
<td>Sensory modality*</td>
<td></td>
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<tr>
<td>Visual HN (pseudo-hemianopia)</td>
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<td>Auditory HN</td>
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<tr>
<td>Processing domain (material-specific forms of neglect)</td>
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<td></td>
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<tr>
<td>Facial neglect</td>
<td>Neglect dyslexia</td>
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</tr>
</tbody>
</table>

**Defective manifestations**

**Avoidance** (active withdrawal from contralesional targets)

**Hyperattention** (magnetic attraction towards ipsilesional targets)

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*defective awareness of targets in the neglected sector of space
*defective awareness of the contralesional side of the body
*defective awareness or denial of contralesional motor, somatosensory and visual half-field deficits
*defective motor programming towards targets in the neglected sector of space
*failure to move the contralesional limb
*defective awareness of contralesional tactile or proprioceptive stimuli
*delusional views concerning the contralesional side of the body
The different dimensions of the disorder may interact, giving rise to additional manifestations. ‘Defective pathological manifestations’ (the better known and more extensively investigated aspect of hemineglect) refer to negative phenomena, characterized by the absence of specific behavioral responses, such as impaired exploration of the contralateral side of space, or the failure to report stimuli presented in that sector of space. ‘Productive pathological manifestations’ refer to positive phenomena, characterized by the presence of specific behaviors (see Ref. 1 for an early, seminal discussion). An illustrative example is provided by the behavior of one patient, who, when requested to collect in a left-to-right order, a number of cubes aligned in front of her, picked up with the right hand those lying on the right, and then pushed the remaining ones towards her, saying, ‘there are no more of them’. Productive disorders have been taken as evidence that patients with hemineglect may suffer from a misperception of space, and cannot be easily accounted for in terms of defective orientation or representational scotomas.

References
- Gleichg.-M. (1952) The Parinaud’s lobes, Further
- Blakeslee and Gentiletta, G. (1991) Anomia associated with hemispheres and hemispheric in nature. In: The neglect of the contralesional side of space, and the failure to report stimuli presented in that sector of space. ‘Productive pathological manifestations’ refer to negative phenomena, characterized by the absence of specific behavioral responses, such as impaired exploration of the contralateral side of space, or the failure to report stimuli presented in that sector of space. ‘Productive pathological manifestations’ refer to positive phenomena, characterized by the presence of specific behaviors (see Ref. 1 for an early, seminal discussion). An illustrative example is provided by the behavior of one patient, who, when requested to collect in a left-to-right order, a number of cubes aligned in front of her, picked up with the right hand those lying on the right, and then pushed the remaining ones towards her, saying, ‘there are no more of them’. Productive disorders have been taken as evidence that patients with hemineglect may suffer from a misperception of space, and cannot be easily accounted for in terms of defective orientation or representational scotomas. The anatomical basis of hemineglect...
Box 3. Disorders associated with neglect

It has long been known by clinical neurologists that patients sometimes fail to move the limbs contralateral to the side of the lesion, or to report contralateral sensory stimuli, owing to higher-order pathological factors different from primary sensory-motor deficits. The terms ‘motor neglect’ (or ‘ignorance motorique’) and ‘sensory hemimeanesthesia’ have been used to denote these neglect-related disorders, which might either add to the primary sensory and motor impairments, increasing their severity, or be the sole responsible factor[5,6]. The clinical relevance of these disorders, and their association with right-brain damage, were revealed by a community-based epidemiological study, which showed that hemianopia, hemiathetosis, and hemiplegia are more frequent after vascular lesions to the right hemisphere, compared to left hemisphere injury[7–9]. A standard neurological examination cannot distinguish the neglect-related from the primary sensory-motor component – hemiatrophia and hemiathetosis (which have sometimes therefore been referred to as ‘pseudo-hemianopsia’ and ‘pseudo-hemimeanesthesia’) and hemiplegia. Neurophysiological methods such as evoked potentials, skin-conductance responses, and magnetic stimulation may reveal preserved elementary sensory and motor processes, suggesting that a higher-order pathological factor underlies the sensory and motor deficits of these patients[10]. The existence of a spatial, neglect-related component has been suggested by the observation that the neurophysiological effects of stimuli presented in the unaffected right side of space, in a somatotopic and retinotopic frame of reference, but still delivered to the left side of space, are still left-sided visual stimuli (left ‘hemimania’) improved when the patient looked rightwards[11]. In both cases, these manoeuvres the stimuli were presented in the unaffected right side of space, in a trunk-centered frame of reference, but still delivered to the left hand and to the left visual half-field, in the somatotopic and retinotopic frames.

References

8. Vallar, G. et al. (1990) Temporary remission of left hemanesthesia after vestibular stimulation Cortes 26, 128–131
The modulation of hemineglect by sensory stimulations

The kinds of spatial representations disrupted in hemineglect are not fixed architectures. Egocentric (e.g. centered on the head, on the trunk) and allocentric frames of reference are computed through the continuous integration of inputs provided by multiple sensory sources (visual, vestibular and proprioceptive-somatosensory) in a changing environment. These processes make available updated spatial representations, intermediate between sensory input (e.g. retinotopic and somatotopic frames of reference) and motor output, such as movements directed towards a target, or avoidance of a dangerous stimulus.

Vestibular and optokinetic stimulations that produce a synoynymia with a slow phase of eye movements towards the left side temporarily improve many components of the neglect syndrome. The effective vestibular and optokinetic stimuli are irrigation of the left external ear canal with cold water, or of the right canal with warm water, and a horizontal movement of luminous dots. The deficits improved by these stimulations include extra-personal visuo-spatial, imaginal and personal hemineglect, and related disorders such as lack of awareness for left-sided motor deficits, delusions concerning the left side of the body, left-sided somatosensory (detection of tactile stimuli, and position sense) and motor impairments (Fig. 6). The effects of transcutaneous mechanical vibration of the left neck muscles and left-sided electrical nervous stimulation are similar (see Ref. 12 for review). A related area concerns the improvement of a number of manifestations of hemineglect through movements of the left hand. Limb activation reduces the rightward bias in visuo-motor exploratory tasks, line bisection and walking trajectories (see also Fig. 1A).

These effects are specific and selective. Vestibular and optokinetic stimulations that bring about a synoynymia with a slow phase towards the right side are ineffective, or worsen these disorders. Furthermore, in a single left-brain-damaged patient vestibular stimulation improved right visuo-spatial hemineglect but not dysphasia. These stimuli ameliorate connotational sensory and motor deficits in the majority of right-brain-damaged patients, both with and without visuo-spatial hemineglect, and only in a few left-brain-damaged patients (see Fig. 6 and Ref. 12).

These findings, together with the well-known evidence that visuo-spatial hemineglect may occur in the absence of somatosensory and motor impairments, support the distinction between extrapersonal and personal ( bodily) aspects of the disorder (Box 1). In some patients the improvement of the somatosensory disorder brought about by vestibular stimulation was dramatic, from zero to a hundred percent correct detection of tactile stimuli. This finding has the two-fold implication that, at least in some patients, neglect accounts entirely for the sensory disorder and that elementary somatosensory processes may be largely preserved (Box 3). The deficit, therefore, may be one of phenomenal ‘sensation’ rather than of ‘perception’, in that the phenomenal component (awareness of sensory input) may be defective, with the percep-tual/cognitive component being comparatively preserved.

Processing without awareness in spatial hemineglect

In recent years, converging evidence has been accumulated to the effect that patients with spatial hemineglect are able to analyse material presented in the contralesional side of space, which they are unable to report and deny perceiving. The anatomo-physiological basis of this preserved processing without awareness includes the sparing of the primary somatosensory and visual cortices in a number of patients.

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**Fig. 1 Hemispheric asymmetries in hemineglect.** Three possible patterns of left hemispheric (LH) and right hemispheric (RH) contributions (dashed lines) to the overall neural representation of egocentric space (continuous line) are represented along a left-right axis. In humans, this representation is assumed to be skewed rightwards. (A) The neural representations of the contralateral and ipsilateral half-spaces are greater in the LH and RH, respectively, so that the two hemispheres provide an equal contribution to the overall neural representation. (B) The contralateral hemispheres are equally represented in the two hemispheres, but the ipsilateral representation is greater in the RH, which provides the major contribution to the overall neural representation. (C) The representations of both the contralateral and the ipsilateral hemispheres are greater in the RH. If unilateral brain damage removes the steeper LH component, the residual RH component has a mild lateral gradient, and contralateral disorders are likely to be minor. If the less steep RH component is removed, the gradient may be such as to produce hemineglect phenomena. (Reproduced, with permission, from Ref. 1.)

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**Fig. 5 The syndrome of spatial hemineglect: anatomical correlates.** In the majority of patients the lesion involves the supramarginal gyrus in the inferior parietal lobule (A), at the temporo-parietal junction (black area). Although less frequently, damage to the dorsolateral prefrontal cortex (Brodmann’s area 46), and medial (anterior cingulate region, supplementary motor area) frontal regions (B) can also bring about hemineglect, and a recent anatomo-clinical correlation study suggests a specific role of damage to Brodmann’s area 44 (Ref. 80). Lesions confined to the primary motor, somatosensory and visual cortices are not associated with hemineglect. (Modified from Ref. 8.)
with hemineglect (see Fig. 5), and the physiological evidence that the presented stimuli undergo some processing, which, in some patients, may be largely preserved (see Box 3).

A number of studies concur to suggest that, under some circumstances, right-brain-damaged patients with left hemineglect may process left-sided, neglected stimuli up to the semantic level. In cross-field priming paradigms the patients’ performance in lexical decision and semantic classification of words or pictures presented in the right visual hemifield is facilitated by the previous presentation of semantically related material in the left hemifield, even though they nonetheless sometimes deny the very presence of the stimulus on the left side. Similarly, patients may show evidence that processing of left-sided material has occurred, when they are required to manifest an option between two stimuli. Finally, a patient with left-neglect dyslexia produced appropriate semantic associations—sometimes identical to the stimulus—to words on which she made paralexic errors (see Fig. 7). In all these conditions patients are not aware of the identity of left-sided stimuli. Reading, lexical decision, semantic and ‘same–different’ judgments, and forced-choice recognition, by contrast, reveal hemineglect.

One basic difference between these two sets of tasks is that the latter (e.g. reading, ‘same–different’ judgments, recognition) may involve the explicit identification of relevant features of the stimulus located in the neglected side of space, within a spatial frame of reference or representation, defective in these patients. Priming effects, optional choices, and semantic association, by contrast, do not require a response that involves the utilization of a spatial content or frame for the neglected portion of the stimulus. Patients of this sort would have no phenomenal experience of their thoughts as percepts, that is, as associated with a particular object in personal or extra-personal space (see Ref. 65 for a related account of amnesia).

Conclusion

From the neuropsychological vantage point discussed in this review, it appears to be the case that the neural system concerned with spatial cognition has a highly articulated architecture. A main development in this area is likely to involve the further fractionation of spatial hemineglect into more and more specific patterns of ‘hemi’ impairment.
Objective space towards the side of the lesion, and of a pathological compression of the patients’ sub- subjective straight ahead or mid-sagittal plane (see Fig. 3), but the precise mechanisms underlying these pathological be- haviours remain unclear. One view is that the basic deficit of hemineglect involves the ipsilesional pathological trans- formation (see Fig. 3) or rotation of spatial egocentric coordi- nates. A main feature of hemineglect, however, is the pa- tients’ defective awareness of contralesional stimuli, rather than a simple displacement of perceived objects towards the ipsilesional side. Furthermore, some patients with hemi- neglect do not show such a displacement of the subjective straight ahead52, which, in turn, may be found also in optic ataxia (a disorder of visually-guided movements of the arm, towards a target)55. Taken together, these results suggest that the ipsilesional displacement of the perceived mid- sagittal plane is not the fundamental disorder underlying all the different manifestations of the hemineglect syndrome. In the visual-spatial domain, the basic distortion is therefore likely to be more complex. Accounts have been put forward in terms of a pathological compression of the patients’ sub- jective space towards the side of the lesion58, and of a patho- logical remapping of the spatial medium from a Euclidean onto a logarithmic scale, producing an expansion on the contralateral side, and a compression on the ipsilesional side (see Figs 1B and 1C). Dysfunctions of this sort may re- sult in a pathological derivation of the extent of contra- lesional stimuli52. Abandoning the view that the basic disorder of hemineglect is the contralateral distortion of the egocentric frame of reference does not necessarily imply that we are bound to search for another basic underlying deficit, which would account for the different facets of hemi- neglect. Rather, the wealth of dissociations reported in recent years appears more consistent with the working hypothesis that different pathological mechanisms, or damage to discrete spatial representations or maps, and attentional sys- tems, may account for the constellation of manifestations of hemineglect.

If so, however, how can it be the case that the introspective representation of space is unitary in nature? From the pathological perspective of hemineglect, a tentative re- sponse to this problem may be related to the fact that the different varieties of the disorder are modulated in a similar fashion by sensory stimulations, that also affect sensory- motor processes in normal subjects53. This suggests com- monalities in some basic features (i.e. the relationships of these spatial media with ongoing sensory inputs), concern- ing the updating of the different spatial maps by inputs from a continuously changing environment. This shared sensory modulation, organized around the invariant vertical orientation of gravity forces54, may contribute to the binding processes that underlie the unitary phenomenal experience of the space around us55.

Acknowledgements
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References
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Neural basis of motor control and its cognitive implications

Emilio Bizzi and Ferdinando A. Mussa-Ivaldi

It has recently been demonstrated that human subjects and nonhuman primates adapt their arm movements when subjected to complex patterns of disturbing forces. The presence of aftereffects following the removal of the disturbing forces indicates that adaptation takes place through the development of an internal model of the disturbing force. The experimental evidence described in this paper has identified some important properties of this internal model: (1) it is limited to a region surrounding that part of the space where the disturbances had been experienced; (2) there is an enhancement of the internal model that depends only on the passage of time; and (3) there is a process of consolidation of the internal model, which takes a minimum of four hours. Anatomically, the substrate of the internal model is distributed; the motor cortex, basal ganglia, and cerebellum are interconnected structures that are active to different degrees during the acquisition of motor skills. Recent investigation of the spinal cord has suggested the existence of modules that organize the motor output in a discrete set of synergies. The outputs of these modules combine by addition, and might thus form the building blocks for the internal models represented by supraspinal structures.